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(54) Title: METHODS OF VARYING LOW EMISSION TURBINE GAS RECYCLE CIRCUITS AND SYSTEMS AND APPARATUS RELATED THERETO

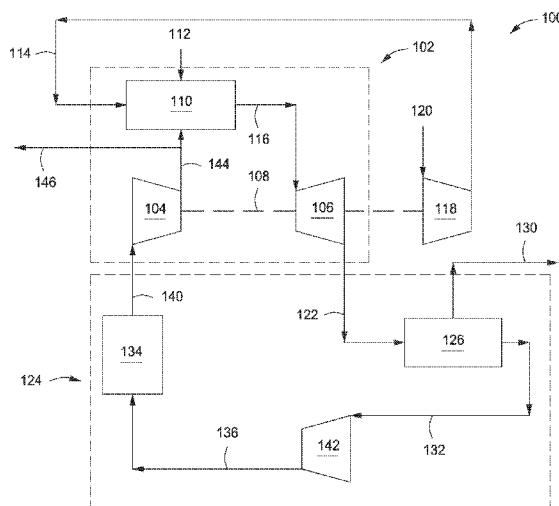


FIG. 1

(57) Abstract: Systems and methods are provided for varying the exhaust gas recycle circuit of low emission gas turbines. In one or more embodiments, the systems and methods incorporate alternatives to the use of a direct contact cooler. In the same or other embodiments, the systems and methods incorporate alternatives intended to reduce or eliminate the erosion or corrosion of compressor blades due to the presence of acidic water droplets in the recycled gas stream.

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**METHODS OF VARYING LOW EMISSION TURBINE GAS RECYCLE CIRCUITS
AND SYSTEMS AND APPARATUS RELATED THERETO**

CROSS REFERENCE TO RELATED APPLICATIONS

5 [0001] This application claims priority to U.S. Provisional Application 61/466,381 filed March 22, 2011 entitled, METHODS OF VARYING LOW EMISSION TURBINE GAS RECYCLE CIRCUITS AND SYSTEMS AND APPARATUS RELATED THERETO; U.S. Provisional Application 61/542,035 filed September 30, 2011 entitled, METHODS OF VARYING LOW EMISSION TURBINE GAS RECYCLE CIRCUITS AND SYSTEMS
10 AND APPARATUS RELATED THERETO, both of which are hereby incorporated by reference in their entirety.

[0002] This application is related to U.S. Provisional Application 61/542,036 filed September 30, 2011 entitled, SYSTEMS AND METHODS FOR CARBON DIOXIDE CAPTURE IN LOW EMISSION TURBINE SYSTEMS; U.S. Provisional Application 15 61/542,037 filed September 30, 2011 entitled, SYSTEMS AND METHODS FOR CARBON DIOXIDE CAPTURE IN LOW EMISSION TURBINE SYSTEMS; U.S. Provisional Application 61/542,039 filed September 30, 2011 entitled, SYSTEMS AND METHODS FOR CARBON DIOXIDE CAPTURE IN LOW EMISSION COMBINED TURBINE SYSTEMS; U.S. Provisional Application 61/542,041 filed September 30, 2011 entitled,
20 LOW EMISSION POWER GENERATION SYSTEMS AND METHODS INCORPORATING CARBON DIOXIDE SEPARATION; U.S. Provisional Application 61/466,384 filed March 22, 2011 entitled, LOW EMISSION TURBINE SYSTEMS HAVING A MAIN AIR COMPRESSOR OXIDANT CONTROL APPARATUS AND METHODS RELATED THERETO; U.S. Provisional Application 61/542,030 filed
25 September 30, 2011 entitled, LOW EMISSION TURBINE SYSTEMS INCORPORATING INLET COMPRESSOR OXIDANT CONTROL APPARATUS AND METHODS RELATED THERETO; U.S. Provisional Application 61/466,385 filed March 22, 2011 entitled, METHODS FOR CONTROLLING STOICHIOMETRIC COMBUSTION ON A FIXED GEOMETRY GAS TURBINE SYSTEM AND APPARATUS AND SYSTEMS
30 RELATED THERETO; U.S. Provisional Application 61/542,031 filed September 30, 2011 entitled, SYSTEMS AND METHODS FOR CONTROLLING STOICHIOMETRIC

COMBUSTION IN LOW EMISSION TURBINE SYSTEMS; all of which are hereby incorporated by reference in their entirety.

