



- (51) International Patent Classification:
F02C 3/34 (2006.01) *G01N 33/00* (2006.01)
F02C 9/00 (2006.01)
- (21) International Application Number:
PCT/US2014/045503
- (22) International Filing Date:
3 July 2014 (03.07.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/860,217 30 July 2013 (30.07.2013) US
14/321,690 1 July 2014 (01.07.2014) US
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- (81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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(54) Title: SYSTEM AND METHOD FOR A GAS TURBINE ENGINE SENSOR

(57) Abstract: A system includes a gas turbine engine that includes a combustor section having a turbine combustor that generates combustion products, a turbine section having one or more turbine stages driven by the combustion products, an exhaust section disposed downstream of the turbine section, an oxygen sensor adaptor housing disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof, and an oxygen sensor disposed in the oxygen sensor adaptor housing. The oxygen sensor adaptor housing is configured to maintain a temperature of a portion of the oxygen sensor below an upper threshold.

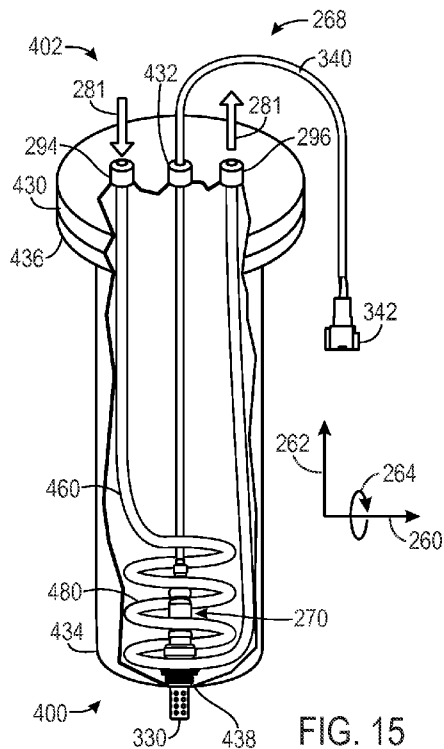


FIG. 15



(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

SYSTEM AND METHOD FOR A GAS TURBINE ENGINE SENSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to and benefit of U.S. Provisional Patent Application No. 61/860,217, entitled “SYSTEM AND METHOD FOR A GAS TURBINE ENGINE SENSOR,” filed on July 30, 2013, and U.S. Non-Provisional Patent Application No. 14/321,690, entitled “SYSTEM AND METHOD FOR A GAS TURBINE ENGINE SENSOR,” filed on July 1, 2014, all of which are hereby incorporated by reference in their entirety for all purposes.

BACKGROUND

[0002] The subject matter disclosed herein relates to gas turbine engines, and more specifically, to systems and methods for sensors of gas turbine engines.

[0003] Gas turbine engines are used in a wide variety of applications, such as power generation, aircraft, and various machinery. Gas turbine engines generally combust a fuel with an oxidant (e.g., air) in a combustor section to generate hot combustion products, which then drive one or more turbine stages of a turbine section. In turn, the turbine section drives one or more compressor stages of a compressor section. Again, the fuel and oxidant mix in the combustor section, and then combust to produce the hot combustion products. Gas turbine engines generally include one or more sensors to detect various conditions within the gas turbine engine. Unfortunately, the high temperatures within the gas turbine engine can cause thermal stress and wear to the sensors and/or decrease the longevity of the sensors. Furthermore, gas turbine engines typically consume a vast amount of air as the oxidant, and output a considerable amount of exhaust gas into the atmosphere. In other words, the exhaust gas is typically wasted as a byproduct of the gas turbine operation.

BRIEF DESCRIPTION

[0004] Certain embodiments commensurate in scope with the originally claimed invention are summarized below. These embodiments are not intended to limit the scope of the claimed invention, but rather these embodiments are intended only to provide a brief summary of possible forms of the invention. Indeed, the invention may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

[0005] In a first embodiment, a system includes a gas turbine engine that includes a combustor section having a turbine combustor that generates combustion products, a turbine section having one or more turbine stages driven by the combustion products, an exhaust section disposed downstream of the turbine section, an oxygen sensor adaptor housing disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof, and an oxygen sensor disposed in the oxygen sensor adaptor housing. The oxygen sensor adaptor housing is configured to maintain a temperature of a portion of the oxygen sensor below an upper threshold.

[0006] In a second embodiment, a system includes an oxygen sensor adaptor housing configured to mount in at least one of a combustor section of a gas turbine engine, a turbine section of the gas turbine engine, or an exhaust section of the gas turbine engine, or any combination thereof, and an oxygen sensor disposed in the oxygen sensor adaptor housing. The oxygen sensor adaptor housing is configured to maintain a temperature of a portion of the oxygen sensor below an upper threshold.

[0007] In a third embodiment, a method includes combusting a fuel with an oxidant in a combustor section of a turbine combustor to generate combustion products, driving a turbine of a turbine section with the combustion products from the turbine combustor, expanding the combustion products from the turbine through an exhaust passage in an exhaust section, sensing an oxygen concentration of the combustion products using an oxygen sensor disposed in an oxygen sensor adaptor housing that is disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof, and maintaining a temperature of a

portion of the oxygen sensor below an upper threshold using the oxygen sensor adaptor housing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0009] FIG. 1 is a diagram of an embodiment of a system having a turbine-based service system coupled to a hydrocarbon production system;

[0010] FIG. 2 is a diagram of an embodiment of the system of FIG. 1, further illustrating a control system and a combined cycle system;

[0011] FIG. 3 is a diagram of an embodiment of the system of FIGS. 1 and 2, further illustrating details of a gas turbine engine, exhaust gas supply system, and exhaust gas processing system;

[0012] FIG. 4 is a flow chart of an embodiment of a process for operating the system of FIGS. 1-3;

[0013] FIG. 5 is a schematic diagram of an embodiment of a gas turbine engine having a plurality of sensors, each having a sensor adaptor housing;

[0014] FIG. 6 is a schematic diagram of an embodiment of a sensor adaptor housing;

[0015] FIG. 7 is a radial cross-sectional view of an embodiment of a gas turbine engine having a plurality of sensors each having a sensor adaptor housing;

[0016] FIG. 8 is a perspective view of a sensor (e.g., an oxygen sensor) that may be used with an embodiment of a sensor adaptor housing;

[0017] FIG. 9 is a graph of a signal characteristic curve of a sensor (e.g., an oxygen sensor) that may be used with an embodiment of a sensor adaptor housing;

[0018] FIG. 10 is an axial side view of an embodiment of a sensor adaptor housing;

[0019] FIG. 11 is an axial cross-sectional view of an embodiment of a sensor adaptor housing;

[0020] FIG. 12 is a partial cutaway perspective view of an embodiment of a sensor adaptor housing;

[0021] FIG. 13 is a partial cutaway perspective view of an embodiment of a sensor adaptor housing that may be used near a bottom of a gas turbine engine;

[0022] FIG. 14 is a partial cutaway perspective view of an embodiment of a sensor adaptor housing with a coolant nozzle;

[0023] FIG. 15 is a partial cutaway perspective view of an embodiment of a sensor adaptor housing with a coolant coil;

[0024] FIG. 16 is a radial cross-sectional view of an embodiment of a sensor adaptor housing; and

[0025] FIG. 17 is a radial cross-sectional view of an embodiment of a sensor adaptor housing with an airfoil-shaped cross-sectional shape.

DETAILED DESCRIPTION

[0026] One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in an engineering or design project, numerous implementation-specific decisions are made to achieve the specific goals, such as compliance with system-related and/or business-related constraints, which may vary from one implementation to another.

Moreover, it should be appreciated that such effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0027] Detailed example embodiments are disclosed herein. However, specific structural and functional details disclosed herein are merely representative for purposes of describing example embodiments. Embodiments of the present invention may, however, be embodied in many alternate forms, and should not be construed as limited to only the embodiments set forth herein.

[0028] Accordingly, while example embodiments are capable of various modifications and alternative forms, embodiments thereof are illustrated by way of example in the figures and will herein be described in detail. It should be understood, however, that there is no intent to limit example embodiments to the particular forms disclosed, but to the contrary, example embodiments are to cover all modifications, equivalents, and alternatives falling within the scope of the present invention.

[0029] The terminology used herein is for describing particular embodiments only and is not intended to be limiting of example embodiments. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises”, “comprising”, “includes” and/or “including”, when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0030] Although the terms first, second, primary, secondary, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, but not limiting to, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of example embodiments. As used herein, the term “and/or” includes any, and all, combinations of one or more of the associated listed items.

[0031] Certain terminology may be used herein for the convenience of the reader only and is not to be taken as a limitation on the scope of the invention. For example, words such as “upper”, “lower”, “left”, “right”, “front”, “rear”, “top”, “bottom”, “horizontal”, “vertical”, “upstream”, “downstream”, “fore”, “aft”, and the like; merely describe the configuration shown in the FIGS. Indeed, the element or elements of an embodiment of the present invention may be oriented in any direction and the terminology, therefore, should be understood as encompassing such variations unless specified otherwise.

[0032] As discussed in detail below, the disclosed embodiments relate generally to gas turbine systems with exhaust gas recirculation (EGR), and particularly stoichiometric operation of the gas turbine systems using EGR. For example, the gas turbine systems may be configured to recirculate the exhaust gas along an exhaust recirculation path, stoichiometrically combust fuel and oxidant along with at least some of the recirculated exhaust gas, and capture the exhaust gas for use in various target systems. The recirculation of the exhaust gas along with stoichiometric combustion may help to increase the concentration level of carbon dioxide (CO₂) in the exhaust gas, which can then be post treated to separate and purify the CO₂ and nitrogen (N₂) for use in various target systems. The gas turbine systems also may employ various exhaust gas processing (e.g., heat recovery, catalyst reactions, etc.) along the exhaust recirculation path, thereby increasing the concentration level of CO₂, reducing concentration levels of other emissions (e.g., carbon monoxide, nitrogen oxides, and unburnt hydrocarbons), and increasing energy recovery (e.g., with heat recovery units). Furthermore, the gas turbine engines may be configured to combust the fuel and oxidant with one or more diffusion flames (e.g., using diffusion fuel nozzles), premix flames (e.g., using premix fuel nozzles), or any combination thereof. In certain embodiments, the diffusion flames may help to maintain stability and operation within certain limits for stoichiometric combustion, which in turn helps to increase production of CO₂. For example, a gas turbine system operating with diffusion flames may enable a greater quantity of EGR, as compared to a gas turbine system operating with premix flames. In turn, the increased quantity of EGR helps to increase CO₂ production. Possible target systems include pipelines, storage tanks,

carbon sequestration systems, and hydrocarbon production systems, such as enhanced oil recovery (EOR) systems.

[0033] The disclosed embodiments provide systems and methods for sensors of gas turbine engines with EGR. Specifically, the gas turbine engine may include a combustor section having a turbine combustor that generates combustion products, a turbine section having one or more turbine stages driven by the combustion products, and an exhaust section disposed downstream of the turbine section. A sensor adaptor housing, such as an oxygen sensor adaptor housing, may be disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof. A sensor (e.g., an oxygen sensor, a carbon monoxide (CO) sensor, a carbon dioxide (CO₂) sensor, a hydrogen (H₂) sensor, a nitrogen oxides (NO_x) sensor, a sulfur oxides (SO_x) sensor, an unburnt fuel sensor, or any other gas composition sensor) may be disposed in the sensor adaptor housing, which may maintain a temperature of a portion (e.g., portion not directly in contact with the combustion products) of the sensor below a threshold (e.g., a maximum operating temperature limit). In certain embodiments, each sensor adaptor housing may include 1, 2, 3, 4, 5, or more sensors. In some embodiments, other types of sensors, such as, but not limited to, temperature sensors, pressure sensors, flow rate sensors, flame sensors, optical sensors, composition sensors, and so forth, may be disposed in a sensor adaptor housing. Each of these sensor adaptor housings may maintain a temperature of a portion of the sensor below a threshold. Although any type of sensor may be used with the disclosed embodiments of sensor adaptor housings, the following discussion presents the sensor adaptor housings in context of oxygen sensors as one possible example of the sensors.

[0034] By maintaining a temperature of the portion of the sensor (e.g., oxygen sensor) below the threshold, the sensor may be protected from the high temperatures associated with the gas turbine engine. Specifically, certain portions of the sensor (e.g., oxygen sensor) may have maximum operating temperature limits less than the operating temperatures within the gas turbine engine. Thus, without using the sensor adaptor housing, these portions of the sensor (e.g., oxygen sensor) may be exposed to temperatures above their maximum operating temperature limits, thereby possibly

causing thermal stress and wear and/or reduced life spans. By using the sensor adaptor housing, portions of the sensor (e.g., oxygen sensor) may be operated below their maximum operating temperature limits, thereby increasing the longevity of the sensor. Although certain sensors (e.g., oxygen sensors) may have maximum operating temperature limits greater than the operating temperatures of the gas turbine engine, such sensors may be costly because of the expensive and/or rare materials (e.g., high-temperature alloys) used to achieve the high maximum operating temperature limits. Thus, less expensive sensors (e.g., oxygen sensors) with lower maximum operating temperature limits may be used with embodiments of the sensor adaptor housing described below, thereby reducing the overall cost of the gas turbine engine.

[0035] FIG. 1 is a diagram of an embodiment of a system 10 having an hydrocarbon production system 12 associated with a turbine-based service system 14. As discussed in further detail below, various embodiments of the turbine-based service system 14 are configured to provide various services, such as electrical power, mechanical power, and fluids (e.g., exhaust gas), to the hydrocarbon production system 12 to facilitate the production or retrieval of oil and/or gas. In the illustrated embodiment, the hydrocarbon production system 12 includes an oil/gas extraction system 16 and an enhanced oil recovery (EOR) system 18, which are coupled to a subterranean reservoir 20 (e.g., an oil, gas, or hydrocarbon reservoir). The oil/gas extraction system 16 includes a variety of surface equipment 22, such as a Christmas tree or production tree 24, coupled to an oil/gas well 26. Furthermore, the well 26 may include one or more tubulars 28 extending through a drilled bore 30 in the earth 32 to the subterranean reservoir 20. The tree 24 includes one or more valves, chokes, isolation sleeves, blowout preventers, and various flow control devices, which regulate pressures and control flows to and from the subterranean reservoir 20. While the tree 24 is generally used to control the flow of the production fluid (e.g., oil or gas) out of the subterranean reservoir 20, the EOR system 18 may increase the production of oil or gas by injecting one or more fluids into the subterranean reservoir 20.

[0036] Accordingly, the EOR system 18 may include a fluid injection system 34, which has one or more tubulars 36 extending through a bore 38 in the earth 32 to the

subterranean reservoir 20. For example, the EOR system 18 may route one or more fluids 40, such as gas, steam, water, chemicals, or any combination thereof, into the fluid injection system 34. For example, as discussed in further detail below, the EOR system 18 may be coupled to the turbine-based service system 14, such that the system 14 routes an exhaust gas 42 (e.g., substantially or entirely free of oxygen) to the EOR system 18 for use as the injection fluid 40. The fluid injection system 34 routes the fluid 40 (e.g., the exhaust gas 42) through the one or more tubulars 36 into the subterranean reservoir 20, as indicated by arrows 44. The injection fluid 40 enters the subterranean reservoir 20 through the tubular 36 at an offset distance 46 away from the tubular 28 of the oil/gas well 26. Accordingly, the injection fluid 40 displaces the oil/gas 48 disposed in the subterranean reservoir 20, and drives the oil/gas 48 up through the one or more tubulars 28 of the hydrocarbon production system 12, as indicated by arrows 50. As discussed in further detail below, the injection fluid 40 may include the exhaust gas 42 originating from the turbine-based service system 14, which is able to generate the exhaust gas 42 on-site as needed by the hydrocarbon production system 12. In other words, the turbine-based system 14 may simultaneously generate one or more services (e.g., electrical power, mechanical power, steam, water (e.g., desalinated water), and exhaust gas (e.g., substantially free of oxygen)) for use by the hydrocarbon production system 12, thereby reducing or eliminating the reliance on external sources of such services.

[0037] In the illustrated embodiment, the turbine-based service system 14 includes a stoichiometric exhaust gas recirculation (SEGR) gas turbine system 52 and an exhaust gas (EG) processing system 54. The gas turbine system 52 may be configured to operate in a stoichiometric combustion mode of operation (e.g., a stoichiometric control mode) and a non-stoichiometric combustion mode of operation (e.g., a non-stoichiometric control mode), such as a fuel-lean control mode or a fuel-rich control mode. In the stoichiometric control mode, the combustion generally occurs in a substantially stoichiometric ratio of a fuel and oxidant, thereby resulting in substantially stoichiometric combustion. In particular, stoichiometric combustion generally involves consuming substantially all of the fuel and oxidant in the combustion reaction, such that the products of combustion are substantially or entirely

free of unburnt fuel and oxidant. One measure of stoichiometric combustion is the equivalence ratio, or ϕ (Φ), which is the ratio of the actual fuel/oxidant ratio relative to the stoichiometric fuel/oxidant ratio. An equivalence ratio of greater than 1.0 results in a fuel-rich combustion of the fuel and oxidant, whereas an equivalence ratio of less than 1.0 results in a fuel-lean combustion of the fuel and oxidant. In contrast, an equivalence ratio of 1.0 results in combustion that is neither fuel-rich nor fuel-lean, thereby substantially consuming all of the fuel and oxidant in the combustion reaction. In context of the disclosed embodiments, the term stoichiometric or substantially stoichiometric may refer to an equivalence ratio of approximately 0.95 to approximately 1.05. However, the disclosed embodiments may also include an equivalence ratio of 1.0 plus or minus 0.01, 0.02, 0.03, 0.04, 0.05, or more. Again, the stoichiometric combustion of fuel and oxidant in the turbine-based service system 14 may result in products of combustion or exhaust gas (e.g., 42) with substantially no unburnt fuel or oxidant remaining. For example, the exhaust gas 42 may have less than 1, 2, 3, 4, or 5 percent by volume of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), hydrogen, and other products of incomplete combustion. By further example, the exhaust gas 42 may have less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, or 5000 parts per million by volume (ppmv) of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), hydrogen, and other products of incomplete combustion. However, the disclosed embodiments also may produce other ranges of residual fuel, oxidant, and other emissions levels in the exhaust gas 42. As used herein, the terms emissions, emissions levels, and emissions targets may refer to concentration levels of certain products of combustion (e.g., NO_x , CO, SO_x , O_2 , N_2 , H_2 , HCs, etc.), which may be present in recirculated gas streams, vented gas streams (e.g., exhausted into the atmosphere), and gas streams used in various target systems (e.g., the hydrocarbon production system 12).

[0038] Although the SEGR gas turbine system 52 and the EG processing system 54 may include a variety of components in different embodiments, the illustrated EG

processing system 54 includes a heat recovery steam generator (HRSG) 56 and an exhaust gas recirculation (EGR) system 58, which receive and process an exhaust gas 60 originating from the SEGR gas turbine system 52. The HRSG 56 may include one or more heat exchangers, condensers, and various heat recovery equipment, which collectively function to transfer heat from the exhaust gas 60 to a stream of water, thereby generating steam 62. The steam 62 may be used in one or more steam turbines, the EOR system 18, or any other portion of the hydrocarbon production system 12. For example, the HRSG 56 may generate low pressure, medium pressure, and/or high pressure steam 62, which may be selectively applied to low, medium, and high pressure steam turbine stages, or different applications of the EOR system 18. In addition to the steam 62, a treated water 64, such as a desalinated water, may be generated by the HRSG 56, the EGR system 58, and/or another portion of the EG processing system 54 or the SEGR gas turbine system 52. The treated water 64 (e.g., desalinated water) may be particularly useful in areas with water shortages, such as inland or desert regions. The treated water 64 may be generated, at least in part, due to the large volume of air driving combustion of fuel within the SEGR gas turbine system 52. While the on-site generation of steam 62 and water 64 may be beneficial in many applications (including the hydrocarbon production system 12), the on-site generation of exhaust gas 42, 60 may be particularly beneficial for the EOR system 18, due to its low oxygen content, high pressure, and heat derived from the SEGR gas turbine system 52. Accordingly, the HRSG 56, the EGR system 58, and/or another portion of the EG processing system 54 may output or recirculate an exhaust gas 66 into the SEGR gas turbine system 52, while also routing the exhaust gas 42 to the EOR system 18 for use with the hydrocarbon production system 12. Likewise, the exhaust gas 42 may be extracted directly from the SEGR gas turbine system 52 (i.e., without passing through the EG processing system 54) for use in the EOR system 18 of the hydrocarbon production system 12.