FIELD OF THE DISCLOSURE

[0003] Embodiments of the disclosure relate to low emission power generation. More 5 particularly, embodiments of the disclosure relate to methods and apparatus for varying low emission turbine gas recycle circuits.

BACKGROUND OF THE DISCLOSURE

[0004] This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present disclosure. This discussion is 10 believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present disclosure. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0005] Many oil producing countries are experiencing strong domestic growth in power demand and have an interest in enhanced oil recovery (EOR) to improve oil recovery from 15 their reservoirs. Two common EOR techniques include nitrogen (N₂) injection for reservoir pressure maintenance and carbon dioxide (CO₂) injection for miscible flooding for EOR. There is also a global concern regarding green house gas (GHG) emissions. This concern combined with the implementation of cap-and-trade policies in many countries makes reducing CO₂ emissions a priority for those countries as well as for the companies that 20 operate hydrocarbon production systems therein.

[0006] Some approaches to lower CO₂ emissions include fuel de-carbonization or post-combustion capture using solvents, such as amines. However, both of these solutions are expensive and reduce power generation efficiency, resulting in lower power production, increased fuel demand and increased cost of electricity to meet domestic power demand. In 25 particular, the presence of oxygen, SO_x, and NO_x components makes the use of amine solvent absorption very problematic. Another approach is an oxyfuel gas turbine in a combined cycle (e.g., where exhaust heat from the gas turbine Brayton cycle is captured to make steam and produce additional power in a Rankin cycle). However, there are no commercially available gas turbines that can operate in such a cycle and the power required 30 to produce high purity oxygen significantly reduces the overall efficiency of the process.

[0007] Moreover, with the growing concern about global climate change and the impact of carbon dioxide emissions, emphasis has been placed on minimizing carbon dioxide

emissions from power plants. Gas turbine combined cycle power plants are efficient and have a lower cost compared to nuclear or coal power generation technologies. Capturing carbon dioxide from the exhaust of a gas turbine combined cycle power plant is very expensive for the following reasons: (a) the low concentration of carbon dioxide in the 5 exhaust stack, (b) the large volume of gas that needs to be treated, (c) the low pressure of the exhaust stream, and the large amount of oxygen that is present in the exhaust stream. All of these factors result in a high cost of carbon dioxide capture from combined cycle plants.

[0008] Accordingly, there is still a substantial need for a low emission, high efficiency power generation and CO₂ capture manufacturing process.

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SUMMARY OF THE DISCLOSURE

[0009] In the combined cycle power plants described herein, exhaust gases from low emission gas turbines, which are vented in a typical natural gas combined cycle (NGCC) plant, are instead cooled and recycled to the gas turbine main compressor inlet. The recycle exhaust gases, rather than excess compressed fresh air, are used to cool the products of 15 combustion down to the material limitations in the expander. The combustion may be stoichiometric or non-stoichiometric. In one or more embodiments, by combining stoichiometric combustion with exhaust gas recycle, the concentration of CO₂ in the recirculating gases is increased while minimizing the presence of excess O₂, both of which make CO₂ recovery easier.

20 [0010] In one or more embodiments herein, methods are provided for varying the exhaust gas recycle circuit of such low emission gas turbine systems and apparatus related thereto. These methods improve the operability and cost effectiveness of low emission gas turbine operation. The methods, apparatus, and systems consider: (a) alternatives to using a direct contact cooler, which is a large and capital intensive piece of equipment, and (b) methods and 25 apparatus for reducing erosion or corrosion on the blades in the first few sections of the main compressor caused by condensation of acidic water droplets in the recycle gas stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The foregoing and other advantages of the present disclosure may become apparent upon reviewing the following detailed description and drawings of non-limiting 30 examples of embodiments in which:

[0012] FIG. 1 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure.

[0013] FIG. 2 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure wherein the blower is downstream of the heat recovery steam generator (HRSG) low pressure boiler.

5 [0014] FIG. 3 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure utilizing psychrometric cooling of the blower inlet.

10 [0015] FIG. 4 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure utilizing cooling water coils in the HRSG.

[0016] FIG. 5 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure, which eliminates the direct contact cooler (DCC) and saturates the inlet to the recycle compressor.