[0039] The exhaust gas recirculation is handled by the EGR system 58 of the EG processing system 54. For example, the EGR system 58 includes one or more conduits, valves, blowers, exhaust gas treatment systems (e.g., filters, particulate removal units, gas separation units, gas purification units, heat exchangers, heat

recovery units, moisture removal units, catalyst units, chemical injection units, or any combination thereof), and controls to recirculate the exhaust gas along an exhaust gas circulation path from an output (e.g., discharged exhaust gas 60) to an input (e.g., intake exhaust gas 66) of the SEGR gas turbine system 52. In the illustrated embodiment, the SEGR gas turbine system 52 intakes the exhaust gas 66 into a compressor section having one or more compressors, thereby compressing the exhaust gas 66 for use in a combustor section along with an intake of an oxidant 68 and one or more fuels 70. The oxidant 68 may include ambient air, pure oxygen, oxygen-enriched air, oxygen-reduced air, oxygen-nitrogen mixtures, or any suitable oxidant that facilitates combustion of the fuel 70. The fuel 70 may include one or more gas fuels, liquid fuels, or any combination thereof. For example, the fuel 70 may include natural gas, liquefied natural gas (LNG), syngas, methane, ethane, propane, butane, naphtha, kerosene, diesel fuel, ethanol, methanol, biofuel, or any combination thereof.

[0040] The SEGR gas turbine system 52 mixes and combusts the exhaust gas 66, the oxidant 68, and the fuel 70 in the combustor section, thereby generating hot combustion gases or exhaust gas 60 to drive one or more turbine stages in a turbine section. In certain embodiments, each combustor in the combustor section includes one or more premix fuel nozzles, one or more diffusion fuel nozzles, or any combination thereof. For example, each premix fuel nozzle may be configured to mix the oxidant 68 and the fuel 70 internally within the fuel nozzle and/or partially upstream of the fuel nozzle, thereby injecting an oxidant-fuel mixture from the fuel nozzle into the combustion zone for a premixed combustion (e.g., a premixed flame). By further example, each diffusion fuel nozzle may be configured to isolate the flows of oxidant 68 and fuel 70 within the fuel nozzle, thereby separately injecting the oxidant 68 and the fuel 70 from the fuel nozzle into the combustion zone for diffusion combustion (e.g., a diffusion flame). In particular, the diffusion combustion provided by the diffusion fuel nozzles delays mixing of the oxidant 68 and the fuel 70 until the point of initial combustion, i.e., the flame region. In embodiments employing the diffusion fuel nozzles, the diffusion flame may provide increased flame stability, because the diffusion flame generally forms at the point of stoichiometry between the separate streams of oxidant 68 and fuel 70 (i.e., as the oxidant 68 and fuel 70 are

mixing). In certain embodiments, one or more diluents (e.g., the exhaust gas 60, steam, nitrogen, or another inert gas) may be pre-mixed with the oxidant 68, the fuel 70, or both, in either the diffusion fuel nozzle or the premix fuel nozzle. In addition, one or more diluents (e.g., the exhaust gas 60, steam, nitrogen, or another inert gas) may be injected into the combustor at or downstream from the point of combustion within each combustor. The use of these diluents may help temper the flame (e.g., premix flame or diffusion flame), thereby helping to reduce NO_x emissions, such as nitrogen monoxide (NO) and nitrogen dioxide (NO₂). Regardless of the type of flame, the combustion produces hot combustion gases or exhaust gas 60 to drive one or more turbine stages. As each turbine stage is driven by the exhaust gas 60, the SEGR gas turbine system 52 generates a mechanical power 72 and/or an electrical power 74 (e.g., via an electrical generator). The system 52 also outputs the exhaust gas 60, and may further output water 64. Again, the water 64 may be a treated water, such as a desalinated water, which may be useful in a variety of applications on-site or off-site.

[0041] Exhaust extraction is also provided by the SEGR gas turbine system 52 using one or more extraction points 76. For example, the illustrated embodiment includes an exhaust gas (EG) supply system 78 having an exhaust gas (EG) extraction system 80 and an exhaust gas (EG) treatment system 82, which receive exhaust gas 42 from the extraction points 76, treat the exhaust gas 42, and then supply or distribute the exhaust gas 42 to various target systems. The target systems may include the EOR system 18 and/or other systems, such as a pipeline 86, a storage tank 88, or a carbon sequestration system 90. The EG extraction system 80 may include one or more conduits, valves, controls, and flow separations, which facilitate isolation of the exhaust gas 42 from the oxidant 68, the fuel 70, and other contaminants, while also controlling the temperature, pressure, and flow rate of the extracted exhaust gas 42. The EG treatment system 82 may include one or more heat exchangers (e.g., heat recovery units such as heat recovery steam generators, condensers, coolers, or heaters), catalyst systems (e.g., oxidation catalyst systems), particulate and/or water removal systems (e.g., gas dehydration units, inertial separators, coalescing filters, water impermeable filters, and other filters), chemical injection systems, solvent based treatment systems (e.g., absorbers, flash tanks, etc.), carbon capture systems,

gas separation systems, gas purification systems, and/or a solvent based treatment system, exhaust gas compressors, any combination thereof. These subsystems of the EG treatment system 82 enable control of the temperature, pressure, flow rate, moisture content (e.g., amount of water removal), particulate content (e.g., amount of particulate removal), and gas composition (e.g., percentage of CO₂, N₂, etc.).

[0042] The extracted exhaust gas 42 is treated by one or more subsystems of the EG treatment system 82, depending on the target system. For example, the EG treatment system 82 may direct all or part of the exhaust gas 42 through a carbon capture system, a gas separation system, a gas purification system, and/or a solvent based treatment system, which is controlled to separate and purify a carbonaceous gas (e.g., carbon dioxide) 92 and/or nitrogen (N₂) 94 for use in the various target systems. For example, embodiments of the EG treatment system 82 may perform gas separation and purification to produce a plurality of different streams 95 of exhaust gas 42, such as a first stream 96, a second stream 97, and a third stream 98. The first stream 96 may have a first composition that is rich in carbon dioxide and/or lean in nitrogen (e.g., a CO₂ rich, N₂ lean stream). The second stream 97 may have a second composition that has intermediate concentration levels of carbon dioxide and/or nitrogen (e.g., intermediate concentration CO₂, N₂ stream). The third stream 98 may have a third composition that is lean in carbon dioxide and/or rich in nitrogen (e.g., a CO₂ lean, N₂ rich stream). Each stream 95 (e.g., 96, 97, and 98) may include a gas dehydration unit, a filter, a gas compressor, or any combination thereof, to facilitate delivery of the stream 95 to a target system. In certain embodiments, the CO₂ rich, N₂ lean stream 96 may have a CO₂ purity or concentration level of greater than approximately 70, 75, 80, 85, 90, 95, 96, 97, 98, or 99 percent by volume, and a N₂ purity or concentration level of less than approximately 1, 2, 3, 4, 5, 10, 15, 20, 25, or 30 percent by volume. In contrast, the CO₂ lean, N₂ rich stream 98 may have a CO₂ purity or concentration level of less than approximately 1, 2, 3, 4, 5, 10, 15, 20, 25, or 30 percent by volume, and a N₂ purity or concentration level of greater than approximately 70, 75, 80, 85, 90, 95, 96, 97, 98, or 99 percent by volume. The intermediate concentration CO₂, N₂ stream 97 may have a CO₂ purity or concentration level and/or a N₂ purity or concentration level of between approximately 30 to 70, 35

to 65, 40 to 60, or 45 to 55 percent by volume. Although the foregoing ranges are merely non-limiting examples, the CO₂ rich, N₂ lean stream 96 and the CO₂ lean, N₂ rich stream 98 may be particularly well suited for use with the EOR system 18 and the other systems 84. However, any of these rich, lean, or intermediate concentration CO₂ streams 95 may be used, alone or in various combinations, with the EOR system 18 and the other systems 84. For example, the EOR system 18 and the other systems 84 (e.g., the pipeline 86, storage tank 88, and the carbon sequestration system 90) each may receive one or more CO₂ rich, N₂ lean streams 96, one or more CO₂ lean, N₂ rich streams 98, one or more intermediate concentration CO₂, N₂ streams 97, and one or more untreated exhaust gas 42 streams (i.e., bypassing the EG treatment system 82).

[0043] The EG extraction system 80 extracts the exhaust gas 42 at one or more extraction points 76 along the compressor section, the combustor section, and/or the turbine section, such that the exhaust gas 42 may be used in the EOR system 18 and other systems 84 at suitable temperatures and pressures. The EG extraction system 80 and/or the EG treatment system 82 also may circulate fluid flows (e.g., exhaust gas 42) to and from the EG processing system 54. For example, a portion of the exhaust gas 42 passing through the EG processing system 54 may be extracted by the EG extraction system 80 for use in the EOR system 18 and the other systems 84. In certain embodiments, the EG supply system 78 and the EG processing system 54 may be independent or integral with one another, and thus may use independent or common subsystems. For example, the EG treatment system 82 may be used by both the EG supply system 78 and the EG processing system 54. Exhaust gas 42 extracted from the EG processing system 54 may undergo multiple stages of gas treatment, such as one or more stages of gas treatment in the EG processing system 54 followed by one or more additional stages of gas treatment in the EG treatment system 82.

[0044] At each extraction point 76, the extracted exhaust gas 42 may be substantially free of oxidant 68 and fuel 70 (e.g., unburnt fuel or hydrocarbons) due to substantially stoichiometric combustion and/or gas treatment in the EG processing system 54. Furthermore, depending on the target system, the extracted exhaust gas 42 may undergo further treatment in the EG treatment system 82 of the EG supply system 78, thereby further reducing any residual oxidant 68, fuel 70, or other

undesirable products of combustion. For example, either before or after treatment in the EG treatment system 82, the extracted exhaust gas 42 may have less than 1, 2, 3, 4, or 5 percent by volume of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), hydrogen, and other products of incomplete combustion. By further example, either before or after treatment in the EG treatment system 82, the extracted exhaust gas 42 may have less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, or 5000 parts per million by volume (ppmv) of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), hydrogen, and other products of incomplete combustion. Thus, the exhaust gas 42 is particularly well suited for use with the EOR system 18.

[0045] The EGR operation of the turbine system 52 specifically enables the exhaust extraction at a multitude of locations 76. For example, the compressor section of the system 52 may be used to compress the exhaust gas 66 without any oxidant 68 (i.e., only compression of the exhaust gas 66), such that a substantially oxygen-free exhaust gas 42 may be extracted from the compressor section and/or the combustor section prior to entry of the oxidant 68 and the fuel 70. The extraction points 76 may be located at interstage ports between adjacent compressor stages, at ports along the compressor discharge casing, at ports along each combustor in the combustor section, or any combination thereof. In certain embodiments, the exhaust gas 66 may not mix with the oxidant 68 and fuel 70 until it reaches the head end portion and/or fuel nozzles of each combustor in the combustor section. Furthermore, one or more flow separators (e.g., walls, dividers, baffles, or the like) may be used to isolate the oxidant 68 and the fuel 70 from the extraction points 76. With these flow separators, the extraction points 76 may be disposed directly along a wall of each combustor in the combustor section.

[0046] Once the exhaust gas 66, oxidant 68, and fuel 70 flow through the head end portion (e.g., through fuel nozzles) into the combustion portion (e.g., combustion chamber) of each combustor, the SEGR gas turbine system 52 is controlled to provide a substantially stoichiometric combustion of the exhaust gas 66, oxidant 68, and fuel

70. For example, the system 52 may maintain an equivalence ratio of approximately 0.95 to approximately 1.05. As a result, the products of combustion of the mixture of exhaust gas 66, oxidant 68, and fuel 70 in each combustor is substantially free of oxygen and unburnt fuel. Thus, the products of combustion (or exhaust gas) may be extracted from the turbine section of the SEGR gas turbine system 52 for use as the exhaust gas 42 routed to the EOR system 18. Along the turbine section, the extraction points 76 may be located at any turbine stage, such as interstage ports between adjacent turbine stages. Thus, using any of the foregoing extraction points 76, the turbine-based service system 14 may generate, extract, and deliver the exhaust gas 42 to the hydrocarbon production system 12 (e.g., the EOR system 18) for use in the production of oil/gas 48 from the subterranean reservoir 20.

[0047] FIG. 2 is a diagram of an embodiment of the system 10 of FIG. 1, illustrating a control system 100 coupled to the turbine-based service system 14 and the hydrocarbon production system 12. In the illustrated embodiment, the turbine-based service system 14 includes a combined cycle system 102, which includes the SEGR gas turbine system 52 as a topping cycle, a steam turbine 104 as a bottoming cycle, and the HRSG 56 to recover heat from the exhaust gas 60 to generate the steam 62 for driving the steam turbine 104. Again, the SEGR gas turbine system 52 receives, mixes, and stoichiometrically combusts the exhaust gas 66, the oxidant 68, and the fuel 70 (e.g., premix and/or diffusion flames), thereby producing the exhaust gas 60, the mechanical power 72, the electrical power 74, and/or the water 64. For example, the SEGR gas turbine system 52 may drive one or more loads or machinery 106, such as an electrical generator, an oxidant compressor (e.g., a main air compressor), a gear box, a pump, equipment of the hydrocarbon production system 12, or any combination thereof. In some embodiments, the machinery 106 may include other drives, such as electrical motors or steam turbines (e.g., the steam turbine 104), in tandem with the SEGR gas turbine system 52. Accordingly, an output of the machinery 106 driven by the SEGR gas turbines system 52 (and any additional drives) may include the mechanical power 72 and the electrical power 74. The mechanical power 72 and/or the electrical power 74 may be used on-site for powering the hydrocarbon production system 12, the electrical power 74 may be distributed to

the power grid, or any combination thereof. The output of the machinery 106 also may include a compressed fluid, such as a compressed oxidant 68 (e.g., air or oxygen), for intake into the combustion section of the SEGR gas turbine system 52. Each of these outputs (e.g., the exhaust gas 60, the mechanical power 72, the electrical power 74, and/or the water 64) may be considered a service of the turbine-based service system 14.

[0048] The SEGR gas turbine system 52 produces the exhaust gas 42, 60, which may be substantially free of oxygen, and routes this exhaust gas 42, 60 to the EG processing system 54 and/or the EG supply system 78. The EG supply system 78 may treat and delivery the exhaust gas 42 (e.g., streams 95) to the hydrocarbon production system 12 and/or the other systems 84. As discussed above, the EG processing system 54 may include the HRSG 56 and the EGR system 58. The HRSG 56 may include one or more heat exchangers, condensers, and various heat recovery equipment, which may be used to recover or transfer heat from the exhaust gas 60 to water 108 to generate the steam 62 for driving the steam turbine 104. Similar to the SEGR gas turbine system 52, the steam turbine 104 may drive one or more loads or machinery 106, thereby generating the mechanical power 72 and the electrical power 74. In the illustrated embodiment, the SEGR gas turbine system 52 and the steam turbine 104 are arranged in tandem to drive the same machinery 106. However, in other embodiments, the SEGR gas turbine system 52 and the steam turbine 104 may separately drive different machinery 106 to independently generate mechanical power 72 and/or electrical power 74. As the steam turbine 104 is driven by the steam 62 from the HRSG 56, the steam 62 gradually decreases in temperature and pressure. Accordingly, the steam turbine 104 recirculates the used steam 62 and/or water 108 back into the HRSG 56 for additional steam generation via heat recovery from the exhaust gas 60. In addition to steam generation, the HRSG 56, the EGR system 58, and/or another portion of the EG processing system 54 may produce the water 64, the exhaust gas 42 for use with the hydrocarbon production system 12, and the exhaust gas 66 for use as an input into the SEGR gas turbine system 52. For example, the water 64 may be a treated water 64, such as a desalinated water for use in other applications. The desalinated water may be particularly useful in regions of low water

availability. Regarding the exhaust gas 60, embodiments of the EG processing system 54 may be configured to recirculate the exhaust gas 60 through the EGR system 58 with or without passing the exhaust gas 60 through the HRSG 56.

[0049] In the illustrated embodiment, the SEGR gas turbine system 52 has an exhaust recirculation path 110, which extends from an exhaust outlet to an exhaust inlet of the system 52. Along the path 110, the exhaust gas 60 passes through the EG processing system 54, which includes the HRSG 56 and the EGR system 58 in the illustrated embodiment. The EGR system 58 may include one or more conduits, valves, blowers, gas treatment systems (e.g., filters, particulate removal units, gas separation units, gas purification units, heat exchangers, heat recovery units such as heat recovery steam generators, moisture removal units, catalyst units, chemical injection units, or any combination thereof) in series and/or parallel arrangements along the path 110. In other words, the EGR system 58 may include any flow control components, pressure control components, temperature control components, moisture control components, and gas composition control components along the exhaust recirculation path 110 between the exhaust outlet and the exhaust inlet of the system 52. Accordingly, in embodiments with the HRSG 56 along the path 110, the HRSG 56 may be considered a component of the EGR system 58. However, in certain embodiments, the HRSG 56 may be disposed along an exhaust path independent from the exhaust recirculation path 110. Regardless of whether the HRSG 56 is along a separate path or a common path with the EGR system 58, the HRSG 56 and the EGR system 58 intake the exhaust gas 60 and output either the recirculated exhaust gas 66, the exhaust gas 42 for use with the EG supply system 78 (e.g., for the hydrocarbon production system 12 and/or other systems 84), or another output of exhaust gas. Again, the SEGR gas turbine system 52 intakes, mixes, and stoichiometrically combusts the exhaust gas 66, the oxidant 68, and the fuel 70 (e.g., premixed and/or diffusion flames) to produce a substantially oxygen-free and fuel-free exhaust gas 60 for distribution to the EG processing system 54, the hydrocarbon production system 12, or other systems 84.

[0050] As noted above with reference to FIG. 1, the hydrocarbon production system 12 may include a variety of equipment to facilitate the recovery or production

of oil/gas 48 from a subterranean reservoir 20 through an oil/gas well 26. For example, the hydrocarbon production system 12 may include the EOR system 18 having the fluid injection system 34. In the illustrated embodiment, the fluid injection system 34 includes an exhaust gas injection EOR system 112 and a steam injection EOR system 114. Although the fluid injection system 34 may receive fluids from a variety of sources, the illustrated embodiment may receive the exhaust gas 42 and the steam 62 from the turbine-based service system 14. The exhaust gas 42 and/or the steam 62 produced by the turbine-based service system 14 also may be routed to the hydrocarbon production system 12 for use in other oil/gas systems 116.

[0051] The quantity, quality, and flow of the exhaust gas 42 and/or the steam 62 may be controlled by the control system 100. The control system 100 may be dedicated entirely to the turbine-based service system 14, or the control system 100 may optionally also provide control (or at least some data to facilitate control) for the hydrocarbon production system 12 and/or other systems 84. In the illustrated embodiment, the control system 100 includes a controller 118 having a processor 120, a memory 122, a steam turbine control 124, a SEGR gas turbine system control 126, and a machinery control 128. The processor 120 may include a single processor or two or more redundant processors, such as triple redundant processors for control of the turbine-based service system 14. The memory 122 may include volatile and/or non-volatile memory. For example, the memory 122 may include one or more hard drives, flash memory, read-only memory, random access memory, or any combination thereof. The controls 124, 126, and 128 may include software and/or hardware controls. For example, the controls 124, 126, and 128 may include various instructions or code stored on the memory 122 and executable by the processor 120. The control 124 is configured to control operation of the steam turbine 104, the SEGR gas turbine system control 126 is configured to control the system 52, and the machinery control 128 is configured to control the machinery 106. Thus, the controller 118 (e.g., controls 124, 126, and 128) may be configured to coordinate various sub-systems of the turbine-based service system 14 to provide a suitable stream of the exhaust gas 42 to the hydrocarbon production system 12.

[0052] In certain embodiments of the control system 100, each element (e.g., system, subsystem, and component) illustrated in the drawings or described herein includes (e.g., directly within, upstream, or downstream of such element) one or more industrial control features, such as sensors and control devices, which are communicatively coupled with one another over an industrial control network along with the controller 118. For example, the control devices associated with each element may include a dedicated device controller (e.g., including a processor, memory, and control instructions), one or more actuators, valves, switches, and industrial control equipment, which enable control based on sensor feedback 130, control signals from the controller 118, control signals from a user, or any combination thereof. Thus, any of the control functionality described herein may be implemented with control instructions stored and/or executable by the controller 118, dedicated device controllers associated with each element, or a combination thereof.

[0053] In order to facilitate such control functionality, the control system 100 includes one or more sensors distributed throughout the system 10 to obtain the sensor feedback 130 for use in execution of the various controls, e.g., the controls 124, 126, and 128. For example, the sensor feedback 130 may be obtained from sensors distributed throughout the SEGR gas turbine system 52, the machinery 106, the EG processing system 54, the steam turbine 104, the hydrocarbon production system 12, or any other components throughout the turbine-based service system 14 or the hydrocarbon production system 12. For example, the sensor feedback 130 may include temperature feedback, pressure feedback, flow rate feedback, flame temperature feedback, combustion dynamics feedback, intake oxidant composition feedback, intake fuel composition feedback, exhaust composition feedback, the output level of mechanical power 72, the output level of electrical power 74, the output quantity of the exhaust gas 42, 60, the output quantity or quality of the water 64, or any combination thereof. For example, the sensor feedback 130 may include a composition of the exhaust gas 42, 60 to facilitate stoichiometric combustion in the SEGR gas turbine system 52. For example, the sensor feedback 130 may include feedback from one or more intake oxidant sensors along an oxidant supply path of the oxidant 68, one or more intake fuel sensors along a fuel supply path of the fuel 70,

and one or more exhaust emissions sensors disposed along the exhaust recirculation path 110 and/or within the SEGR gas turbine system 52. The intake oxidant sensors, intake fuel sensors, and exhaust emissions sensors may include temperature sensors, pressure sensors, flow rate sensors, and composition sensors. The emissions sensors may include sensors for nitrogen oxides (e.g., NO_x sensors), carbon oxides (e.g., CO sensors and CO₂ sensors), sulfur oxides (e.g., SO_x sensors), hydrogen (e.g., H₂ sensors), oxygen (e.g., O₂ sensors), unburnt hydrocarbons (e.g., HC sensors), or other products of incomplete combustion, or any combination thereof.

[0054] Using this feedback 130, the control system 100 may adjust (e.g., increase, decrease, or maintain) the intake flow of exhaust gas 66, oxidant 68, and/or fuel 70 into the SEGR gas turbine system 52 (among other operational parameters) to maintain the equivalence ratio within a suitable range, e.g., between approximately 0.95 to approximately 1.05, between approximately 0.95 to approximately 1.0, between approximately 1.0 to approximately 1.05, or substantially at 1.0. For example, the control system 100 may analyze the feedback 130 to monitor the exhaust emissions (e.g., concentration levels of nitrogen oxides, carbon oxides such as CO and CO₂, sulfur oxides, hydrogen, oxygen, unburnt hydrocarbons, and other products of incomplete combustion) and/or determine the equivalence ratio, and then control one or more components to adjust the exhaust emissions (e.g., concentration levels in the exhaust gas 42) and/or the equivalence ratio. The controlled components may include any of the components illustrated and described with reference to the drawings, including but not limited to, valves along the supply paths for the oxidant 68, the fuel 70, and the exhaust gas 66; an oxidant compressor, a fuel pump, or any components in the EG processing system 54; any components of the SEGR gas turbine system 52, or any combination thereof. The controlled components may adjust (e.g., increase, decrease, or maintain) the flow rates, temperatures, pressures, or percentages (e.g., equivalence ratio) of the oxidant 68, the fuel 70, and the exhaust gas 66 that combust within the SEGR gas turbine system 52. The controlled components also may include one or more gas treatment systems, such as catalyst units (e.g., oxidation catalyst units), supplies for the catalyst units (e.g., oxidation fuel, heat, electricity, etc.), gas purification and/or separation units (e.g., solvent based separators, absorbers, flash

tanks, etc.), and filtration units. The gas treatment systems may help reduce various exhaust emissions along the exhaust recirculation path 110, a vent path (e.g., exhausted into the atmosphere), or an extraction path to the EG supply system 78.

[0055] In certain embodiments, the control system 100 may analyze the feedback 130 and control one or more components to maintain or reduce emissions levels (e.g., concentration levels in the exhaust gas 42, 60, 95) to a target range, such as less than approximately 10, 20, 30, 40, 50, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, 5000, or 10000 parts per million by volume (ppmv). These target ranges may be the same or different for each of the exhaust emissions, e.g., concentration levels of nitrogen oxides, carbon monoxide, sulfur oxides, hydrogen, oxygen, unburnt hydrocarbons, and other products of incomplete combustion. For example, depending on the equivalence ratio, the control system 100 may selectively control exhaust emissions (e.g., concentration levels) of oxidant (e.g., oxygen) within a target range of less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 250, 500, 750, or 1000 ppmv; carbon monoxide (CO) within a target range of less than approximately 20, 50, 100, 200, 500, 1000, 2500, or 5000 ppmv; and nitrogen oxides (NO_x) within a target range of less than approximately 50, 100, 200, 300, 400, or 500 ppmv. In certain embodiments operating with a substantially stoichiometric equivalence ratio, the control system 100 may selectively control exhaust emissions (e.g., concentration levels) of oxidant (e.g., oxygen) within a target range of less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100 ppmv; and carbon monoxide (CO) within a target range of less than approximately 500, 1000, 2000, 3000, 4000, or 5000 ppmv. In certain embodiments operating with a fuel-lean equivalence ratio (e.g., between approximately 0.95 to 1.0), the control system 100 may selectively control exhaust emissions (e.g., concentration levels) of oxidant (e.g., oxygen) within a target range of less than approximately 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, or 1500 ppmv; carbon monoxide (CO) within a target range of less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, or 200 ppmv; and nitrogen oxides (e.g., NO_x) within a target range of less than approximately 50, 100, 150, 200, 250, 300, 350, or 400 ppmv. The foregoing target ranges are merely examples, and are not intended to limit the scope of the disclosed embodiments.

[0056] The control system 100 also may be coupled to a local interface 132 and a remote interface 134. For example, the local interface 132 may include a computer workstation disposed on-site at the turbine-based service system 14 and/or the hydrocarbon production system 12. In contrast, the remote interface 134 may include a computer workstation disposed off-site from the turbine-based service system 14 and the hydrocarbon production system 12, such as through an internet connection. These interfaces 132 and 134 facilitate monitoring and control of the turbine-based service system 14, such as through one or more graphical displays of sensor feedback 130, operational parameters, and so forth.

[0057] Again, as noted above, the controller 118 includes a variety of controls 124, 126, and 128 to facilitate control of the turbine-based service system 14. The steam turbine control 124 may receive the sensor feedback 130 and output control commands to facilitate operation of the steam turbine 104. For example, the steam turbine control 124 may receive the sensor feedback 130 from the HRSG 56, the machinery 106, temperature and pressure sensors along a path of the steam 62, temperature and pressure sensors along a path of the water 108, and various sensors indicative of the mechanical power 72 and the electrical power 74. Likewise, the SEGR gas turbine system control 126 may receive sensor feedback 130 from one or more sensors disposed along the SEGR gas turbine system 52, the machinery 106, the EG processing system 54, or any combination thereof. For example, the sensor feedback 130 may be obtained from temperature sensors, pressure sensors, clearance sensors, vibration sensors, flame sensors, fuel composition sensors, exhaust gas composition sensors, or any combination thereof, disposed within or external to the SEGR gas turbine system 52. Finally, the machinery control 128 may receive sensor feedback 130 from various sensors associated with the mechanical power 72 and the electrical power 74, as well as sensors disposed within the machinery 106. Each of these controls 124, 126, and 128 uses the sensor feedback 130 to improve operation of the turbine-based service system 14.

[0058] In the illustrated embodiment, the SEGR gas turbine system control 126 may execute instructions to control the quantity and quality of the exhaust gas 42, 60, 95 in the EG processing system 54, the EG supply system 78, the hydrocarbon

production system 12, and/or the other systems 84. For example, the SEGR gas turbine system control 126 may maintain a level of oxidant (e.g., oxygen) and/or unburnt fuel in the exhaust gas 60 below a threshold suitable for use with the exhaust gas injection EOR system 112. In certain embodiments, the threshold levels may be less than 1, 2, 3, 4, or 5 percent of oxidant (e.g., oxygen) and/or unburnt fuel by volume of the exhaust gas 42, 60; or the threshold levels of oxidant (e.g., oxygen) and/or unburnt fuel (and other exhaust emissions) may be less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, or 5000 parts per million by volume (ppmv) in the exhaust gas 42, 60. By further example, in order to achieve these low levels of oxidant (e.g., oxygen) and/or unburnt fuel, the SEGR gas turbine system control 126 may maintain an equivalence ratio for combustion in the SEGR gas turbine system 52 between approximately 0.95 and approximately 1.05. The SEGR gas turbine system control 126 also may control the EG extraction system 80 and the EG treatment system 82 to maintain the temperature, pressure, flow rate, and gas composition of the exhaust gas 42, 60, 95 within suitable ranges for the exhaust gas injection EOR system 112, the pipeline 86, the storage tank 88, and the carbon sequestration system 90. As discussed above, the EG treatment system 82 may be controlled to purify and/or separate the exhaust gas 42 into one or more gas streams 95, such as the CO₂ rich, N₂ lean stream 96, the intermediate concentration CO₂, N₂ stream 97, and the CO₂ lean, N₂ rich stream 98. In addition to controls for the exhaust gas 42, 60, and 95, the controls 124, 126, and 128 may execute one or more instructions to maintain the mechanical power 72 within a suitable power range, or maintain the electrical power 74 within a suitable frequency and power range.

[0059] FIG. 3 is a diagram of embodiment of the system 10, further illustrating details of the SEGR gas turbine system 52 for use with the hydrocarbon production system 12 and/or other systems 84. In the illustrated embodiment, the SEGR gas turbine system 52 includes a gas turbine engine 150 coupled to the EG processing system 54. The illustrated gas turbine engine 150 includes a compressor section 152, a combustor section 154, and an expander section or turbine section 156. The compressor section 152 includes one or more exhaust gas compressors or compressor

stages 158, such as 1 to 20 stages of rotary compressor blades disposed in a series arrangement. Likewise, the combustor section 154 includes one or more combustors 160, such as 1 to 20 combustors 160 distributed circumferentially about a rotational axis 162 of the SEGR gas turbine system 52. Furthermore, each combustor 160 may include one or more fuel nozzles 164 configured to inject the exhaust gas 66, the oxidant 68, and/or the fuel 70. For example, a head end portion 166 of each combustor 160 may house 1, 2, 3, 4, 5, 6, or more fuel nozzles 164, which may inject streams or mixtures of the exhaust gas 66, the oxidant 68, and/or the fuel 70 into a combustion portion 168 (e.g., combustion chamber) of the combustor 160.

[0060] The fuel nozzles 164 may include any combination of premix fuel nozzles 164 (e.g., configured to premix the oxidant 68 and fuel 70 for generation of an oxidant/fuel premix flame) and/or diffusion fuel nozzles 164 (e.g., configured to inject separate flows of the oxidant 68 and fuel 70 for generation of an oxidant/fuel diffusion flame). Embodiments of the premix fuel nozzles 164 may include swirl vanes, mixing chambers, or other features to internally mix the oxidant 68 and fuel 70 within the nozzles 164, prior to injection and combustion in the combustion chamber 168. The premix fuel nozzles 164 also may receive at least some partially mixed oxidant 68 and fuel 70. In certain embodiments, each diffusion fuel nozzle 164 may isolate flows of the oxidant 68 and the fuel 70 until the point of injection, while also isolating flows of one or more diluents (e.g., the exhaust gas 66, steam, nitrogen, or another inert gas) until the point of injection. In other embodiments, each diffusion fuel nozzle 164 may isolate flows of the oxidant 68 and the fuel 70 until the point of injection, while partially mixing one or more diluents (e.g., the exhaust gas 66, steam, nitrogen, or another inert gas) with the oxidant 68 and/or the fuel 70 prior to the point of injection. In addition, one or more diluents (e.g., the exhaust gas 66, steam, nitrogen, or another inert gas) may be injected into the combustor (e.g., into the hot products of combustion) either at or downstream from the combustion zone, thereby helping to reduce the temperature of the hot products of combustion and reduce emissions of NO_x (e.g., NO and NO₂). Regardless of the type of fuel nozzle 164, the SEGR gas turbine system 52 may be controlled to provide substantially stoichiometric combustion of the oxidant 68 and fuel 70.

[0061] In diffusion combustion embodiments using the diffusion fuel nozzles 164, the fuel 70 and oxidant 68 generally do not mix upstream from the diffusion flame, but rather the fuel 70 and oxidant 68 mix and react directly at the flame surface and/or the flame surface exists at the location of mixing between the fuel 70 and oxidant 68. In particular, the fuel 70 and oxidant 68 separately approach the flame surface (or diffusion boundary/interface), and then diffuse (e.g., via molecular and viscous diffusion) along the flame surface (or diffusion boundary/interface) to generate the diffusion flame. It is noteworthy that the fuel 70 and oxidant 68 may be at a substantially stoichiometric ratio along this flame surface (or diffusion boundary/interface), which may result in a greater flame temperature (e.g., a peak flame temperature) along this flame surface. The stoichiometric fuel/oxidant ratio generally results in a greater flame temperature (e.g., a peak flame temperature), as compared with a fuel-lean or fuel-rich fuel/oxidant ratio. As a result, the diffusion flame may be substantially more stable than a premix flame, because the diffusion of fuel 70 and oxidant 68 helps to maintain a stoichiometric ratio (and greater temperature) along the flame surface. Although greater flame temperatures can also lead to greater exhaust emissions, such as NO_x emissions, the disclosed embodiments use one or more diluents to help control the temperature and emissions while still avoiding any premixing of the fuel 70 and oxidant 68. For example, the disclosed embodiments may introduce one or more diluents separate from the fuel 70 and oxidant 68 (e.g., after the point of combustion and/or downstream from the diffusion flame), thereby helping to reduce the temperature and reduce the emissions (e.g., NO_x emissions) produced by the diffusion flame.

[0062] In operation, as illustrated, the compressor section 152 receives and compresses the exhaust gas 66 from the EG processing system 54, and outputs a compressed exhaust gas 170 to each of the combustors 160 in the combustor section 154. Upon combustion of the fuel 60, oxidant 68, and exhaust gas 170 within each combustor 160, additional exhaust gas or products of combustion 172 (i.e., combustion gas) is routed into the turbine section 156. Similar to the compressor section 152, the turbine section 156 includes one or more turbines or turbine stages 174, which may include a series of rotary turbine blades. These turbine blades are

then driven by the products of combustion 172 generated in the combustor section 154, thereby driving rotation of a shaft 176 coupled to the machinery 106. Again, the machinery 106 may include a variety of equipment coupled to either end of the SEGR gas turbine system 52, such as machinery 106, 178 coupled to the turbine section 156 and/or machinery 106, 180 coupled to the compressor section 152. In certain embodiments, the machinery 106, 178, 180 may include one or more electrical generators, oxidant compressors for the oxidant 68, fuel pumps for the fuel 70, gear boxes, or additional drives (e.g. steam turbine 104, electrical motor, etc.) coupled to the SEGR gas turbine system 52. Non-limiting examples are discussed in further detail below with reference to TABLE 1. As illustrated, the turbine section 156 outputs the exhaust gas 60 to recirculate along the exhaust recirculation path 110 from an exhaust outlet 182 of the turbine section 156 to an exhaust inlet 184 into the compressor section 152. Along the exhaust recirculation path 110, the exhaust gas 60 passes through the EG processing system 54 (e.g., the HRSG 56 and/or the EGR system 58) as discussed in detail above.

[0063] Again, each combustor 160 in the combustor section 154 receives, mixes, and stoichiometrically combusts the compressed exhaust gas 170, the oxidant 68, and the fuel 70 to produce the additional exhaust gas or products of combustion 172 to drive the turbine section 156. In certain embodiments, the oxidant 68 is compressed by an oxidant compression system 186, such as a main oxidant compression (MOC) system (e.g., a main air compression (MAC) system) having one or more oxidant compressors (MOCs). The oxidant compression system 186 includes an oxidant compressor 188 coupled to a drive 190. For example, the drive 190 may include an electric motor, a combustion engine, or any combination thereof. In certain embodiments, the drive 190 may be a turbine engine, such as the gas turbine engine 150. Accordingly, the oxidant compression system 186 may be an integral part of the machinery 106. In other words, the compressor 188 may be directly or indirectly driven by the mechanical power 72 supplied by the shaft 176 of the gas turbine engine 150. In such an embodiment, the drive 190 may be excluded, because the compressor 188 relies on the power output from the turbine engine 150. However, in certain embodiments employing more than one oxidant compressor is employed, a first

oxidant compressor (e.g., a low pressure (LP) oxidant compressor) may be driven by the drive 190 while the shaft 176 drives a second oxidant compressor (e.g., a high pressure (HP) oxidant compressor), or vice versa. For example, in another embodiment, the HP MOC is driven by the drive 190 and the LP oxidant compressor is driven by the shaft 176. In the illustrated embodiment, the oxidant compression system 186 is separate from the machinery 106. In each of these embodiments, the compression system 186 compresses and supplies the oxidant 68 to the fuel nozzles 164 and the combustors 160. Accordingly, some or all of the machinery 106, 178, 180 may be configured to increase the operational efficiency of the compression system 186 (e.g., the compressor 188 and/or additional compressors).

[0064] The variety of components of the machinery 106, indicated by element numbers 106A, 106B, 106C, 106D, 106E, and 106F, may be disposed along the line of the shaft 176 and/or parallel to the line of the shaft 176 in one or more series arrangements, parallel arrangements, or any combination of series and parallel arrangements. For example, the machinery 106, 178, 180 (e.g., 106A through 106F) may include any series and/or parallel arrangement, in any order, of: one or more gearboxes (e.g., parallel shaft, epicyclic gearboxes), one or more compressors (e.g., oxidant compressors, booster compressors such as EG booster compressors), one or more power generation units (e.g., electrical generators), one or more drives (e.g., steam turbine engines, electrical motors), heat exchange units (e.g., direct or indirect heat exchangers), clutches, or any combination thereof. The compressors may include axial compressors, radial or centrifugal compressors, or any combination thereof, each having one or more compression stages. Regarding the heat exchangers, direct heat exchangers may include spray coolers (e.g., spray intercoolers), which inject a liquid spray into a gas flow (e.g., oxidant flow) for direct cooling of the gas flow. Indirect heat exchangers may include at least one wall (e.g., a shell and tube heat exchanger) separating first and second flows, such as a fluid flow (e.g., oxidant flow) separated from a coolant flow (e.g., water, air, refrigerant, or any other liquid or gas coolant), wherein the coolant flow transfers heat from the fluid flow without any direct contact. Examples of indirect heat exchangers include intercooler heat exchangers and heat recovery units, such as heat recovery steam generators. The heat exchangers also may

include heaters. As discussed in further detail below, each of these machinery components may be used in various combinations as indicated by the non-limiting examples set forth in TABLE 1.

[0065] Generally, the machinery 106, 178, 180 may be configured to increase the efficiency of the compression system 186 by, for example, adjusting operational speeds of one or more oxidant compressors in the system 186, facilitating compression of the oxidant 68 through cooling, and/or extraction of surplus power. The disclosed embodiments are intended to include any and all permutations of the foregoing components in the machinery 106, 178, 180 in series and parallel arrangements, wherein one, more than one, all, or none of the components derive power from the shaft 176. As illustrated below, TABLE 1 depicts some non-limiting examples of arrangements of the machinery 106, 178, 180 disposed proximate and/or coupled to the compressor and turbine sections 152, 156.

106A	106B	106C	106D	106E	106F
MOC	GEN				
MOC	GBX	GEN			
LP MOC	HP MOC	GEN			
HP MOC	GBX	LP MOC	GEN		
MOC MOC	GBX	GEN			
HP MOC	GBX	GEN	LP MOC		
MOC MOC	GBX GBX	GEN DRV			
DRV	GBX	LP MOC	HP MOC	GBX	GEN
DRV	GBX	HP MOC	LP MOC	GEN	
HP MOC	GBX CLR	LP MOC	GEN		
HP MOC	GBX CLR	LP MOC	GBX	GEN	
HP MOC	GBX HTR STGN	LP MOC	GEN		
MOC	GEN	DRV			
MOC	DRV	GEN			
DRV	MOC	GEN			
DRV	CLU	MOC	GEN		
DRV	CLU	MOC	GBX	GEN	

TABLE 1

[0066] As illustrated above in TABLE 1, a cooling unit is represented as CLR, a clutch is represented as CLU, a drive is represented by DRV, a gearbox is represented as GBX, a generator is represented by GEN, a heating unit is represented by HTR, a main oxidant compressor unit is represented by MOC, with low pressure and high pressure variants being represented as LP MOC and HP MOC, respectively, and a steam generator unit is represented as STGN. Although TABLE 1 illustrates the machinery 106, 178, 180 in sequence toward the compressor section 152 or the turbine section 156, TABLE 1 is also intended to cover the reverse sequence of the machinery 106, 178, 180. In TABLE 1, any cell including two or more components is intended to cover a parallel arrangement of the components. TABLE 1 is not intended to exclude any non-illustrated permutations of the machinery 106, 178, 180. These components of the machinery 106, 178, 180 may enable feedback control of temperature, pressure, and flow rate of the oxidant 68 sent to the gas turbine engine 150. As discussed in further detail below, the oxidant 68 and the fuel 70 may be supplied to the gas turbine engine 150 at locations specifically selected to facilitate isolation and extraction of the compressed exhaust gas 170 without any oxidant 68 or fuel 70 degrading the quality of the exhaust gas 170.