15 [0017] FIG. 6 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure, which eliminates the DCC and superheats the inlet to the recycle compressor.

20 [0018] FIG. 7A depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure incorporating glycol dehydration of the cooled recycle gas.

[0019] FIG. 7B illustrates the relationship between the pressure and the external heat source temperature in a triethylene glycol (TEG) regeneration system.

[0020] FIG. 7C illustrates the relationship between the ejector steam load and the external heat source temperature in a TEG regeneration system.

25 [0021] FIG. 8 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure incorporating glycol dehydration of the cooled recycle gas with glycol regeneration integrated into the cooling unit.

30 [0022] FIG. 9 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure

incorporating glycol dehydration of the cooled recycle gas with glycol regeneration and a desuperheater integrated into the cooling unit.

[0023] FIG. 10 depicts an integrated system for low emission power generation and enhanced CO₂ recovery according to one or more embodiments of the present disclosure 5 incorporating a feed/effluent cross exchanger across the recycle gas cooling equipment.

DETAILED DESCRIPTION

[0024] In the following detailed description section, the specific embodiments of the present disclosure are described in connection with preferred embodiments. However, to the extent that the following description is specific to a particular embodiment or a particular use 10 of the present disclosure, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the disclosure is not limited to the specific embodiments described below, but rather, it includes all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0025] Various terms as used herein are defined below. To the extent a term used in a 15 claim is not defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent.

[0026] As used herein, the term "natural gas" refers to a multi-component gas obtained from a crude oil well (associated gas) and/or from a subterranean gas-bearing formation (non-associated gas). The composition and pressure of natural gas can vary significantly. A 20 typical natural gas stream contains methane (CH₄) as a major component, i.e. greater than 50 mol% of the natural gas stream is methane. The natural gas stream can also contain ethane (C₂H₆), higher molecular weight hydrocarbons (e.g., C₃-C₂₀ hydrocarbons), one or more acid gases (e.g., hydrogen sulfide), or any combination thereof. The natural gas can also contain minor amounts of contaminants such as water, nitrogen, iron sulfide, wax, crude oil, or any 25 combination thereof.

[0027] As used herein, the term "stoichiometric combustion" refers to a combustion reaction having a volume of reactants comprising a fuel and an oxidizer and a volume of products formed by combusting the reactants where the entire volume of the reactants is used to form the products. As used herein, the term "substantially stoichiometric combustion" 30 refers to a combustion reaction having an equivalence ratio ranging from about 0.9:1 to about 1.1:1, or more preferably from about 0.95:1 to about 1.05:1.

[0028] As used herein, the term "stream" refers to a volume of fluids, although use of the term stream typically means a moving volume of fluids (e.g., having a velocity or mass flow rate). The term "stream," however, does not require a velocity, mass flow rate, or a particular type of conduit for enclosing the stream.

5 [0029] Embodiments of the presently disclosed systems and processes may be used to produce ultra low emission electric power and CO₂ for applications such as enhanced oil recovery (EOR) or sequestration. According to embodiments disclosed herein, a mixture of air and fuel can be combusted and simultaneously mixed with a stream of recycled exhaust gas. The stream of recycled exhaust gas, generally including products of combustion such as
10 CO₂, can be used as a diluent to control or otherwise moderate the temperature of the combustion and flue gas entering the succeeding expander.

15 [0030] The combustion may be stoichiometric or non-stoichiometric. Combustion at near stoichiometric conditions (or "slightly rich" combustion) can prove advantageous in order to eliminate the cost of excess oxygen removal. By cooling the flue gas and condensing the water out of the stream, a relatively high content CO₂ stream can be produced. While a portion of the recycled exhaust gas can be utilized for temperature moderation in the closed
20 Brayton cycle, a remaining purge stream can be used for EOR applications and electric power can be produced with little or no SO_X, NO_X, or CO₂ being emitted to the atmosphere. For example, the purge stream can be treated in a CO₂ separator adapted to discharge a nitrogen-rich gas which can be subsequently expanded in a gas expander to generate additional mechanical power. The result of the systems disclosed herein is the production of power and the manufacturing or capture of additional CO₂ at a more economically efficient level.

25 [0031] In one or more embodiments, the present invention is directed to integrated systems comprising a gas turbine system and an exhaust gas recirculation system. The gas turbine system comprises a combustion chamber configured to combust one or more oxidants and one or more fuels in the presence of a compressed recycle stream and an exhaust gas recirculation system. The combustion chamber directs a first discharge stream to an expander to generate a gaseous exhaust stream and at least partially drive a main compressor, and the main compressor compresses the gaseous exhaust stream and thereby generates the
30 compressed recycle stream. The exhaust gas recirculation system comprises at least one cooling unit configured to receive and cool the gaseous exhaust stream and at least one blower configured to receive and increase the pressure of the gaseous exhaust stream before directing a cooled recycle gas to the main compressor.

[0032] In certain embodiments, the at least one cooling unit may be a heat recovery steam generator (HRSG) configured to receive and cool the gaseous exhaust stream before introduction to the at least one blower. In the same or other embodiments, the exhaust gas recirculation system may further comprise a second cooling unit configured to receive the 5 gaseous exhaust stream from the at least one blower and further cool the gaseous exhaust stream to generate the cooled recycle gas. The second cooling unit may comprise a direct contact cooler (DCC) section. Alternately, the second cooling unit may comprise a HRSG.

[0033] In some embodiments, the exhaust gas recirculation system may further comprise a third cooling unit configured to receive the gaseous exhaust stream from the at least one 10 blower and further cool the gaseous exhaust stream before introduction to the second cooling unit. In such embodiments, the first cooling unit and the third cooling unit may comprise HRSGs. In one or more embodiments, the first cooling unit may comprise a HRSG comprising a high pressure boiler section, an intermediate pressure boiler section, and a low pressure boiler section, and the third cooling unit may comprise a HRSG comprising a low 15 pressure boiler section and an economizer section.

[0034] In some embodiments, one or more HRSGs employed in the exhaust gas recirculation system may further comprise cooling water coils. In such embodiments, the system may further comprise a separator configured to receive the gaseous exhaust stream from the cooling water coils of the HRSG and remove water droplets from the gaseous 20 exhaust stream before introduction to the blower or main compressor. In one or more embodiments, the separator is a vane pack, mesh pad, or other demisting device.

[0035] In one or more embodiments of the present invention, the exhaust gas recirculation system may employ psychrometric cooling of the gaseous exhaust stream. In some embodiments, water is added to the gaseous exhaust stream to saturate or nearly 25 saturate the gaseous exhaust stream downstream of the first cooling unit but before introduction to the blower, and the exhaust gas recirculation system further comprises a separator configured to receive the saturated or nearly saturated gaseous exhaust stream and remove water droplets from the saturated or nearly saturated gaseous exhaust stream before introduction to the blower. In such embodiments, the second cooling unit is further 30 configured to remove water from the gaseous exhaust stream and recycle at least part of the water removed. The water removed from the gaseous exhaust stream by the second cooling unit may be divided into two or more portions, such that a first portion of the water is

recycled and added to the gaseous exhaust stream upstream of the separator and a second portion of the water is recycled to the second cooling unit.

[0036] In one or more embodiments, the exhaust gas recirculation system may further comprise a feed/effluent cross exchanger across the second cooling unit configured to adjust 5 the temperature of the cooled recycle gas such that a dew point margin of at least about 20 °F, or at least about 25 °F, or at least about 30 °F, or at least about 35 °F, or at least about 40 °F, or at least about 45 °F, or at least about 50 °F is achieved.

[0037] In one or more embodiments, the second cooling unit further comprises a glycol absorption section, such as for example a triethylene glycol (TEG) absorption section, 10 configured to receive the cooled recycle gas from the upstream recycle gas cooling equipment and at least partially dehydrate the cooled recycle gas before introduction to the main compressor, and the exhaust gas recirculation system further comprises a glycol regeneration system configured to receive rich glycol from the glycol absorption section of the second cooling unit, thermally regenerate the rich glycol in a glycol regeneration column 15 to form regenerated lean glycol, and return the regenerated lean glycol to the glycol absorption section. In some embodiments, the glycol regeneration system is operated under vacuum conditions. The glycol regeneration system may be separate from or integrated into the second cooling unit. In one or more embodiments, the second cooling unit comprises the glycol regeneration column and the glycol regeneration column is configured to receive the 20 gaseous exhaust stream from the blower before introduction to the upstream recycle gas cooling equipment. In the same or other embodiments, the second cooling unit may further comprise a desuperheating section positioned between the glycol regeneration column and the upstream recycle gas cooling equipment. Any suitable glycol may be used in the glycol absorption systems described herein. For example, in one or more embodiments the glycol is 25 triethylene glycol (TEG). Further, in one or more other embodiments of the present invention, another suitable method for dehydrating the cooled recycle gas may be employed in place of glycol dehydration, such as for example mole sieves or methanol dehydration.