[0067] The EG supply system 78, as illustrated in FIG. 3, is disposed between the gas turbine engine 150 and the target systems (e.g., the hydrocarbon production system 12 and the other systems 84). In particular, the EG supply system 78, e.g., the EG extraction system (EGES) 80, may be coupled to the gas turbine engine 150 at one or more extraction points 76 along the compressor section 152, the combustor section 154, and/or the turbine section 156. For example, the extraction points 76 may be located between adjacent compressor stages, such as 2, 3, 4, 5, 6, 7, 8, 9, or 10 interstage extraction points 76 between compressor stages. Each of these interstage extraction points 76 provides a different temperature and pressure of the extracted exhaust gas 42. Similarly, the extraction points 76 may be located between adjacent turbine stages, such as 2, 3, 4, 5, 6, 7, 8, 9, or 10 interstage extraction points 76 between turbine stages. Each of these interstage extraction points 76 provides a different temperature and pressure of the extracted exhaust gas 42. By further example, the extraction points 76 may be located at a multitude of locations

throughout the combustor section 154, which may provide different temperatures, pressures, flow rates, and gas compositions. Each of these extraction points 76 may include an EG extraction conduit, one or more valves, sensors, and controls, which may be used to selectively control the flow of the extracted exhaust gas 42 to the EG supply system 78.

[0068] The extracted exhaust gas 42, which is distributed by the EG supply system 78, has a controlled composition suitable for the target systems (e.g., the hydrocarbon production system 12 and the other systems 84). For example, at each of these extraction points 76, the exhaust gas 170 may be substantially isolated from injection points (or flows) of the oxidant 68 and the fuel 70. In other words, the EG supply system 78 may be specifically designed to extract the exhaust gas 170 from the gas turbine engine 150 without any added oxidant 68 or fuel 70. Furthermore, in view of the stoichiometric combustion in each of the combustors 160, the extracted exhaust gas 42 may be substantially free of oxygen and fuel. The EG supply system 78 may route the extracted exhaust gas 42 directly or indirectly to the hydrocarbon production system 12 and/or other systems 84 for use in various processes, such as enhanced oil recovery, carbon sequestration, storage, or transport to an offsite location. However, in certain embodiments, the EG supply system 78 includes the EG treatment system (EGTS) 82 for further treatment of the exhaust gas 42, prior to use with the target systems. For example, the EG treatment system 82 may purify and/or separate the exhaust gas 42 into one or more streams 95, such as the CO₂ rich, N₂ lean stream 96, the intermediate concentration CO₂, N₂ stream 97, and the CO₂ lean, N₂ rich stream 98. These treated exhaust gas streams 95 may be used individually, or in any combination, with the hydrocarbon production system 12 and the other systems 84 (e.g., the pipeline 86, the storage tank 88, and the carbon sequestration system 90).

[0069] Similar to the exhaust gas treatments performed in the EG supply system 78, the EG processing system 54 may include a plurality of exhaust gas (EG) treatment components 192, such as indicated by element numbers 194, 196, 198, 200, 202, 204, 206, 208, and 210. These EG treatment components 192 (e.g., 194 through 210) may be disposed along the exhaust recirculation path 110 in one or more series arrangements, parallel arrangements, or any combination of series and parallel

arrangements. For example, the EG treatment components 192 (e.g., 194 through 210) may include any series and/or parallel arrangement, in any order, of: one or more heat exchangers (e.g., heat recovery units such as heat recovery steam generators, condensers, coolers, or heaters), catalyst systems (e.g., oxidation catalyst systems), particulate and/or water removal systems (e.g., inertial separators, coalescing filters, water impermeable filters, and other filters), chemical injection systems, solvent based treatment systems (e.g., absorbers, flash tanks, etc.), carbon capture systems, gas separation systems, gas purification systems, and/or a solvent based treatment system, or any combination thereof. In certain embodiments, the catalyst systems may include an oxidation catalyst, a carbon monoxide reduction catalyst, a nitrogen oxides reduction catalyst, an aluminum oxide, a zirconium oxide, a silicone oxide, a titanium oxide, a platinum oxide, a palladium oxide, a cobalt oxide, or a mixed metal oxide, or a combination thereof. The disclosed embodiments are intended to include any and all permutations of the foregoing components 192 in series and parallel arrangements. As illustrated below, TABLE 2 depicts some non-limiting examples of arrangements of the components 192 along the exhaust recirculation path 110.

194	196	198	200	202	204	206	208	210
CU	HRU	BB	MRU	PRU				
CU	HRU	HRU	BB	MRU	PRU	DIL		
CU	HRSG	HRSG	BB	MRU	PRU			
OCU	HRU	OCU	HRU	OCU	BB	MRU	PRU	
HRU CU	HRU CU	BB	MRU	PRU				
HRSG OCU	HRSG OCU	BB	MRU	PRU	DIL			
OCU	HRSG OCU	OCU	HRSG OCU	OCU	BB	MRU	PRU	DIL
OCU	HRSG ST	HRSG ST	BB	COND	INNER	WFIL	CFIL	DIL
OCU HRSG ST	OCU HRSG ST	BB	COND	INNER	FIL	DIL		
OCU	HRSG ST	HRSG ST	OCU	BB	MRU HE COND	MRU WFIL	PRU INNER	PRU FIL CFIL
CU	HRU COND	HRU COND	HRU COND	BB	MRU HE COND WFIL	PRU INNER	PRU FIL CFIL	DIL

TABLE 2

[0070] As illustrated above in TABLE 2, a catalyst unit is represented by CU, an oxidation catalyst unit is represented by OCU, a booster blower is represented by BB, a heat exchanger is represented by HX, a heat recovery unit is represented by HRU, a heat recovery steam generator is represented by HRSG, a condenser is represented by COND, a steam turbine is represented by ST, a particulate removal unit is represented by PRU, a moisture removal unit is represented by MRU, a filter is represented by

FIL, a coalescing filter is represented by CFIL, a water impermeable filter is represented by WFIL, an inertial separator is represented by INER, and a diluent supply system (e.g., steam, nitrogen, or other inert gas) is represented by DIL. Although TABLE 2 illustrates the components 192 in sequence from the exhaust outlet 182 of the turbine section 156 toward the exhaust inlet 184 of the compressor section 152, TABLE 2 is also intended to cover the reverse sequence of the illustrated components 192. In TABLE 2, any cell including two or more components is intended to cover an integrated unit with the components, a parallel arrangement of the components, or any combination thereof. Furthermore, in context of TABLE 2, the HRU, the HRSG, and the COND are examples of the HE; the HRSG is an example of the HRU; the COND, WFIL, and CFIL are examples of the WRU; the INER, FIL, WFIL, and CFIL are examples of the PRU; and the WFIL and CFIL are examples of the FIL. Again, TABLE 2 is not intended to exclude any non-illustrated permutations of the components 192. In certain embodiments, the illustrated components 192 (e.g., 194 through 210) may be partially or completely integrated within the HRSG 56, the EGR system 58, or any combination thereof. These EG treatment components 192 may enable feedback control of temperature, pressure, flow rate, and gas composition, while also removing moisture and particulates from the exhaust gas 60. Furthermore, the treated exhaust gas 60 may be extracted at one or more extraction points 76 for use in the EG supply system 78 and/or recirculated to the exhaust inlet 184 of the compressor section 152.

[0071] As the treated, recirculated exhaust gas 66 passes through the compressor section 152, the SEGR gas turbine system 52 may bleed off a portion of the compressed exhaust gas along one or more lines 212 (e.g., bleed conduits or bypass conduits). Each line 212 may route the exhaust gas into one or more heat exchangers 214 (e.g., cooling units), thereby cooling the exhaust gas for recirculation back into the SEGR gas turbine system 52. For example, after passing through the heat exchanger 214, a portion of the cooled exhaust gas may be routed to the turbine section 156 along line 212 for cooling and/or sealing of the turbine casing, turbine shrouds, bearings, and other components. In such an embodiment, the SEGR gas turbine system 52 does not route any oxidant 68 (or other potential contaminants)

through the turbine section 156 for cooling and/or sealing purposes, and thus any leakage of the cooled exhaust gas will not contaminate the hot products of combustion (e.g., working exhaust gas) flowing through and driving the turbine stages of the turbine section 156. By further example, after passing through the heat exchanger 214, a portion of the cooled exhaust gas may be routed along line 216 (e.g., return conduit) to an upstream compressor stage of the compressor section 152, thereby improving the efficiency of compression by the compressor section 152. In such an embodiment, the heat exchanger 214 may be configured as an interstage cooling unit for the compressor section 152. In this manner, the cooled exhaust gas helps to increase the operational efficiency of the SEGR gas turbine system 52, while simultaneously helping to maintain the purity of the exhaust gas (e.g., substantially free of oxidant and fuel).

[0072] FIG. 4 is a flow chart of an embodiment of an operational process 220 of the system 10 illustrated in FIGS 1-3. In certain embodiments, the process 220 may be a computer implemented process, which accesses one or more instructions stored on the memory 122 and executes the instructions on the processor 120 of the controller 118 shown in FIG. 2. For example, each step in the process 220 may include instructions executable by the controller 118 of the control system 100 described with reference to FIG. 2.

[0073] The process 220 may begin by initiating a startup mode of the SEGR gas turbine system 52 of FIGS. 1-3, as indicated by block 222. For example, the startup mode may involve a gradual ramp up of the SEGR gas turbine system 52 to maintain thermal gradients, vibration, and clearance (e.g., between rotating and stationary parts) within acceptable thresholds. For example, during the startup mode 222, the process 220 may begin to supply a compressed oxidant 68 to the combustors 160 and the fuel nozzles 164 of the combustor section 154, as indicated by block 224. In certain embodiments, the compressed oxidant may include a compressed air, oxygen, oxygen-enriched air, oxygen-reduced air, oxygen-nitrogen mixtures, or any combination thereof. For example, the oxidant 68 may be compressed by the oxidant compression system 186 illustrated in FIG. 3. The process 220 also may begin to supply fuel to the combustors 160 and the fuel nozzles 164 during the startup mode

222, as indicated by block 226. During the startup mode 222, the process 220 also may begin to supply exhaust gas (as available) to the combustors 160 and the fuel nozzles 164, as indicated by block 228. For example, the fuel nozzles 164 may produce one or more diffusion flames, premix flames, or a combination of diffusion and premix flames. During the startup mode 222, the exhaust gas 60 being generated by the gas turbine engine 156 may be insufficient or unstable in quantity and/or quality. Accordingly, during the startup mode, the process 220 may supply the exhaust gas 66 from one or more storage units (e.g., storage tank 88), the pipeline 86, other SEGR gas turbine systems 52, or other exhaust gas sources.

[0074] The process 220 may then combust a mixture of the compressed oxidant, fuel, and exhaust gas in the combustors 160 to produce hot combustion gas 172, as indicated by block 230. In particular, the process 220 may be controlled by the control system 100 of FIG. 2 to facilitate stoichiometric combustion (e.g., stoichiometric diffusion combustion, premix combustion, or both) of the mixture in the combustors 160 of the combustor section 154. However, during the startup mode 222, it may be particularly difficult to maintain stoichiometric combustion of the mixture (and thus low levels of oxidant and unburnt fuel may be present in the hot combustion gas 172). As a result, in the startup mode 222, the hot combustion gas 172 may have greater amounts of residual oxidant 68 and/or fuel 70 than during a steady state mode as discussed in further detail below. For this reason, the process 220 may execute one or more control instructions to reduce or eliminate the residual oxidant 68 and/or fuel 70 in the hot combustion gas 172 during the startup mode.

[0075] The process 220 then drives the turbine section 156 with the hot combustion gas 172, as indicated by block 232. For example, the hot combustion gas 172 may drive one or more turbine stages 174 disposed within the turbine section 156. Downstream of the turbine section 156, the process 220 may treat the exhaust gas 60 from the final turbine stage 174, as indicated by block 234. For example, the exhaust gas treatment 234 may include filtration, catalytic reaction of any residual oxidant 68 and/or fuel 70, chemical treatment, heat recovery with the HRSG 56, and so forth. The process 220 may also recirculate at least some of the exhaust gas 60 back to the compressor section 152 of the SEGR gas turbine system 52, as indicated by block

236. For example, the exhaust gas recirculation 236 may involve passage through the exhaust recirculation path 110 having the EG processing system 54 as illustrated in FIGS. 1-3.

[0076] In turn, the recirculated exhaust gas 66 may be compressed in the compressor section 152, as indicated by block 238. For example, the SEGR gas turbine system 52 may sequentially compress the recirculated exhaust gas 66 in one or more compressor stages 158 of the compressor section 152. Subsequently, the compressed exhaust gas 170 may be supplied to the combustors 160 and fuel nozzles 164, as indicated by block 228. Steps 230, 232, 234, 236, and 238 may then repeat, until the process 220 eventually transitions to a steady state mode, as indicated by block 240. Upon the transition 240, the process 220 may continue to perform the steps 224 through 238, but may also begin to extract the exhaust gas 42 via the EG supply system 78, as indicated by block 242. For example, the exhaust gas 42 may be extracted from one or more extraction points 76 along the compressor section 152, the combustor section 154, and the turbine section 156 as indicated in FIG. 3. In turn, the process 220 may supply the extracted exhaust gas 42 from the EG supply system 78 to the hydrocarbon production system 12, as indicated by block 244. The hydrocarbon production system 12 may then inject the exhaust gas 42 into the earth 32 for enhanced oil recovery, as indicated by block 246. For example, the extracted exhaust gas 42 may be used by the exhaust gas injection EOR system 112 of the EOR system 18 illustrated in FIGS. 1-3.

[0077] FIG. 5 is a schematic diagram of a portion of the gas turbine engine 150. Elements in FIG. 5 in common with those shown in previous figures are labeled with the same reference numerals. The axial direction of the gas turbine engine 150 is indicated by arrow 260, the radial direction is indicated by arrow 262, and the circumferential direction is indicated by arrow 264. These directions are all with respect to the rotational axis 162. In the illustrated embodiment, an exhaust section 266 is disposed downstream of the turbine section 156. The exhaust section 266 may be used to expand and/or cool the exhaust gas 60 before directing the exhaust gas 60 to the exhaust recirculation path 110. Specifically, a cross-sectional area of the exhaust section 266 may increase in the direction of the exhaust gas 60 flow, thereby

increasing the static pressure of the exhaust gas 60 by decreasing the kinetic energy of the exhaust gas 60. In the illustrated embodiment, a plurality of sensor adaptor housings 268 (e.g., oxygen sensor adaptor housings) may be disposed in the turbine section 156 and the exhaust section 266. Each of the oxygen sensor adaptor housings 268 may include a sensor (e.g., an oxygen sensor) 270. In other words, the oxygen sensor 270 is disposed within the oxygen sensor adaptor housing 268, which may surround and protect the oxygen sensor 270 from the high temperatures within the gas turbine engine 150. Specifically, the sensor adaptor housings 268 adapt a variety of sensors 270 to fit within the gas turbine engine 150, regardless of size or other characteristics of the sensor 270. In addition, each sensor adaptor housing 268 may include 1, 2, 3, 4, 5, or more sensors 270, each of which may be the same or different from one another. The plurality of oxygen sensor adaptor housings 268 may be disposed at one or more axial 260 locations in the turbine section 156 and/or the exhaust section 266. In addition, the plurality of oxygen sensor adaptor housings 268 may be distributed radially 262 and/or circumferentially 264 throughout the turbine section 156 and/or the exhaust section 266. In other embodiments, the plurality of oxygen sensor adaptor housings 268 may be disposed in at least one of the combustor section 154, turbine section 156, or the exhaust section 266, or any combination thereof. In various embodiments, the oxygen sensor adaptor housings 268 may be disposed wherever oxygen sensor readings may be desired throughout the gas turbine engine 150. In particular embodiments, it may be desirable to dispose the oxygen sensor adaptor housings 268 in the exhaust section 266 because of the lower temperatures, pressures, and/or flow rates associated with the exhaust section 266. As described in detail below, the oxygen sensor adaptor housings 268 may maintain a temperature of a portion (e.g., portion not directly in contact with the combustion products) of the oxygen sensor 270 below a threshold (e.g., a maximum operating temperature limit). As shown in FIG. 5, the sensor feedback 130 from the plurality of oxygen sensors 270 may be sent to the control system 100 to be used to adjust the operation of the gas turbine engine 150. Specifically, the sensor feedback 130 from the plurality of oxygen sensors 270 may be used by the control system 100 to maintain the equivalence ratio of the gas turbine engine 150 within a range, such as a range between approximately 0.95 to approximately 1.05. In turn, this helps

reduce residual oxygen in the exhaust gas, so that the exhaust gas is substantially or entirely free of oxygen.

[0078] FIG. 6 is a schematic diagram of an embodiment of the oxygen sensor adaptor housing 268 (e.g., one-piece or multi-piece cylindrical housing) coupled to a coolant supply system 280 that supplies a coolant 281 to the oxygen sensor adaptor housing 268. As shown in FIG. 6, the oxygen sensor adaptor housing 268 is disposed in an opening 282 formed in a wall 284, which may correspond to a wall or other structure of the combustor section 154, turbine section 156, or exhaust section 266. The oxygen sensor adaptor housing 268 may be secured to the wall 284 via a variety of mounting techniques, such as, but not limited to, threaded connections, bolted flanges, and so forth. The oxygen sensor adaptor housing 268 may include an insertion portion 286 (e.g., immersive housing) configured to extend a distance 288 radially 262 into a gas stream 290, which may correspond to any gas stream flowing through the combustor section 154, turbine section 156, or exhaust section 266. In certain embodiments, the distance 288 may be between approximately 35 cm to 65 cm, 40 cm to 60 cm, or 45 cm to 55 cm. In various embodiments, the oxygen sensor adaptor housing 268 may be recessed, flush, or protrude into the gas stream 290. Thus, the distance 288 may be zero, positive, or negative. An external portion 292 of the oxygen sensor adaptor housing 268 may be disposed outside or external of the wall 284. In other words, the insertion portion 286 may be exposed to high temperatures associated with the gas stream 290, while the external portion 292 may be exposed to ambient or near-ambient temperatures outside of the gas turbine engine 150.

[0079] As shown in FIG. 6, the coolant supply system 280 is coupled to the oxygen sensor adaptor housing 268. Specifically, the oxygen sensor adaptor housing 268 includes a coolant inlet 294 that conveys the coolant 281 (e.g., gas and/or liquid coolant) to the oxygen sensor adaptor housing 268 and a coolant outlet 296 that conveys the coolant 281 away from the oxygen sensor adaptor housing 268. In certain embodiments, the coolant 281 may include air, nitrogen, carbon dioxide, inert gas, refrigerant, or water, or any combination thereof. More generally, the coolant supply system 280 may use any liquid coolant and/or gas coolant to help maintain the

temperature of the portion (e.g., portion not directly in contact with the gas stream 290) of the oxygen sensor 270 below the threshold (e.g., a maximum operating temperature limit). In certain embodiments, the coolant supply system 280 may be configured to supply the coolant 281 at a flow rate that removes heat from the oxygen sensor adaptor housing 268, such that the temperature of the portion of the oxygen sensor 270 is maintained below the threshold. In other embodiments, the coolant 281 may be used to maintain the temperature of the portion of the oxygen sensor 270 within a range (e.g., between upper and lower temperature thresholds). For example, in certain embodiments, the coolant supply system 280 may supply air as the coolant 281 to the coolant inlet 294 at a flow rate between approximately 30 m³/hr to 105 m³/hr, 40 m³/hr to 95 m³/hr, or 50 m³/hr to 85 m³/hr. In further embodiments, a portion of the coolant 281 may enter (e.g., bleed) into the gas stream 290 via an opening in the oxygen sensor adaptor housing 268, which may be utilized when the coolant 281 is compatible with the gas stream 290 (e.g., exhaust gas coolant).

[0080] As shown in FIG. 6, the coolant supply system 280 may include one or more different components. For example, the coolant supply system 280 may include a coolant supply pump 298 to provide the coolant 281 to the coolant inlet 294. In further embodiments, a coolant supply valve 300 may be used to adjust the flow rate of the coolant 281 to the coolant inlet 294. In other embodiments, a coolant cooler 302 (e.g., heat exchanger) may be used to cool the coolant 281 from the coolant outlet 296 before returning the coolant 281 to the coolant inlet 294 for additional cooling of the oxygen sensor 270. The coolant cooler 302 may use another coolant, such as water, refrigerant, air, and so forth, to cool the coolant 281. Thus, the various components of the coolant supply system 280 may be disposed along a coolant recirculation path 304. In addition, the control system 100 may generate one or more output signals 306 to certain components of the coolant supply system 280, such as the coolant supply pump 280 motor, coolant supply valve 300 actuator, and/or coolant cooler 302 valve or fan motor. Specifically, the control system 100 may use the output signals 306 to adjust the flow rate of the coolant 281 flowing through the coolant recirculation path 304 to help maintain the temperature of the portion of the oxygen sensor 270 below the threshold. For example, the control system 100 may increase a

speed of the coolant supply pump 298 motor, open the coolant supply valve 300 via the actuator, and/or increase cooling supplied by the coolant cooler 302 by opening a coolant valve or increase a fan speed if sensor feedback 130 indicates that additional cooling of the oxygen sensor 270 is desired. Alternatively, the control system 100 may be used if sensor feedback 130 indicates that less cooling of the oxygen sensor 270 is desired.

[0081] FIG. 7 is a radial cross-sectional view of an embodiment of the gas turbine engine 150 with a plurality of oxygen sensor adaptor housings 268. Specifically, the plurality of oxygen sensor adaptor housings 268 are disposed circumferentially 264 through the wall 284 of the combustor section 154, turbine section 156, or exhaust section 266. Each of the plurality of oxygen sensor adaptor housings 268 may provide sensor feedback 130 to the control system 100. By distributing the oxygen sensor adaptor housings 268 circumferentially 264, the control system 100 may be used to detect undesired radial 262 and/or circumferential 264 distribution of the gas stream 290 (e.g., variations in the oxygen levels) flowing within the wall 284. For example, this may help with control of combustion and particularly with reducing residual oxygen and helping to provide stoichiometric combustion. In certain embodiments, each of the plurality of oxygen sensor adaptor housings 268 may be separated by a separation distance 320. In other words, the plurality of oxygen sensor adaptor housings 268 may be distributed circumferentially 264 in a uniform manner. In other embodiments, the plurality of oxygen sensor adaptor housings 268 may be distributed circumferentially 264 in a non-uniform manner. For example, more of the plurality of oxygen sensor adaptor housings 286 may be distributed along an upper portion of the wall 284 than a lower portion of the wall 284.

[0082] FIG. 8 is a perspective view of an embodiment of the oxygen sensor 270 that may be disposed in embodiments of the oxygen sensor adaptor housing 268. Specifically, the oxygen sensor 270 may include a sensor tip 330 that may be configured to be exposed to the gas stream 290 during operation of the oxygen sensor 270. Thus, the sensor tip 330 may extend outward from (e.g., beyond) the oxygen sensor adaptor housing 268. The sensor tip 330 may have a maximum sustained operating temperature limit greater than other portions of the oxygen sensor 270 and

also greater than the temperature of the gas stream 290. For example, the maximum sustained operating temperature limit of the sensor tip 330 may be greater than or equal to approximately 500, 600, 700, 800, 900, 1000, 1250, 1500, or greater degrees Celsius. Coupled to the sensor tip 330 may be a hex section 332 that is configured to couple the oxygen sensor 270 to the oxygen sensor adaptor housing 268, as described in detail below. As shown in FIG. 8, the hex section 332 (e.g., a tool-engageable hex portion) may include one or more threaded sections 334 (e.g., male threads) and/or nuts 336 to couple the oxygen sensor 270 to an opening (e.g., threaded opening) formed in the oxygen sensor adaptor housing 268 to enable the sensor tip 330 to extend into the gas stream 290. For example, the threaded section 334 may interface with a mating threaded section (e.g., female threads) formed in the opening of the oxygen sensor adaptor housing 268 and the nut 336 may be used to secure the oxygen sensor 270 against the oxygen sensor adaptor housing 268. The maximum sustained operating temperature limit of the hex section 332 may be less than that of the sensor tip 330. For example the maximum sustained operating temperature limit of the hex section 332 may be approximately 500 degrees Celsius. Thus, the oxygen sensor adaptor housing 268 may be configured to maintain the temperature of the hex section 332 below the maximum sustained operating temperature limit of the hex section 332.

[0083] As shown in FIG. 8, the oxygen sensor 270 also includes a gland packing 338, which may be coupled to the hex section 332. The gland packing 338 may enclose the upper portion of the sensor tip 330 and serve as an interface with wiring 340. As with the hex section 332, the maximum sustained operating temperature limits of the gland packing 338 and the wiring 340 may be less than that of the sensor tip 330. For example, the maximum sustained operating temperature limit of the gland packing 338 may be approximately 200 degrees Celsius and the maximum sustained operating temperature limit of the wiring 340 may be approximately 150 degrees Celsius. Thus, the oxygen sensor adaptor housing 268 may be used to maintain the temperatures of the gland packing 338 and wiring 340 below their respective maximum sustained operating temperature limits, as described in detail below. Specifically, the oxygen sensor adaptor housing 268 may maintain the wiring 340 below approximately 125 degrees Celsius, 100 degrees Celsius, or 95 degrees Celsius.

The wiring 340 may pass through and out of the oxygen sensor adaptor housing 268 before coupling to the control system 100 via a connector shell 342. Thus, the wiring 340 may be used to convey the sensor feedback 130 to the control system 100. The maximum sustained operating temperature limit of the connector shell 342 may be less than that of the sensor tip 330. For example, the maximum sustained operating temperature limit of the connector shell 342 may be approximately 120 degrees Celsius. As the connector shell 342 may be disposed outside of the gas turbine engine 150, the connector shell 342 may not be expected to be exposed to the high temperatures associated with the gas stream 290, and may not be cooled or protected by the oxygen sensor adaptor housing 268. In certain embodiments, the oxygen sensor 270 may be a wideband oxygen sensor, a lambda oxygen sensor, an air/fuel meter, or a universal exhaust gas oxygen sensor (UEGO), or any combination thereof, as described in further detail below.

[0084] FIG. 9 is a graph 360 of a signal characteristic curve of a wideband oxygen sensor or lambda oxygen sensor (e.g., sensor 270). As shown in FIG. 9, the graph 360 includes an x-axis 362 that represents lambda, which is the reciprocal of the equivalence ratio, or phi. As discussed above, the equivalence ratio is the ratio of the actual fuel/oxidant ratio relative to the stoichiometric fuel/oxidant ratio. Thus, lambda is the ratio of the stoichiometric fuel/oxidant ratio relative to the ratio of the actual fuel/oxidant ratio. A lambda of greater than 1.0 results in a fuel-lean combustion of the fuel and oxidant whereas a lambda of less than 1.0 results in a fuel-rich combustion of the fuel and oxidant. In contrast, a lambda of 1.0 results in combustion that is neither fuel-rich nor fuel-lean, thereby substantially consuming all of the fuel and the oxidant in the combustion reaction.

[0085] In FIG. 9, a y-axis 364 represents a pumping current of the oxygen sensor 270. A wideband oxygen sensor may include an oxygen sensor cell and a Nernst concentration cell separated by a diffusion gap through which the gas stream 290 may diffuse into. An electronic circuit controls the pump flow through the oxygen pump cell in such a way that the composition of the gas in the diffusion gas remains constant with a lambda of approximately one. This is measured by the Nernst cell. If the gas stream 290 is lean, the oxygen pump cell is activated to pump oxygen out the

diffusion gap. If the gas stream 290 is rich, the direction of flow is reversed so that the cell pumps oxygen into the diffusion gap. The flow from the pump is proportional to the oxygen concentration in the lean gas stream 290 or to the oxygen deficit in the rich gas stream 290. Plotted on FIG. 9 is a sensor response curve 366 for the wideband oxygen sensor. As shown in FIG. 9, for values of λ greater than one (e.g., positive), the pumping current is greater than zero and for λ values less than one, the pumping current is less than zero (e.g., negative). As shown in FIG. 9 the signal response curve 366 extends over a wide range of λ values. In other words, the response of the pumping current is gradual as the response curve 366 moves from negative to positive regions of the pumping current. Thus, small changes in the value of λ may result in relatively small changes in the value of the pumping current. In contrast, narrowband oxygen sensors may exhibit rapid or large changes in pumping current near values of λ of approximately one. As the value of λ may be used by the control system 100 to maintain stoichiometric operation of the gas turbine engine 150, wideband oxygen sensors may be well-suited for enabling control of SEGR gas turbine systems 52. In other words, wideband λ oxygen sensors may provide accurate values of oxygen concentrations while narrowband oxygen sensors may typically be used to only indicate a presence or absence of oxygen at a particular concentration.

[0086] FIG. 10 is a side view of an embodiment of the oxygen sensor adaptor housing 268. Elements in FIG. 10 in common with those shown in previous figures are labeled with the same reference numerals. In the illustrated embodiment, the oxygen sensor adaptor housing 268 includes a first conduit 380 (e.g., annular housing portion) and a second conduit 382 (e.g., annular housing portion). The first conduit 380 includes the coolant inlet 294 and the second conduit 382 includes the coolant outlet 296. As shown in FIG. 10, the second conduit 382 at least partially surrounds (e.g., coaxial or concentric) the first conduit 380. The first conduit 380 includes a first distal opening 386 through which the wiring 340 extends. The second conduit 382 includes a second proximal opening 384 through which the sensor tip 330 extends. In certain embodiments, a sheath 388 surrounds the second conduit 382. The sheath 388 (e.g., annular sheath) may include a mounting flange 390 (e.g., annular flange), which

may be used to couple the oxygen sensor adaptor housing 268 to the wall 284. For example, the mounting flange 390 may include bolt holes to receive bolts. In addition, the sheath 388 may help protect the outer portion 292 of the oxygen sensor adaptor housing 268.

[0087] FIG. 11 is a cross-sectional view of an embodiment of the oxygen sensor adaptor housing 268 of FIG. 10. The oxygen sensor adaptor housing 268 includes a proximal end 400 and a distal end 402. As shown in FIG. 11, the wiring 340 enters the first conduit 380 through the first distal opening 386. The wiring extends through the first conduit 380 and couples with the oxygen sensor 270 at least partially disposed in a first proximal opening 404 of the first conduit 380. For example, the gland packing 338 of the oxygen sensor 270 may be disposed within the first proximal opening 404. A first inner diameter 406 of the first conduit 380 may be greater than an oxygen sensor diameter 408, thereby enabling coolant 281 to flow adjacent the oxygen sensor 270 out through the first proximal opening 404. The oxygen sensor 270 may be disposed in the second proximal opening 384. Specifically, the oxygen sensor may be sealingly disposed in the second proximal opening 384, such that the coolant 281 is blocked from flowing out of the second conduit through the second proximal opening 384 by the oxygen sensor 270. For example, the nut 336 of the hex region 332 may be used to secure the oxygen sensor to the second conduit 382. Thus, the first and second conduits 380 and 382 create coaxial or concentric passages, which enable the flow of the coolant 281 to reverse.

[0088] As shown in FIG. 11, the coolant 281 enters the first conduit 380 through the coolant inlet 294 and flows toward the proximal end 400 as indicated by arrows 410. Thus, the coolant 281 flows adjacent the wiring 340 and the portion of the oxygen sensor 270 disposed in the first proximal opening 404, thereby providing forced convective cooling for maintaining the wiring 404 and the oxygen sensor 270 below the temperature threshold, such as the maximum sustained operating temperature limits described above. At the proximal end 400, the coolant 281 may change directions and move toward the distal end 402 as indicated by arrows 412. Specifically, the coolant 281 may move adjacent the gland packing 338 and the hex region 332 before turning toward the distal end 402 and moving through the interior

of the second conduit 382. As shown in FIG. 11, a second diameter 414 of the second conduit 382 may be greater than the first diameter 406 of the first conduit 380. The coolant 281 may exit the second conduit 382 through the coolant outlet 296. The coolant 281 flowing through the interior of the second conduit 382 may further help maintain the temperature of the portion of the oxygen sensor 270 disposed within the oxygen sensor adaptor housing 268 below the threshold temperature. Specifically, the coolant 281 flowing through the second conduit 382 may provide a second barrier to the high temperature of the gas stream 290 in addition to the first barrier provided by the coolant 281 flowing through the first conduit 380. In addition, the coolant 281 may transfer heat from the gas stream 290 away from the oxygen sensor 270 and oxygen sensor adaptor housing 268. As shown in FIG. 11, the first conduit 380 is inserted through a second distal opening 416 of the second conduit 382. In addition, the second conduit 382 may constitute the insertion portion 286 (e.g., immersive housing).

[0089] FIG. 12 is a partial cutaway perspective view of an embodiment of the oxygen sensor adaptor housing 268. In the illustrated embodiment, the oxygen sensor adaptor housing 268 includes a distal cap 430 disposed at the distal end 402 of the oxygen sensor adaptor housing 268. The distal cap 430 includes the coolant inlet 294, coolant outlet 296, and a wiring opening 432 through which the wiring 340 passes through. The distal cap 430 is coupled to a proximal cap 434 disposed at the proximal end 400 of the oxygen sensor adaptor housing 268. The proximal cap 434 e.g., annular cap) may include a flange 436 (e.g., annular flange) to enable the proximal cap 434 to be coupled to the distal cap 430 (e.g., via bolt holes). For example, a plurality of bolts may be used to couple the distal cap 430 to the proximal cap 434. In other embodiments, the proximal cap 434 may be coupled to the distal cap 430 via a threaded connection. The proximal cap 434 may include the insertion portion 286 (e.g., immersive housing). In addition, the proximal cap 434 may include an oxygen sensor opening 438 through which the sensor tip 330 of the oxygen sensor 270 may extend therethrough. The flow of the coolant 281 through the interior of the proximal cap 434 may help maintain the temperature of the portions of the oxygen sensor 270

disposed in the interior of the proximal cap 434 below the temperature thresholds of those portions of the oxygen sensor 270.

[0090] In certain embodiments, the oxygen sensor 270 may be mounted in the oxygen sensor adaptor housing 268 at an angle 440 from a longitudinal axis of the gas turbine engine 150, which may be generally parallel to the axial axis 260. In certain embodiments, the angle 440 may be greater than approximately 10 degrees, 20 degrees, 30 degrees, 40 degrees, 50 degrees, 60 degrees, 70 degrees, or 80 degrees. By positioning the oxygen sensor 270 at the angle 440, the sensor tip 330 may be oriented facing the gas stream 290, which may improve the accuracy of readings obtained by the oxygen sensor 270. In addition, by placing the oxygen sensor 270 at the angle 440, any condensation or moisture that may form on the sensor tip 330 may be blown off the oxygen sensor 270 or fall off as a result of gravity. In other embodiments, the sensor tip 330 may include a heater that maintains a tip temperature of the sensor tip 330 within a temperature range, such as a temperature range above which condensation may form. In further embodiments, the oxygen sensor adaptor housing 268 may include an access port 442 (e.g., a removable cover) to provide access to the oxygen sensor 270. Specifically, by using the access port 442, the oxygen sensor 270 may be removed or repaired without disassembling the oxygen sensor adaptor housing 268, which may simplify maintenance and/or reduce maintenance costs associated with the gas turbine engine 150. In certain embodiments, one or both of the distal cap 430 and the proximal cap 434 may include a positioning key 444 (e.g., protruding tab, pin, or panel) that orients the oxygen sensor 270 facing upstream against the gas stream 290. For example, the positioning key 444 may fit into a slot formed in the wall 284. In other embodiments, the wall may include the positioning key and the oxygen sensor adaptor housing 268 may include the slot. In further embodiments, the positioning key 444 may be used to position the sensor 270 in other orientations, such as upstream, downstream, sideways, and so forth.

[0091] FIG. 13 is a partial cutaway perspective view of an embodiment of the oxygen sensor adaptor housing 268. In the illustrated embodiment, the oxygen sensor adaptor housing 268 may be disposed near the bottom of the gas turbine engine 150.

Thus, the proximal end 400 is located above the distal end 402. As shown in FIG. 13, the oxygen sensor 270 is disposed at the angle 440. Thus, the sensor tip 330 of the oxygen sensor 270 points downward as with the oxygen sensor 270 shown in FIG. 12. Thus, any condensation that forms on the sensor tip 330 may drip off the sensor tip 330 as a result of gravity. In other respects, the oxygen sensor adaptor housing 268 is similar to that shown in FIG. 12. In certain embodiments, all of the oxygen sensors disposed in the plurality of oxygen sensor adaptor housings 268 (e.g., the plurality of housings 268 shown in FIG. 7) may be disposed at the angle 440 (e.g., pointed in a downward manner).

[0092] FIG. 14 is a partial cutaway perspective view of an embodiment of the oxygen sensor adaptor housing 268. A coolant pipe 460 may be coupled to the coolant inlet 294 and disposed within the interior of the proximal cap 434. The coolant pipe 460 may terminate in a coolant nozzle 462 configured to direct the coolant 281 toward the oxygen sensor 270, thereby helping to maintain the temperature of the portion of the oxygen sensor 270 disposed within the interior of the proximal cap 434 below the temperature threshold. In certain embodiments, the oxygen sensor opening 438 may be located at the proximal end 400 of the proximal cap 434. In other words, the oxygen sensor 270 may be disposed at a value of approximately 90 degrees for the angle 440. In other respects, the embodiment of the oxygen sensor adaptor housing 268 shown in FIG. 14 is similar to those shown in FIGS. 12 and 13.

[0093] FIG. 15 is a partial cutaway perspective view of an embodiment of the oxygen sensor adaptor housing 268. In the illustrated embodiment, the coolant pipe 460 is coupled to the coolant inlet 294. In addition, a coolant coil 480 (e.g., a spiraling or helical coil of pipe) is coupled to the coolant pipe 460 and at least partially surrounds the oxygen sensor 270, thereby maintaining the temperature of the portion of the oxygen sensor 270 disposed within the proximal cap 434 below the temperature threshold. In other words, the flow of the coolant 281 through the coil 480 may help maintain the temperature of the space surrounding the oxygen sensor 270 at a temperature below that of the gas stream 290. In other respects, the embodiment of the oxygen sensor adaptor housing 268 shown in FIG. 15 is similar to those shown in previous figures.

[0094] FIG. 16 is a radial cross-sectional view of an embodiment of the oxygen sensor adaptor housing 268 taken along the line labeled 16-16 in FIG. 12. As shown in FIG. 16, the proximal cap 434 of the oxygen sensor adaptor housing 268 has a generally circular cross-sectional shape and the wiring 340 may be generally located at the center of the proximal cap 434. As such, the wiring 340 is disposed far away from the gas stream 290, thereby helping to maintain the temperature of the wiring 340 below the temperature threshold. In other embodiments, the proximal cap 434 may have other cross-sectional shapes, such as circular, oval, or airfoil-shaped cross-sectional shapes. In addition, although FIG. 16 shows a cross-sectional view of the proximal cap 434, it is understood that FIG. 16 may also represent a radial cross-sectional view of the first conduit 380 shown in FIGS. 10 and 11.

[0095] FIG. 17 is a radial cross-sectional of an embodiment of the oxygen sensor adaptor housing 268 taken along the line labeled 17-17 in FIG. 12. In the illustrated embodiment, the proximal cap 434 has an airfoil-shaped cross-sectional shape. Such a cross-sectional shape for the proximal cap 434 may reduce the resistance posed by the oxygen sensor adaptor housing 268 to the gas stream 290, thereby reducing any pressure drop associated with the oxygen sensor adaptor housing 268. As shown in FIG. 17, the wiring 340 is disposed toward the center of the proximal cap 434, thereby helping to maintain the temperature of the wiring 340 below the temperature threshold. As with the embodiment shown in FIG. 16, the cross-sectional shape shown in FIG. 17 may also apply to the first conduit 380 shown in FIGS. 10 and 11. In addition, it should be noted that features of all figures are intended to be used in any and all combinations with one another. For example, it is contemplated that certain embodiments may use all features of FIGS. 5 and 17 in a single assembly.

[0096] As described above, certain embodiments of the gas turbine engine 150 may include the combustor section 154 having the turbine combustor 160 that generates combustion products, the turbine section 156 having one or more turbine stages 174 driven by the combustion products, and an exhaust section 266 disposed downstream of the turbine section 156. In addition, the gas turbine engine 150 may include the oxygen sensor adaptor housing 268 disposed in at least one of the combustor section 154, the turbine section 156, or the exhaust section 266, or any

combination thereof. In addition, the oxygen sensor 270 may be disposed in the oxygen sensor adaptor housing 268, which may help maintain the temperature of the portion of the oxygen sensor 270 below the temperature threshold. Specifically, the portion of the oxygen sensor that is maintained below the threshold may be disposed within the oxygen sensor adaptor housing 268. Thus, another portion of the oxygen sensor 270, such as the sensor tip 330 may be disposed outside of the oxygen sensor adaptor housing 268 and be exposed to the high temperatures associated with the gas stream 290. In certain embodiments, the coolant 281 may flow through the interior of the oxygen sensor adaptor housing 268 to help maintain the temperature of the portion of the oxygen sensor 270 below the temperature of threshold, thereby extending the life of the oxygen sensor 270 and/or enabling the use of oxygen sensors 270 that may have maximum sustained operating temperature limits less than the temperature of the gas stream 290, such as wideband oxygen sensors, lambda oxygen sensors, and/or UEGO oxygen sensors.