[0038] In one or more embodiments, the present invention is directed to methods of generating power. The methods comprise combusting at least one oxidant and at least one 30 fuel in a combustion chamber in the presence of a compressed recycle exhaust gas, thereby generating a discharge stream, expanding the discharge stream in an expander to at least partially drive a main compressor and generate a gaseous exhaust stream, and directing the gaseous exhaust stream to an exhaust gas recirculation system. The main compressor

compresses the gaseous exhaust stream and thereby generates the compressed recycle stream. In such methods, the exhaust gas recirculation system comprises at least one cooling unit and at least one blower, such that the gaseous exhaust stream is cooled in at the least one cooling unit and the pressure of the gaseous exhaust stream is increased in the at least one blower, 5 thereby generating a cooled recycle gas directed to the main compressor.

[0039] In one or more methods of the present invention, the at least one cooling unit is a direct contact cooler (DCC), heat recovery steam generator (HRSG), or other suitable cooling device that cools the gaseous exhaust stream before the gaseous exhaust stream is introduced to the at least one blower. In the same or other methods, the exhaust gas recirculation system 10 further comprises a second cooling unit that receives the gaseous exhaust stream from the at least one blower and further cools the gaseous exhaust stream, thereby generating the cooled recycle gas. The second cooling unit may comprise a DCC, a HRSG, or other suitable cooling device.

[0040] In some methods, the exhaust gas recirculation system may further comprise a 15 third cooling unit that receives the gaseous exhaust stream from the at least one blower and further cools the gaseous exhaust stream before the gaseous exhaust stream is introduced to the second cooling unit. In one or more methods, the first cooling unit and the third cooling unit comprise HRSGs. In the same or other methods, the first cooling unit may comprise a HRSG comprising a high pressure boiler section, an intermediate pressure boiler section, and 20 a low pressure boiler section, and the third cooling unit may comprise a HRSG comprising a low pressure boiler section and an economizer section.

[0041] In some methods, one or more of the HRSGs employed in the exhaust gas recirculation system may further comprise cooling water coils. In such methods, a separator 25 may receive the gaseous exhaust stream from the cooling water coils of the HRSG and remove water droplets from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower or main compressor. In one or more embodiments, the separator is a vane pack, mesh pad, or other demisting device.

[0042] In one or more methods of the present invention, the exhaust gas recirculation system employs psychrometric cooling to further cool the gaseous exhaust stream. In some 30 of those methods, the gaseous exhaust stream is saturated or nearly saturated with water before the gaseous exhaust stream is introduced to the blower, the exhaust gas recirculation system further comprises a separator that receives the saturated or nearly saturated gaseous

exhaust stream and removes water droplets from the saturated or nearly saturated gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower, and the second cooling unit removes water from the gaseous exhaust stream and at least part of the water removed by the second cooling unit is recycled. In one or more methods, the water removed from the gaseous exhaust stream by the second cooling unit is divided into two or more portions and a first portion of the water is recycled and added to the gaseous exhaust stream upstream of the separator while a second portion of the water is recycled to the second cooling unit.

[0043] In one or more embodiments of the present invention, a dew point margin of at least about 20 °F, or at least about 25 °F, or at least about 30 °F, or at least about 35 °F, or at least about 40 °F, or at least about 45 °F, or at least about 50 °F is achieved in the cooled recycle gas by modifying the temperature of the cooled recycle gas in a feed/effluent cross exchanger across the second cooling unit.