ADDITIONAL DESCRIPTION

[0097] The present embodiments provide systems and methods for gas turbine engines. It should be noted that any one or a combination of the features described above may be utilized in any suitable combination. Indeed, all permutations of such combinations are presently contemplated. By way of example, the following clauses are offered as further description of the present disclosure:

[0098] Embodiment 1. A system, comprising: a gas turbine engine, comprising: a combustor section having a turbine combustor that generates combustion products; a turbine section having one or more turbine stages driven by the combustion products; an exhaust section disposed downstream of the turbine section; an oxygen sensor adaptor housing disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof; and an oxygen sensor disposed in the oxygen sensor adaptor housing, wherein the oxygen sensor adaptor housing is

configured to maintain a temperature of a portion of the oxygen sensor below an upper threshold.

[0099] Embodiment 2. The system of embodiment 1, wherein the oxygen sensor comprises at least one of a wideband oxygen sensor, a lambda sensor, an air/fuel meter, or a universal exhaust gas oxygen (UEGO) sensor, or any combination thereof.

[00100] Embodiment 3. The system defined in any preceding embodiment, wherein the portion of the oxygen sensor comprises at least one of a hex section, a gland packing, wiring, or a connector shell, or any combination thereof.

[00101] Embodiment 4. The system defined in any preceding embodiment, wherein the oxygen sensor comprises a heater configured to maintain a tip temperature of a tip portion of the oxygen sensor within a temperature range.

[00102] Embodiment 5. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises: a coolant inlet configured to convey a coolant to the oxygen sensor adaptor housing to maintain the temperature of the portion of the oxygen sensor below the upper threshold; and a coolant outlet configured to convey the coolant away from the oxygen sensor adaptor housing.

[00103] Embodiment 6. The system defined in any preceding embodiment, comprising a coolant supply system configured to supply the coolant to the coolant inlet of the oxygen sensor adaptor housing.

[00104] Embodiment 7. The system defined in any preceding embodiment, wherein the coolant comprises at least one of air, nitrogen, carbon dioxide, cooled exhaust gas, inert gas, or water, or any combination thereof.

[00105] Embodiment 8. The system defined in any preceding embodiment, wherein the coolant supply system is configured to supply air to the coolant inlet at a flow rate between approximately 30 m³/hr to approximately 105 m³/hr.

[00106] Embodiment 9. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises: a first conduit comprising a first proximal opening, a first distal opening, and a first passage, wherein the coolant inlet is coupled to the first distal opening, the oxygen sensor is disposed at least partially within the first proximal opening, and the first passage is configured to convey the coolant from the distal opening, adjacent the oxygen sensor, and out through the first proximal opening; and a second conduit at least partially surrounding the first conduit and comprising a second proximal opening, a second distal opening, and a second passage, wherein the coolant outlet is coupled to the second distal opening, the oxygen sensor is sealingly disposed within the second proximal opening, and the second passage is configured to convey the coolant from adjacent the oxygen sensor to the second distal opening.

[00107] Embodiment 10. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises: a distal cap, wherein the coolant inlet and the coolant outlet are coupled to the distal cap; and a proximal cap, wherein the oxygen sensor is disposed in an oxygen sensor opening of the proximal cap.

[00108] Embodiment 11. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises an access port configured to provide access to the oxygen sensor.

[00109] Embodiment 12. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises at least one of a coolant nozzle configured to direct the coolant toward the oxygen sensor, or a coolant coil configured to convey the coolant from the coolant inlet to the coolant outlet and configured to at least partially surround the oxygen sensor, or any combination thereof.

[00110] Embodiment 13. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises an immersive housing at least partially disposed in a gas flow of at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof.

[00111] Embodiment 14. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises a positioning key configured to orient the oxygen sensor facing upstream against a gas flow of at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof.

[00112] Embodiment 15. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing is configured to position the oxygen sensor at an angle from a longitudinal axis of the gas turbine engine, wherein the angle is greater than approximately 10 degrees.

[00113] Embodiment 16. The system defined in any preceding embodiment, comprising a gas turbine engine controller configured to receive an oxygen signal from the oxygen sensor to maintain an equivalence ratio of the gas turbine engine within a range.

[00114] Embodiment 17. The system defined in any preceding embodiment, wherein the range of the equivalence ratio is between approximately 0.95 to approximately 1.05.

[00115] Embodiment 18. The system defined in any preceding embodiment, wherein the gas turbine engine comprises an exhaust gas compressor driven by the turbine section, wherein the exhaust gas compressor is configured to compress and route an exhaust gas to the turbine combustor.

[00116] Embodiment 19. The system defined in any preceding embodiment, comprising an exhaust gas extraction system coupled to the gas turbine engine, and a hydrocarbon production system coupled to the exhaust gas extraction system.

[00117] Embodiment 20. The system defined in any preceding embodiment, wherein the gas turbine engine is a stoichiometric exhaust gas recirculation (SEGR) gas turbine engine.

[00118] Embodiment 21. The system defined in any preceding embodiment, comprising a plurality of oxygen sensor adaptor housings configured to mount

circumferentially about at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof.

[00119] Embodiment 22. A system, comprising: an oxygen sensor adaptor housing configured to mount in at least one of a combustor section of a gas turbine engine, a turbine section of the gas turbine engine, or an exhaust section of the gas turbine engine, or any combination thereof; and an oxygen sensor disposed in the oxygen sensor adaptor housing, wherein the oxygen sensor adaptor housing is configured to maintain a temperature of a portion of the oxygen sensor below an upper threshold.

[00120] Embodiment 23. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises an insertion portion configured to extend a distance into a gas stream of at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof.

[00121] Embodiment 24. The system defined in any preceding embodiment, wherein the distance is between approximately 35 cm to approximately 65 cm.

[00122] Embodiment 25. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises a circular, oval, or airfoil-shaped cross-sectional shape.

[00123] Embodiment 26. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises: a coolant inlet configured to convey a coolant to the oxygen sensor adaptor housing to maintain the temperature of the portion of the oxygen sensor below the upper threshold; and a coolant outlet configured to convey the coolant away from the oxygen sensor adaptor housing.

[00124] Embodiment 27. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises: a first conduit comprising a first proximal opening, a first distal opening, and a first passage, wherein the coolant inlet is coupled to the first distal opening, the oxygen sensor is disposed at least partially within the first proximal opening, and the first passage is configured to

convey the coolant from the distal opening, adjacent the oxygen sensor, and out through the first proximal opening; and a second conduit at least partially surrounding the first conduit and comprising a second proximal opening, a second distal opening, and a second passage, wherein the coolant outlet is coupled to the second distal opening, the oxygen sensor is sealingly disposed within the second proximal opening, and the second passage is configured to convey the coolant from adjacent the oxygen sensor to the second distal opening.

[00125] Embodiment 28. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises: a distal cap, wherein the coolant inlet and the coolant outlet are coupled to the distal cap; and a proximal cap, wherein the oxygen sensor is disposed in an oxygen sensor opening of the proximal cap.

[00126] Embodiment 29. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises an access port configured to provide access to the oxygen sensor.

[00127] Embodiment 30. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises at least one of a coolant nozzle configured to direct the coolant toward the oxygen sensor, or a coolant coil configured to convey the coolant from the coolant inlet to the coolant outlet and at least partially surround the oxygen sensor, or any combination thereof.

[00128] Embodiment 31. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing comprises a positioning key configured to orient the oxygen sensor facing upstream against a gas flow of at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof.

[00129] Embodiment 32. The system defined in any preceding embodiment, wherein the oxygen sensor adaptor housing is configured to position the oxygen sensor at an angle from a longitudinal axis of the gas turbine engine, wherein the angle is greater than approximately 10 degrees.

[00130] Embodiment 33. The system defined in any preceding embodiment, wherein the portion of the oxygen sensor comprises at least one of a hex section, a gland packing, wiring, or a connector shell, or any combination thereof.

[00131] Embodiment 34. A method, comprising: combusting a fuel with an oxidant in a combustor section of a turbine combustor to generate combustion products; driving a turbine of a turbine section with the combustion products from the turbine combustor; expanding the combustion products from the turbine through an exhaust passage in an exhaust section; sensing an oxygen concentration of the combustion products using an oxygen sensor disposed in an oxygen sensor adaptor housing that is disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof; and maintaining a temperature of a portion of the oxygen sensor below an upper threshold using the oxygen sensor adaptor housing.

[00132] Embodiment 35. The method or system defined in any preceding embodiment, comprising combusting an exhaust gas with the fuel and the oxidant in the combustor section.

[00133] Embodiment 36. The method or system defined in any preceding embodiment, wherein maintaining the temperature of the portion of the oxygen sensor below the upper threshold comprises cooling the portion of the oxygen sensor using a coolant flowing through the oxygen sensor adaptor housing.

[00134] Embodiment 37. The method or system defined in any preceding embodiment, comprising maintaining the temperature of the portion of the oxygen sensor below approximately 95 degrees Celsius.

[00135] Embodiment 38. The method or system defined in any preceding embodiment, wherein the portion of the oxygen sensor comprises at least one of a hex section, a gland packing, wiring, or a connector shell, or any combination thereof.

[00136] Embodiment 39. The method or system defined in any preceding embodiment, comprising controlling an equivalence ratio of a gas turbine engine

having the combustor section, the turbine section, and the exhaust section within a range using a gas turbine engine controller configured to receive an oxygen signal from the oxygen sensor.

[00137] Embodiment 40. The method or system defined in any preceding embodiment, wherein the range of the equivalence ratio is between approximately 0.95 to approximately 1.05.

[00138] Embodiment 41. The method or system defined in any preceding embodiment, comprising maintaining a tip temperature of a tip portion of the oxygen sensor within a temperature range using a heater of the oxygen sensor.

[00139] Embodiment 42. The method or system defined in any preceding embodiment, comprising: conveying a coolant to the oxygen sensor adaptor housing using a coolant inlet of the oxygen sensor adaptor housing; and conveying the coolant away from the oxygen sensor adaptor housing using a coolant outlet of the oxygen sensor adaptor housing.

[00140] Embodiment 43. The method or system defined in any preceding embodiment, comprising conveying the coolant from the coolant inlet to the coolant outlet using a coolant coil at least partially surrounding the oxygen sensor.

[00141] Embodiment 44. The method or system defined in any preceding embodiment, comprising: flowing a coolant through a first conduit of the oxygen sensor adaptor housing; flowing the coolant adjacent the oxygen sensor, wherein the oxygen sensor is at least partially within a first proximal opening of the first conduit; flowing the coolant out of the first proximal opening of the first conduit and into a second conduit at least partially surrounding the first conduit; and flowing the coolant through the second conduit and out of a second distal opening of the second conduit.

[00142] Embodiment 45. The method or system defined in any preceding embodiment, comprising directing a coolant toward the oxygen sensor using a coolant nozzle of the oxygen sensor adaptor housing.

[00143] Embodiment 46. The method or system defined in any preceding embodiment, comprising disposing an immersive housing of the oxygen sensor adaptor housing at least partially in a gas flow of at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof.

[00144] Embodiment 47. The method or system defined in any preceding embodiment, comprising orienting the oxygen sensor facing upstream against a gas flow of at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof using a positioning key of the oxygen sensor adaptor housing.

[00145] Embodiment 48. The method or system defined in any preceding embodiment, comprising positioning the oxygen sensor at an angle from a longitudinal axis of the gas turbine engine using the oxygen sensor adaptor housing, wherein the angle is greater than approximately 10 degrees.

[00146] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

CLAIMS:

1. A system, comprising:
 - a gas turbine engine, comprising:
 - a combustor section having a turbine combustor that generates combustion products;
 - a turbine section having one or more turbine stages driven by the combustion products;
 - an exhaust section disposed downstream of the turbine section;
 - an oxygen sensor adaptor housing disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof; and
 - an oxygen sensor disposed in the oxygen sensor adaptor housing, wherein the oxygen sensor adaptor housing is configured to maintain a temperature of a portion of the oxygen sensor below an upper threshold.
2. The system of claim 1, wherein the oxygen sensor comprises at least one of a wideband oxygen sensor, a lambda sensor, an air/fuel meter, or a universal exhaust gas oxygen (UEGO) sensor, or any combination thereof.
3. The system of claim 1, wherein the portion of the oxygen sensor comprises at least one of a hex section, a gland packing, wiring, or a connector shell, or any combination thereof.
4. The system of claim 1, wherein the oxygen sensor comprises a heater configured to maintain a tip temperature of a tip portion of the oxygen sensor within a temperature range.

5. The system of claim 1, wherein the oxygen sensor adaptor housing comprises:
a coolant inlet configured to convey a coolant to the oxygen sensor adaptor housing to maintain the temperature of the portion of the oxygen sensor below the upper threshold; and
a coolant outlet configured to convey the coolant away from the oxygen sensor adaptor housing.
6. The system of claim 5, wherein the oxygen sensor adaptor housing comprises:
a first conduit comprising a first proximal opening, a first distal opening, and a first passage, wherein the coolant inlet is coupled to the first distal opening, the oxygen sensor is disposed at least partially within the first proximal opening, and the first passage is configured to convey the coolant from the distal opening, adjacent the oxygen sensor, and out through the first proximal opening; and
a second conduit at least partially surrounding the first conduit and comprising a second proximal opening, a second distal opening, and a second passage, wherein the coolant outlet is coupled to the second distal opening, the oxygen sensor is sealingly disposed within the second proximal opening, and the second passage is configured to convey the coolant from adjacent the oxygen sensor to the second distal opening.
7. The system of claim 5, wherein the oxygen sensor adaptor housing comprises:
a distal cap, wherein the coolant inlet and the coolant outlet are coupled to the distal cap; and
a proximal cap, wherein the oxygen sensor is disposed in an oxygen sensor opening of the proximal cap.
8. The system of claim 1, wherein the oxygen sensor adaptor housing comprises an access port configured to provide access to the oxygen sensor.
9. The system of claim 5, wherein the oxygen sensor adaptor housing comprises at least one of a coolant nozzle configured to direct the coolant toward the oxygen sensor, or a coolant coil configured to convey the coolant from the coolant inlet to the

coolant outlet and configured to at least partially surround the oxygen sensor, or any combination thereof.

10. The system of claim 1, wherein the gas turbine engine comprises an exhaust gas compressor driven by the turbine section, wherein the exhaust gas compressor is configured to compress and route an exhaust gas to the turbine combustor.

11. The system of claim 10, comprising an exhaust gas extraction system coupled to the gas turbine engine, and a hydrocarbon production system coupled to the exhaust gas extraction system.

12. The system of claim 10, wherein the gas turbine engine is a stoichiometric exhaust gas recirculation (SEGR) gas turbine engine.

13. A system, comprising:

an oxygen sensor adaptor housing configured to mount in at least one of a combustor section of a gas turbine engine, a turbine section of the gas turbine engine, or an exhaust section of the gas turbine engine, or any combination thereof; and

an oxygen sensor disposed in the oxygen sensor adaptor housing, wherein the oxygen sensor adaptor housing is configured to maintain a temperature of a portion of the oxygen sensor below an upper threshold.

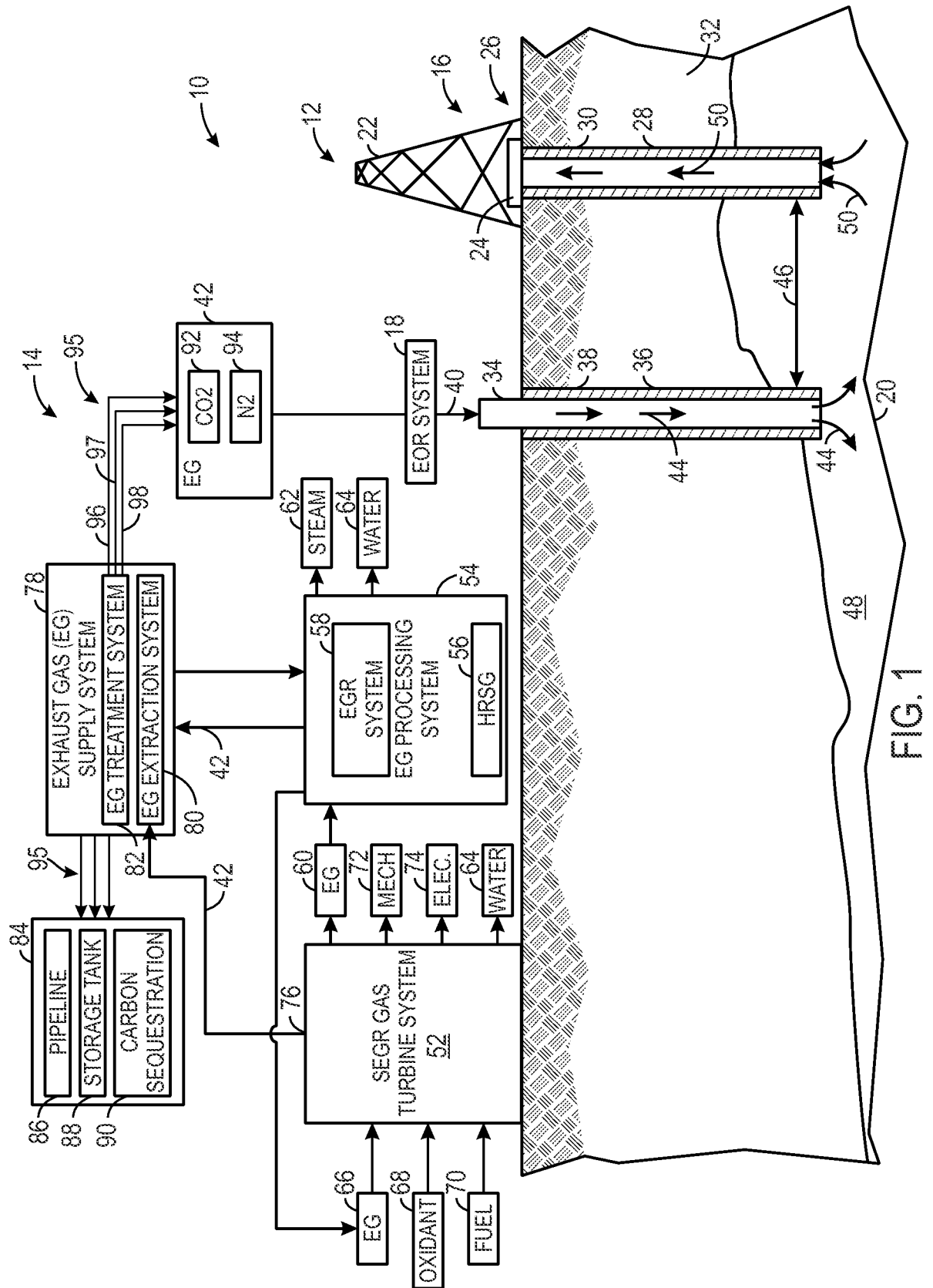
14. The system of claim 13, wherein the oxygen sensor adaptor housing comprises an insertion portion configured to extend a distance into a gas stream of at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof.

15. The system of claim 14, wherein the distance is between approximately 35 cm to approximately 65 cm.

16. The system of claim 13, wherein the oxygen sensor adaptor housing comprises a circular, oval, or airfoil-shaped cross-sectional shape.

17. A method, comprising:
- combusting a fuel with an oxidant in a combustor section of a turbine combustor to generate combustion products;
 - driving a turbine of a turbine section with the combustion products from the turbine combustor;
 - expanding the combustion products from the turbine through an exhaust passage in an exhaust section;
 - sensing an oxygen concentration of the combustion products using an oxygen sensor disposed in an oxygen sensor adaptor housing that is disposed in at least one of the combustor section, the turbine section, or the exhaust section, or any combination thereof; and
 - maintaining a temperature of a portion of the oxygen sensor below an upper threshold using the oxygen sensor adaptor housing.
18. The method of claim 17, comprising maintaining the temperature of the portion of the oxygen sensor below approximately 95 degrees Celsius.
19. The method of claim 17, comprising controlling an equivalence ratio of a gas turbine engine having the combustor section, the turbine section, and the exhaust section within a range using a gas turbine engine controller configured to receive an oxygen signal from the oxygen sensor.
20. The method of claim 19, wherein the range of the equivalence ratio is between approximately 0.95 to approximately 1.05.

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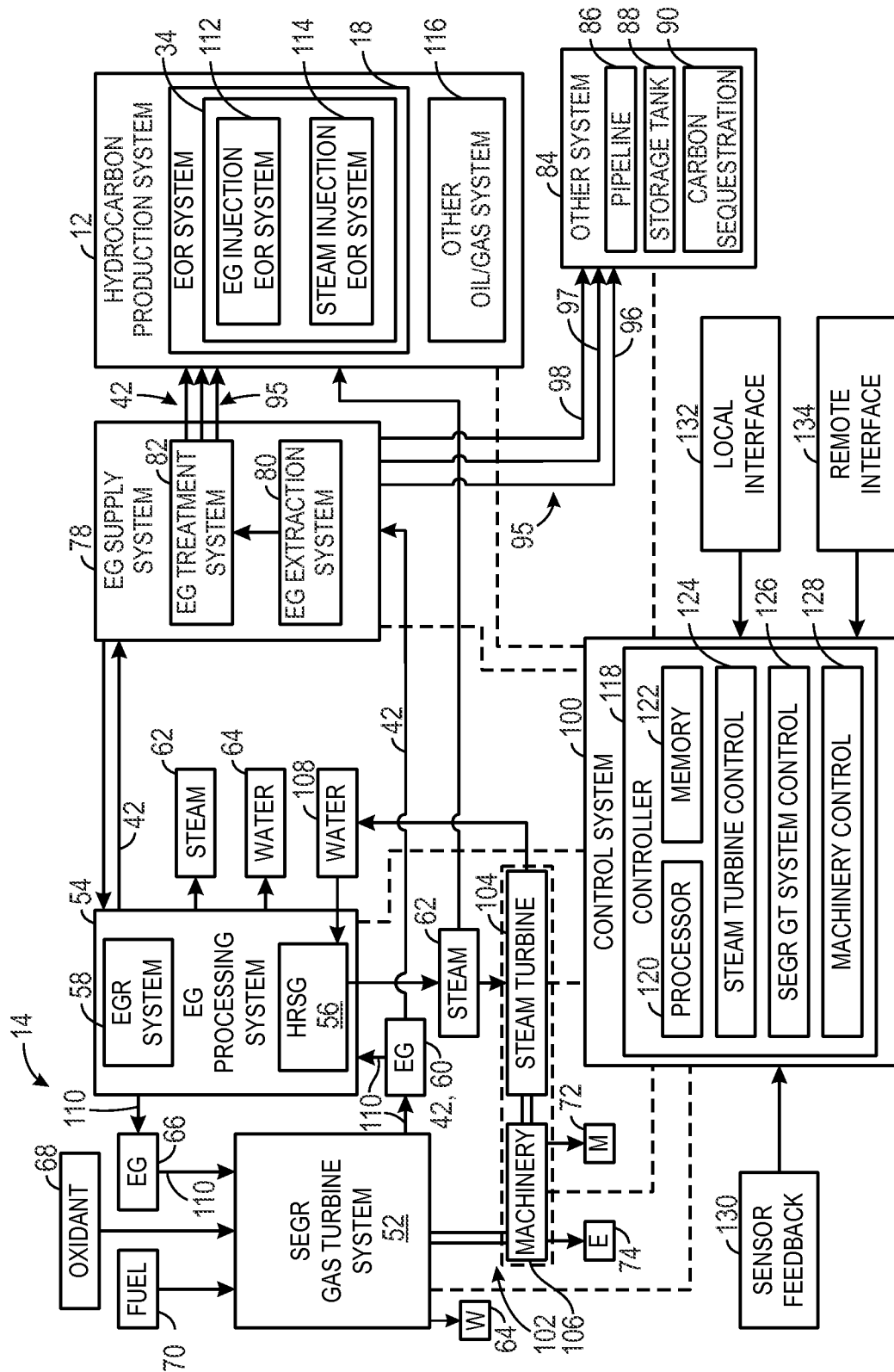


FIG. 2

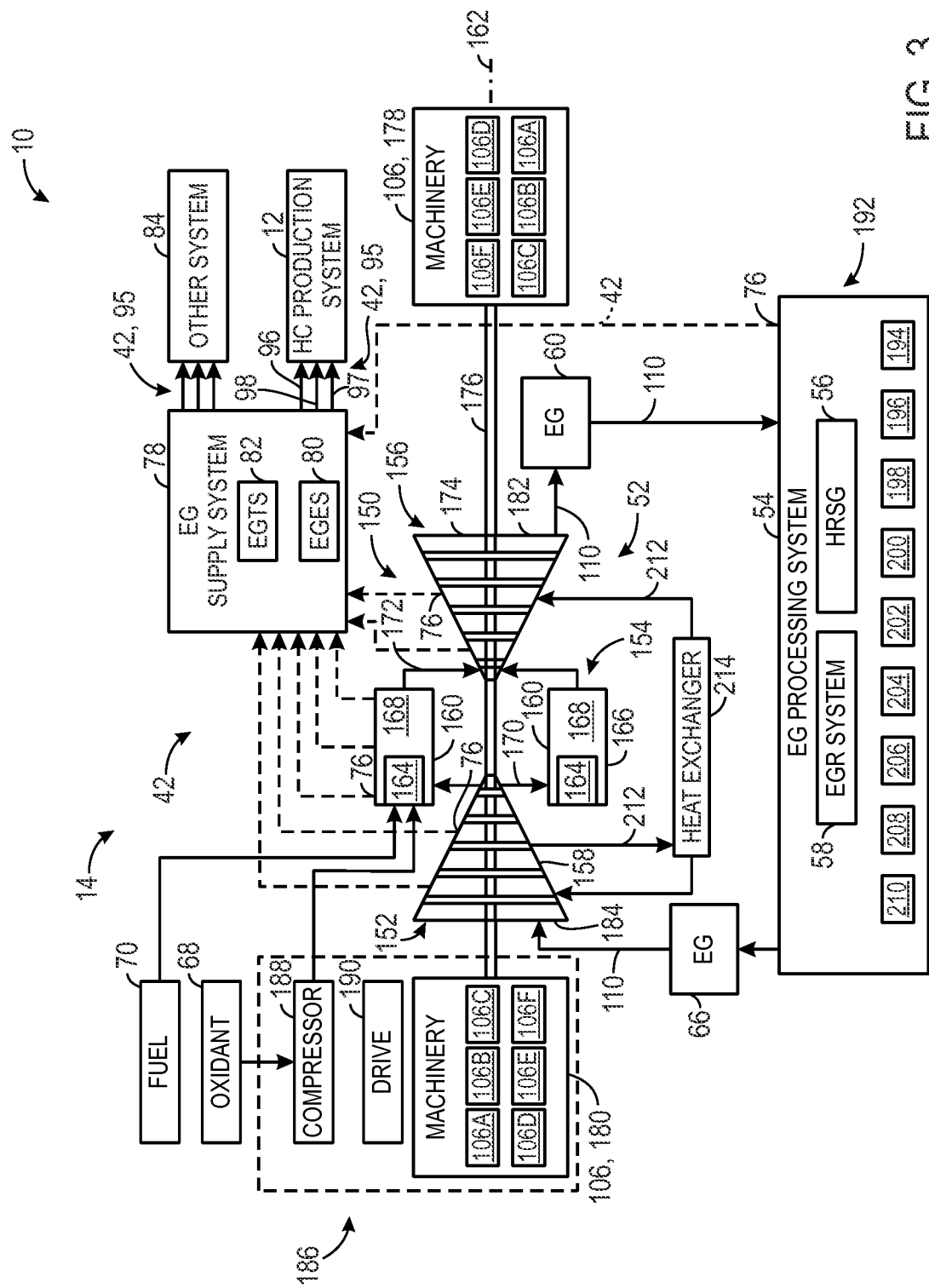


FIG. 3

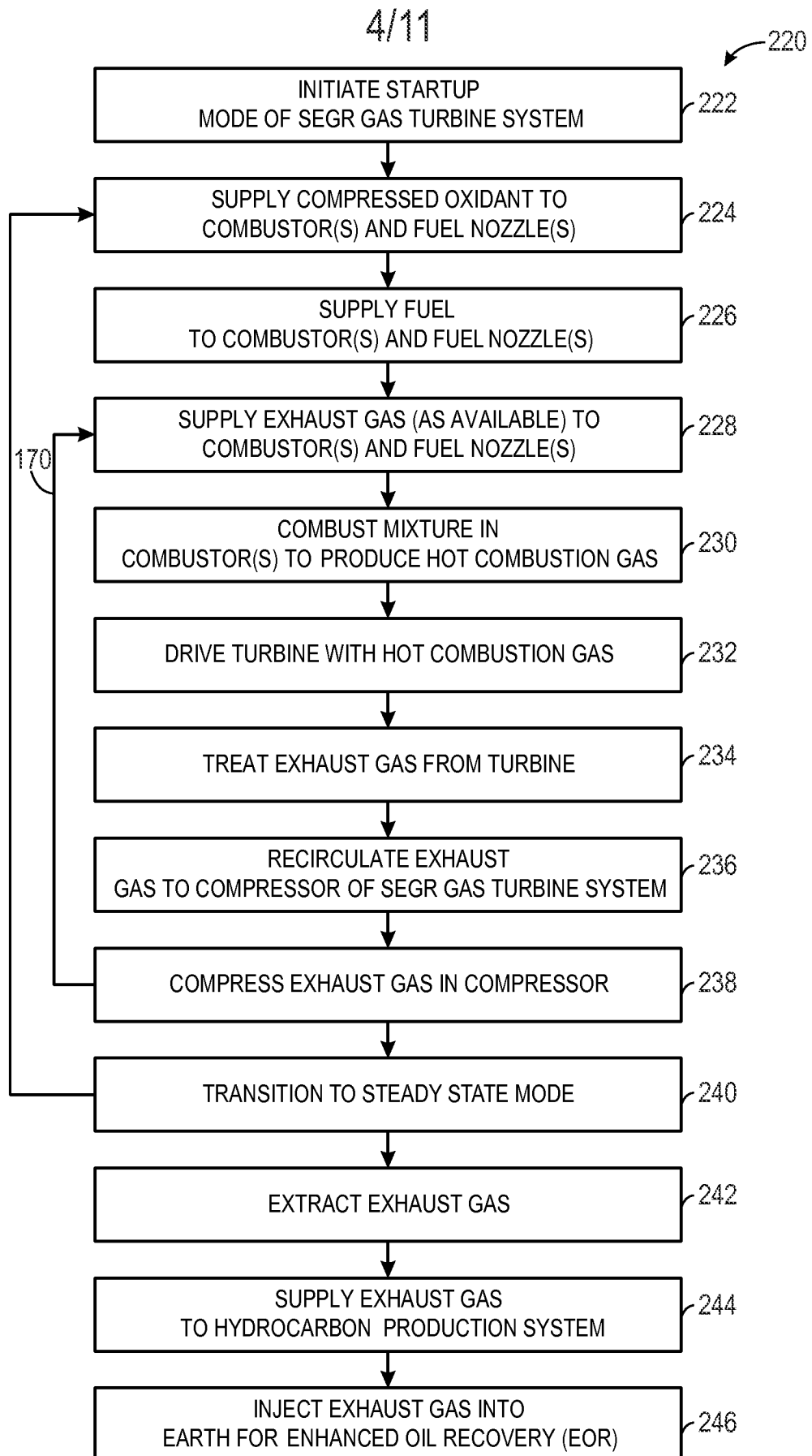


FIG. 4

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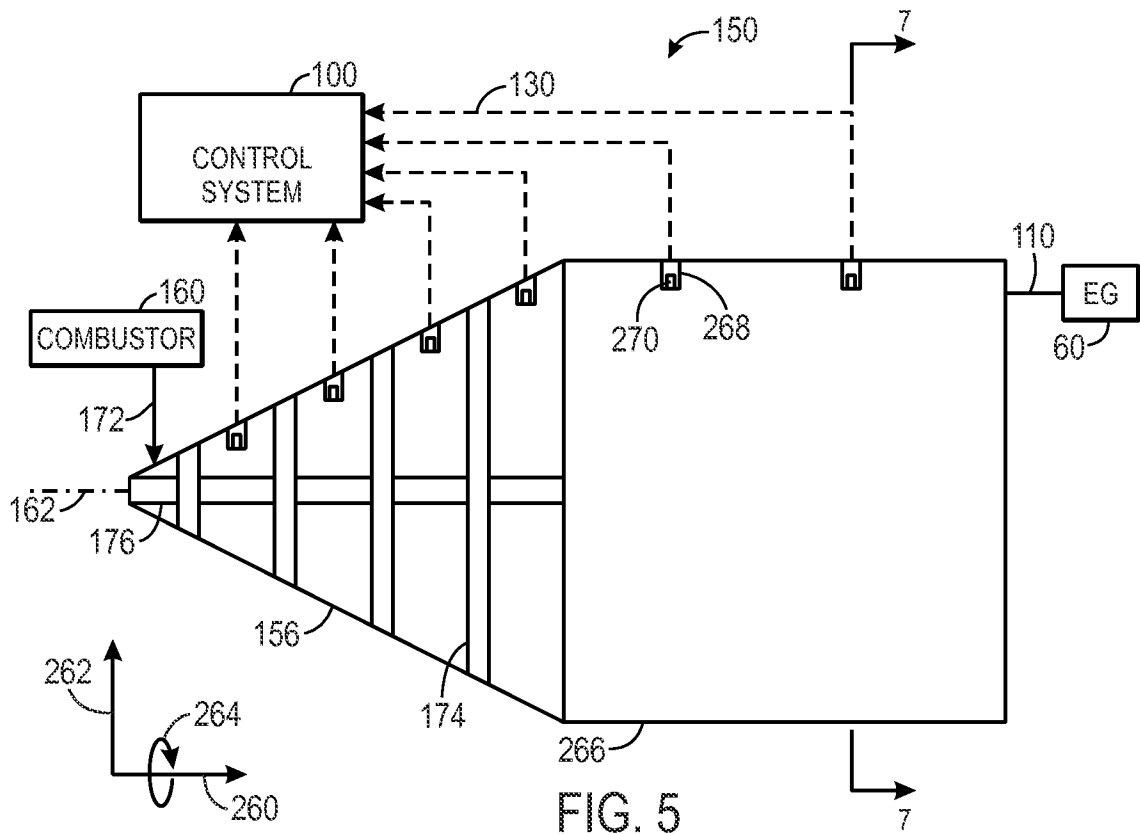


FIG. 5

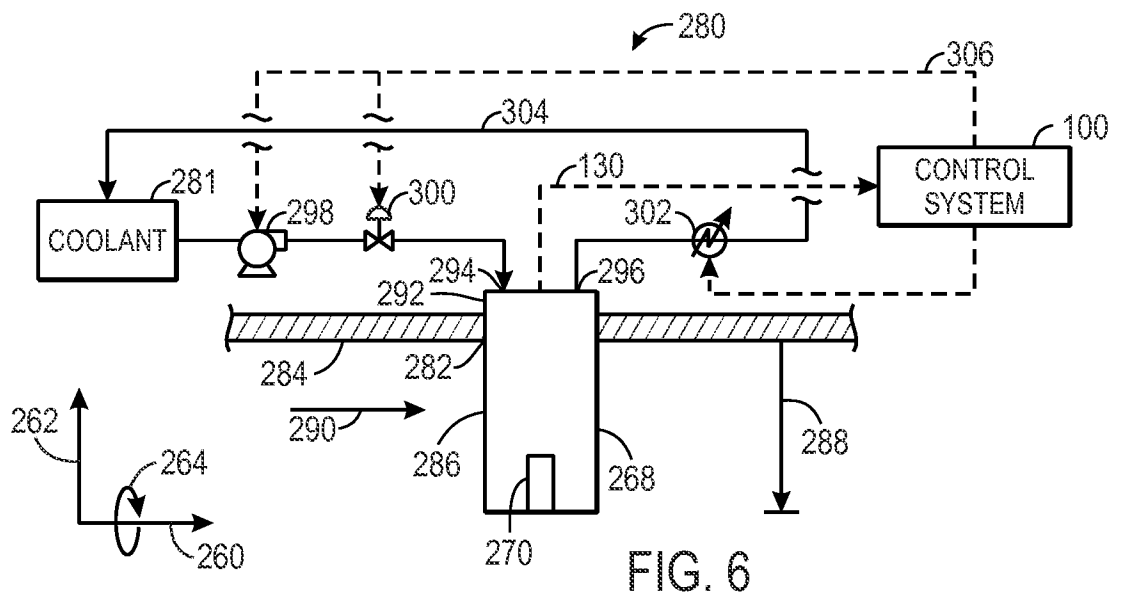


FIG. 6

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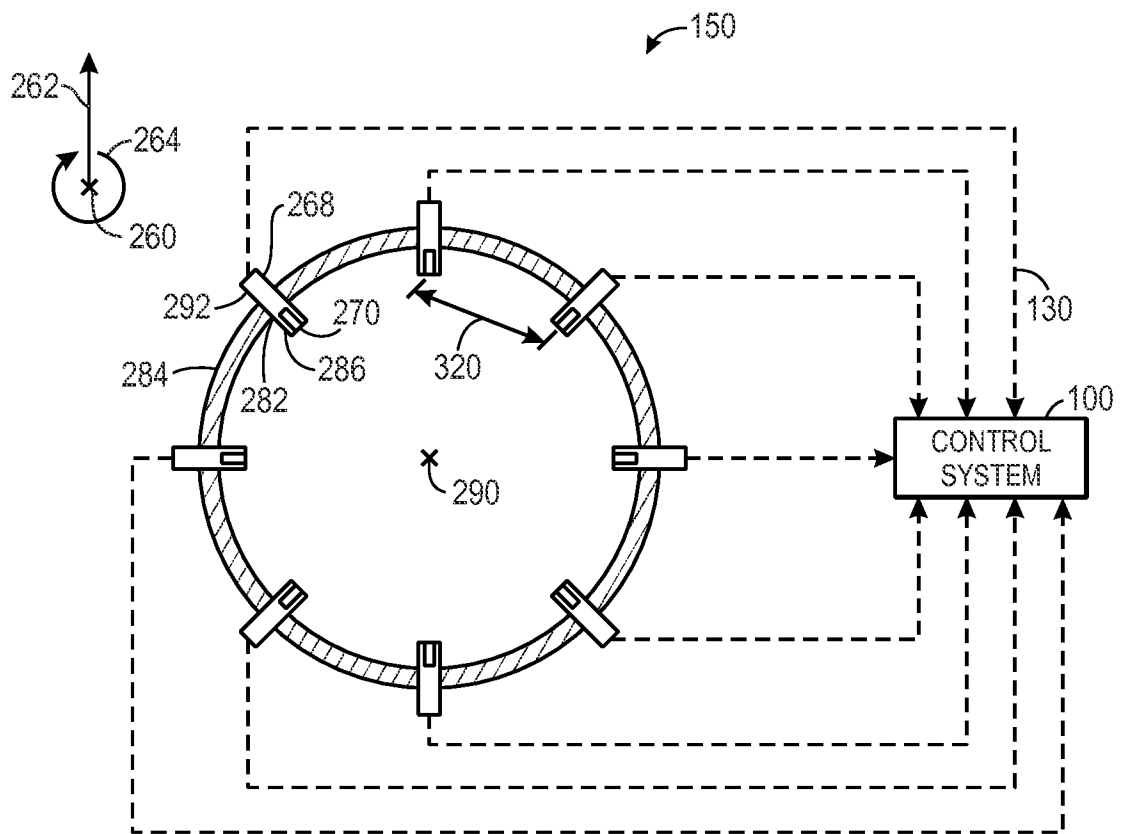