[0044] In one or more methods of the present invention, the second cooling unit further comprises a glycol absorption section that receives the cooled recycle gas from the upstream recycle gas cooling equipment and at least partially dehydrates the cooled recycle gas before the cooled recycle gas is introduced to the main compressor, and the exhaust gas recirculation system further comprises a glycol regeneration system that receives rich glycol from the glycol absorption section of the second cooling unit, thermally regenerates the rich glycol in a glycol regeneration column to form regenerated lean glycol, and returns the regenerated lean glycol to the glycol absorption section. In some methods, the glycol regeneration system is operated under vacuum conditions. The glycol regeneration system may be separate from or integrated into the second cooling unit. In one or more methods, the second cooling unit comprises the glycol regeneration column and the glycol regeneration column receives the gaseous exhaust stream from the blower before the gaseous exhaust stream is introduced to the upstream recycle gas cooling equipment. In the same or other methods, the second cooling unit may further comprise a desuperheating section positioned between the glycol regeneration column and the upstream recycle gas cooling equipment that receives the gaseous exhaust stream from the glycol regeneration column and cools the gaseous exhaust stream to a temperature sufficient to at least partially condense glycol from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the upstream recycle gas cooling equipment.

[0045] Referring now to the figures, FIG. 1 illustrates a power generation system **100** configured to provide an improved post-combustion CO₂ capture process. In at least one embodiment, the power generation system **100** can include a gas turbine system **102** that can be characterized as a closed Brayton cycle. In one embodiment, the gas turbine system **102** 5 can have a first or main compressor **104** coupled to an expander **106** through a common shaft **108** or other mechanical, electrical, or other power coupling, thereby allowing a portion of the mechanical energy generated by the expander **106** to drive the compressor **104**. The expander **106** may generate power for other uses as well, such as to power a second or inlet 10 compressor **118**. The gas turbine system **102** can be a standard gas turbine, where the main compressor **104** and expander **106** form the compressor and expander ends, respectively, of the standard gas turbine. In other embodiments, however, the main compressor **104** and expander **106** can be individualized components in a system **102**.

[0046] The gas turbine system **102** can also include a combustion chamber **110** configured to combust a fuel stream **112** mixed with a compressed oxidant **114**. In one or 15 more embodiments, the fuel stream **112** can include any suitable hydrocarbon gas or liquid, such as natural gas, methane, naphtha, butane, propane, syngas, diesel, kerosene, aviation fuel, coal derived fuel, bio-fuel, oxygenated hydrocarbon feedstock, or combinations thereof. The compressed oxidant **114** can be derived from a second or inlet compressor **118** fluidly coupled to the combustion chamber **110** and adapted to compress a feed oxidant **120**. In one 20 or more embodiments, the feed oxidant **120** can include any suitable gas containing oxygen, such as air, oxygen-rich air, or combinations thereof.

[0047] As will be described in more detail below, the combustion chamber **110** can also receive a compressed recycle stream **144**, including a flue gas primarily having CO₂ and nitrogen components. The compressed recycle stream **144** can be derived from the main 25 compressor **104** and adapted to help facilitate the combustion of the compressed oxidant **114** and fuel **112**, and also increase the CO₂ concentration in the working fluid. A discharge stream **116** directed to the inlet of the expander **106** can be generated as a product of combustion of the fuel stream **112** and the compressed oxidant **114**, in the presence of the compressed recycle stream **144**. In at least one embodiment, the fuel stream **112** can be 30 primarily natural gas, thereby generating a discharge **116** including volumetric portions of vaporized water, CO₂, nitrogen, nitrogen oxides (NO_x), and sulfur oxides (SO_x). In some embodiments, a small portion of unburned fuel **112** or other compounds may also be present in the discharge **116** due to combustion equilibrium limitations. As the discharge stream **116**

expands through the expander **106** it generates mechanical power to drive the main compressor **104**, or other facilities, and also produces a gaseous exhaust stream **122** having a heightened CO₂ content.

[0048] The power generation system **100** can also include an exhaust gas recirculation (EGR) system **124**. While the EGR system **124** illustrated in the figures incorporates various apparatus, the illustrated configurations are representative only and any system that recirculates the exhaust gas **122** back to the main compressor to accomplish the goals stated herein may be used. In one or more embodiments, the EGR system **124** can include a heat recovery steam generator (HRSG) **126**, or similar device. The gaseous exhaust stream **122** can be sent to the HRSG **126** in order to generate a stream of steam **130** and a cooled exhaust gas **132**. The steam **130** can optionally be sent to a steam gas turbine (not shown) to generate additional electrical power. In such configurations, the combination of the HRSG **126** and the steam gas turbine can be characterized as a closed Rankine cycle. In combination with the gas turbine system **102**, the HRSG **126** and the steam gas turbine can form part of a combined-cycle power generating plant, such as a natural gas combined-cycle (NGCC) plant.