FIG. 7

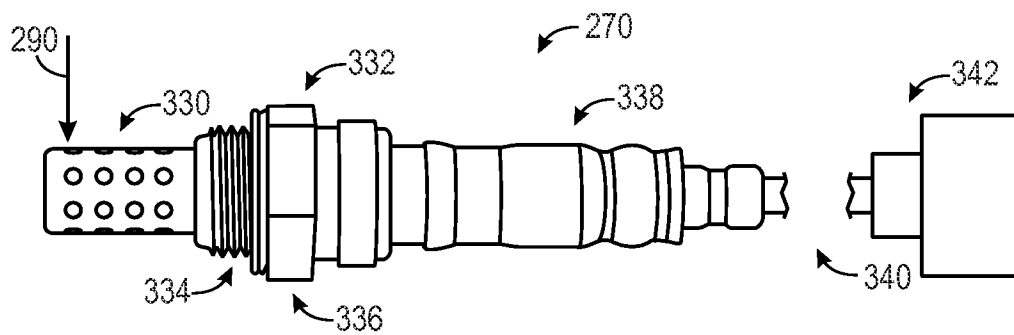


FIG. 8

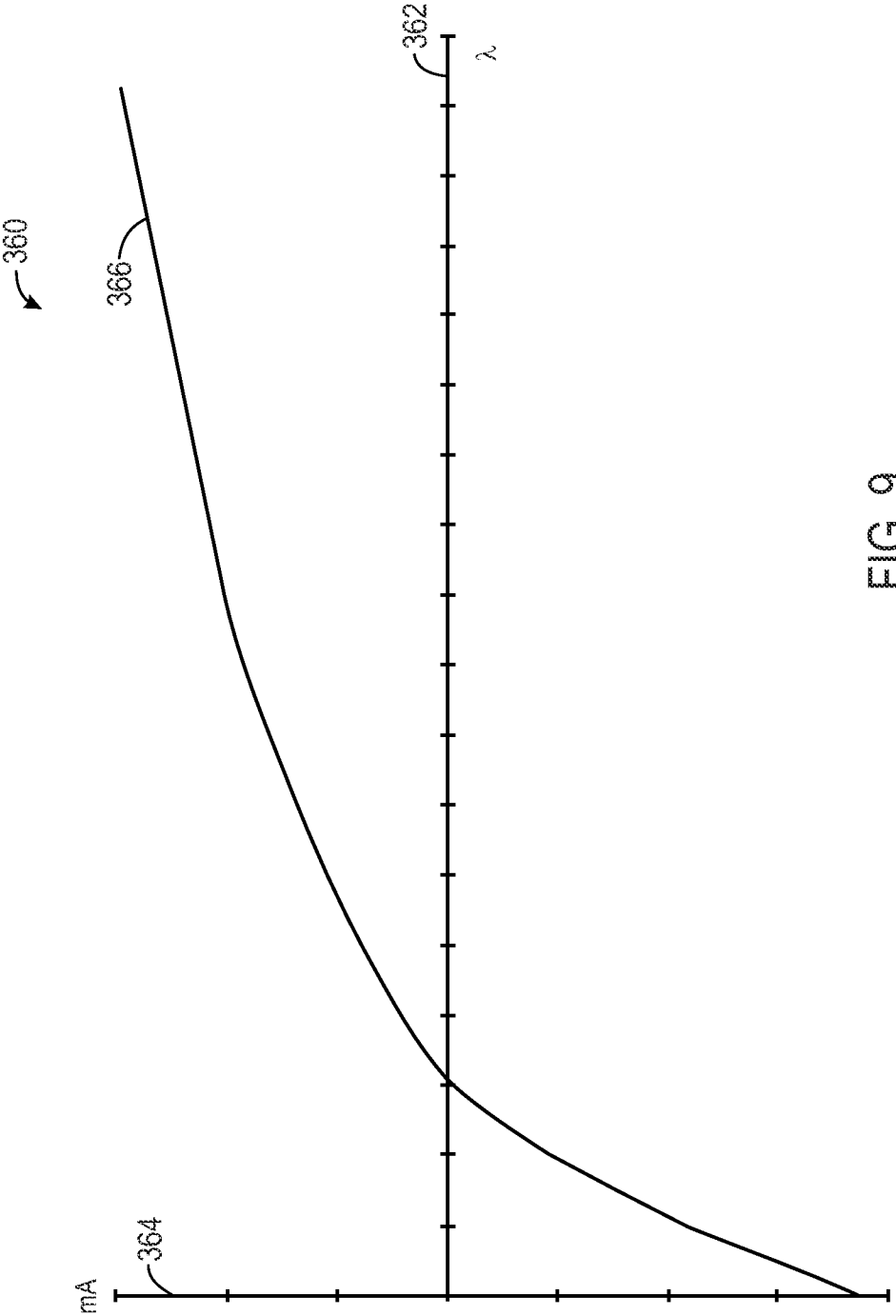


FIG. 9

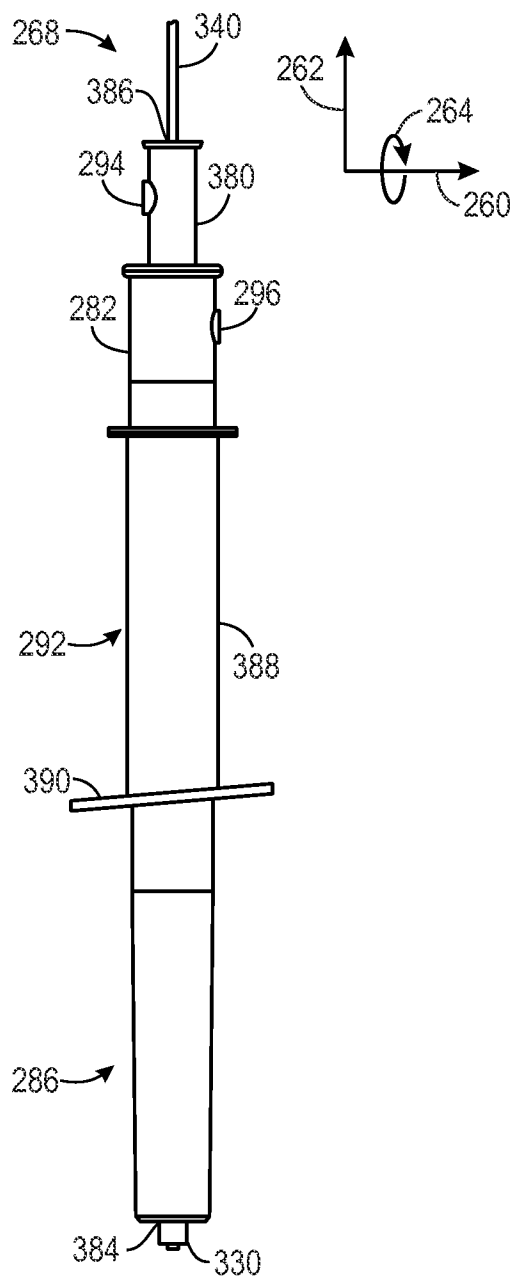


FIG. 10

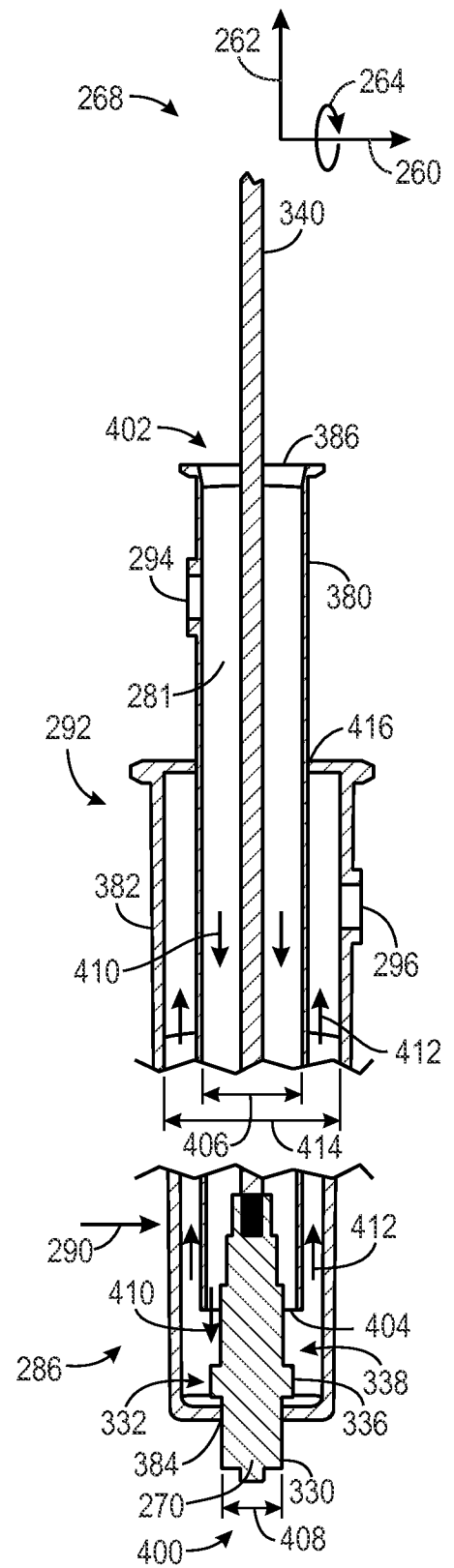
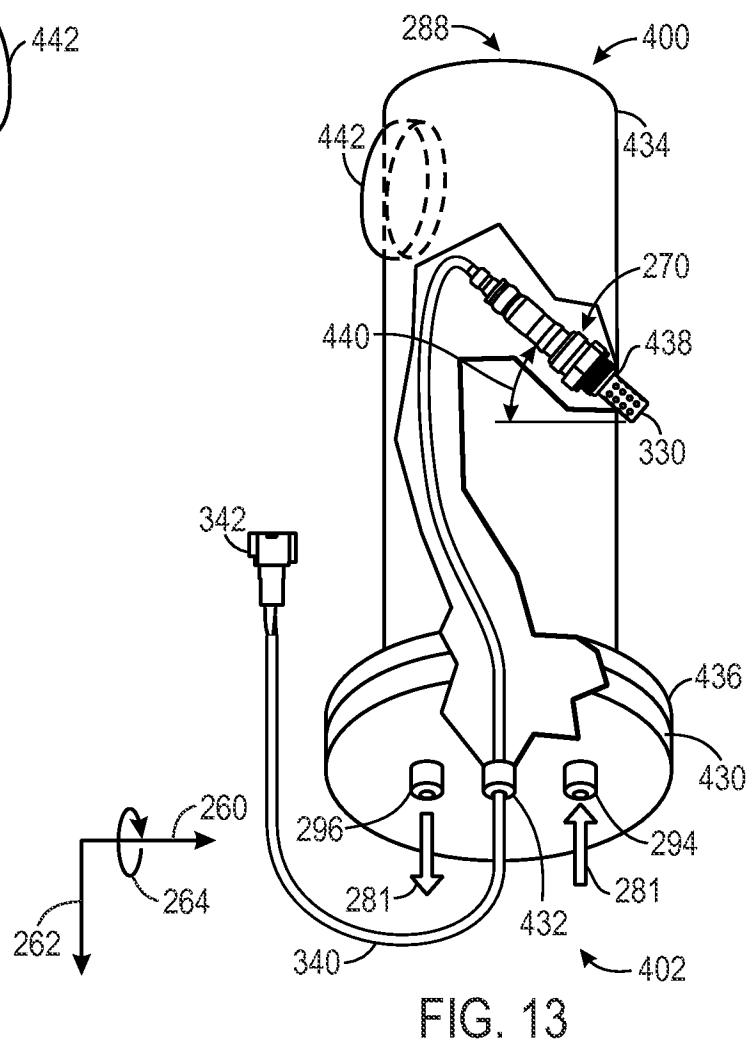
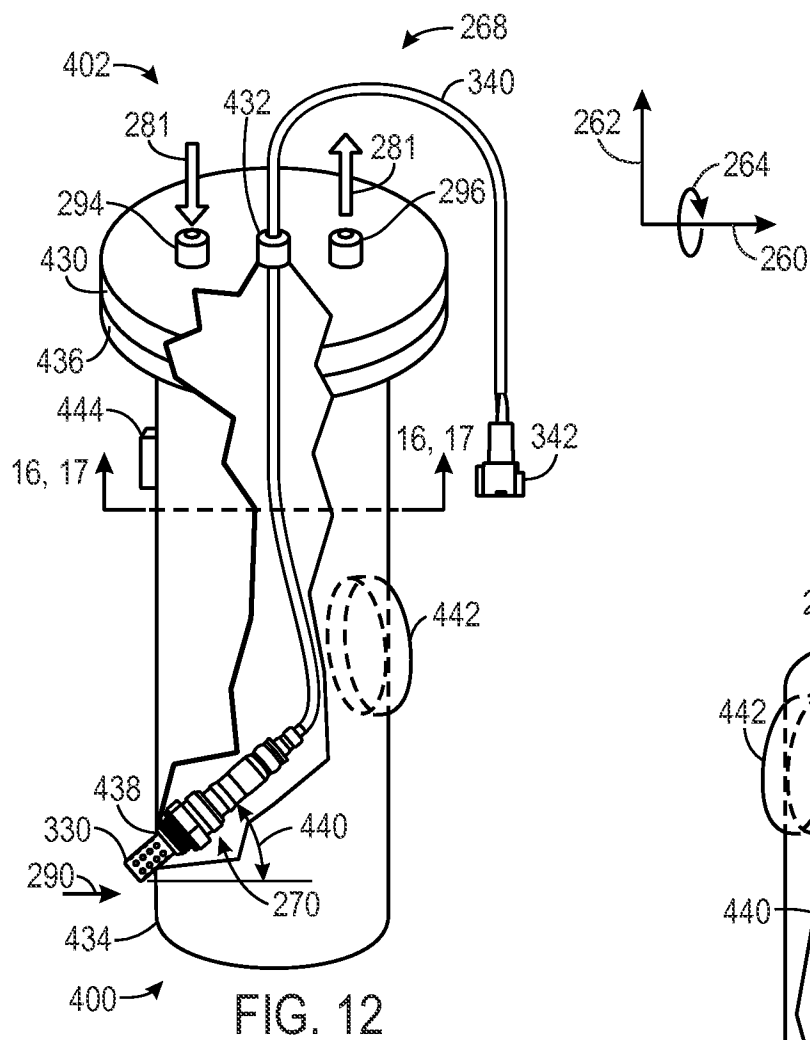
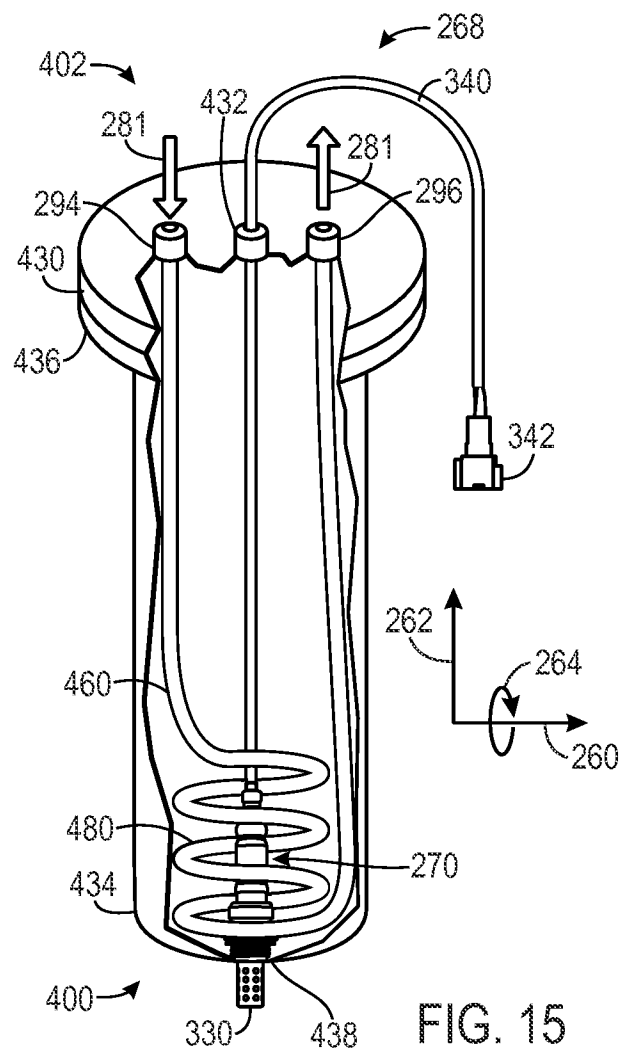
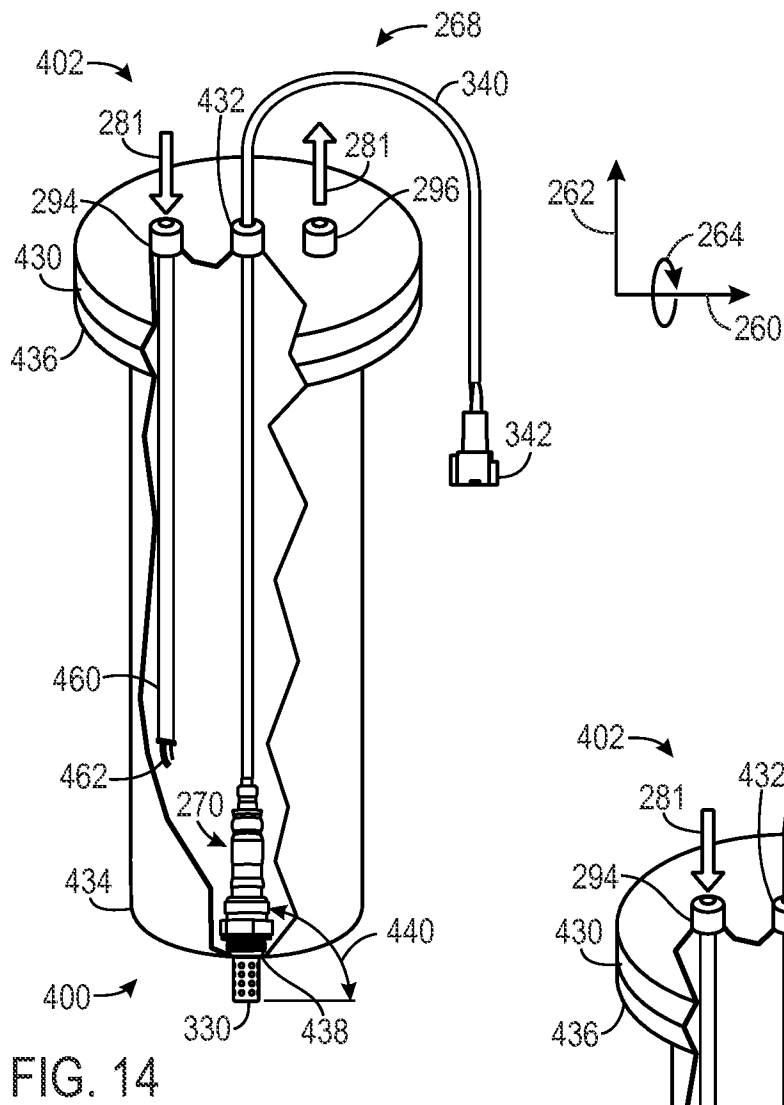


FIG. 11

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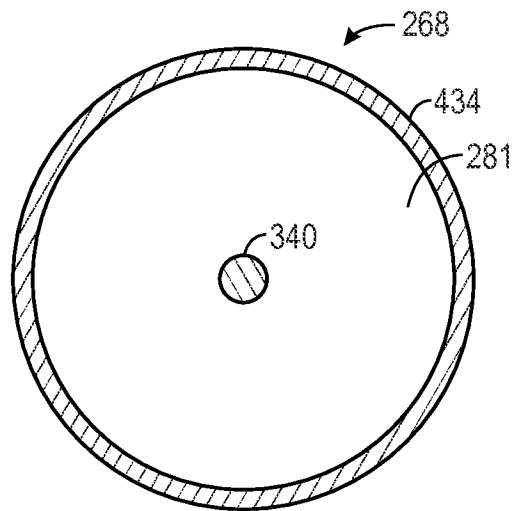


FIG. 16

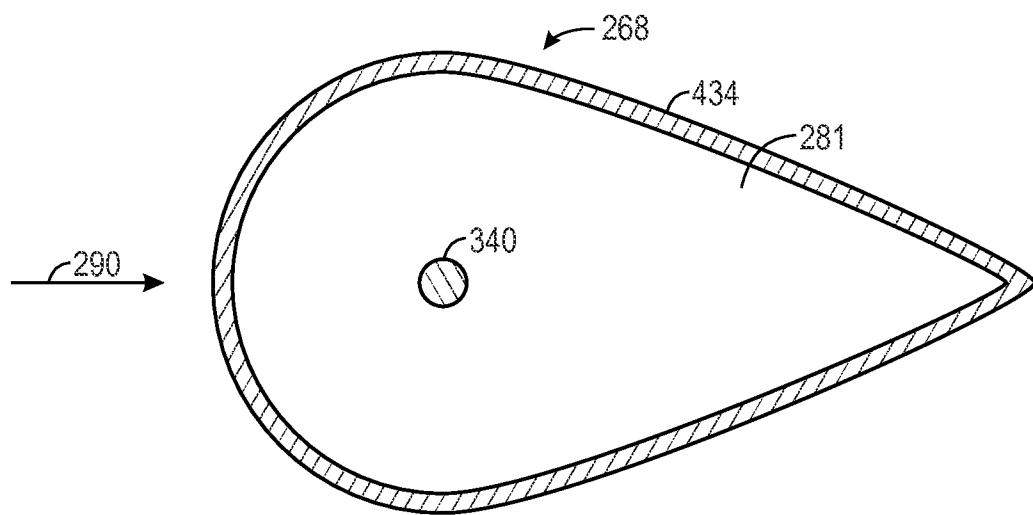


FIG. 17

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/045503

A. CLASSIFICATION OF SUBJECT MATTER

INV. F02C3/34 F02C9/00 G01N33/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02C G01N

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	figure 1 claims 1,2,9 column 1, lines 40-64	
X	EP 2 581 583 A1 (ALSTOM TECHNOLOGY LTD [CH]) 17 April 2013 (2013-04-17) figures 1-2 column 4, lines 5-10 paragraphs [0018], [0028]	1-3,8, 10,12, 13,17-20
X	EP 2 107 305 A1 (SIEMENS AG [DE]) 7 October 2009 (2009-10-07) abstract; figure 1	1-3,8, 10,12, 13,17-20
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Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

28 November 2014

Date of mailing of the international search report

05/12/2014

Name and mailing address of the ISA/

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Authorized officer

Fortugno, Eugenio

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/045503

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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International application No

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