[0049] FIG. 1 illustrates additional apparatus in the EGR system **124** that may be incorporated in some embodiments. The cooled exhaust gas **132** can be sent to at least one cooling unit **134** configured to reduce the temperature of the cooled exhaust gas **132** and generate a cooled recycle gas stream **140**. In one or more embodiments, the cooling unit **134** is considered herein to be a direct contact cooler (DCC), but may be any suitable cooling device such as a direct contact cooler, trim cooler, a mechanical refrigeration unit, or combinations thereof. The cooling unit **134** can also be configured to remove a portion of condensed water via a water dropout stream (not shown). In one or more embodiments, the cooled exhaust gas stream **132** can be directed to a blower or boost compressor **142** fluidly coupled to the cooling unit **134**. In such embodiments, compressed exhaust gas stream **136** exits the blower **142** and is directed to the cooling unit **134**.

[0050] The blower **142** can be configured to increase the pressure of the cooled exhaust gas stream **132** before it is introduced into the main compressor **104**. In one or more embodiments, the blower **142** increases the overall density of the cooled exhaust gas stream **132**, thereby directing an increased mass flow rate for the same volumetric flow to the main compressor **104**. Because the main compressor **104** is typically volume-flow limited, directing more mass flow through the main compressor **104** can result in a higher discharge pressure from the main compressor **104**, thereby translating into a higher pressure ratio across

the expander **106**. A higher pressure ratio generated across the expander **106** can allow for higher inlet temperatures and, therefore, an increase in expander **106** power and efficiency. This can prove advantageous since the CO₂-rich discharge **116** generally maintains a higher specific heat capacity. Accordingly, the cooling unit **134** and the blower **142**, when 5 incorporated, may each be adapted to optimize or improve the operation of the gas turbine system **102**. It should be noted that, although the blower **142** is shown in a particular location in the EGR system **124** in FIG. 1 and in the other drawings and examples described herein, the blower may be located anywhere throughout the recycle loop.

[0051] The main compressor **104** can be configured to compress the cooled recycle gas 10 stream **140** received from the EGR system **124** to a pressure nominally above the combustion chamber **110** pressure, thereby generating the compressed recycle stream **144**. In at least one embodiment, a purge stream **146** can be tapped from the compressed recycle stream **144** and subsequently treated in a CO₂ separator or other apparatus (not shown) to capture CO₂. The separated CO₂ can be used for sales, used in another process requiring carbon dioxide, and/or 15 compressed and injected into a terrestrial reservoir for enhanced oil recovery (EOR), sequestration, or another purpose.

[0052] The EGR system **124** as described herein can be implemented to achieve a higher concentration of CO₂ in the working fluid of the power generation system **100**, thereby 20 allowing for more effective CO₂ separation for subsequent sequestration, pressure maintenance, or EOR applications. For instance, embodiments disclosed herein can effectively increase the concentration of CO₂ in the flue gas exhaust stream to about 10 wt% or higher. To accomplish this, the combustion chamber **110** can be adapted to stoichiometrically combust the incoming mixture of fuel **112** and compressed oxidant **114**. In order to moderate the temperature of the stoichiometric combustion to meet expander **106** 25 inlet temperature and component cooling requirements, a portion of the exhaust gas derived from the compressed recycle stream **144** can be injected into the combustion chamber **110** as a diluent. Thus, embodiments of the disclosure can essentially eliminate any excess oxygen from the working fluid while simultaneously increasing its CO₂ composition. As such, the gaseous exhaust stream **122** can have less than about 3.0 vol% oxygen, or less than about 1.0 30 vol% oxygen, or less than about 0.1 vol% oxygen, or even less than about 0.001 vol% oxygen. In some implementations, the combustion chamber **110**, or more particularly, the inlet streams to the combustion chamber may be controlled with a preference to

substoichiometric combustion to further reduce the oxygen content of the gaseous exhaust stream **122**.

[0053] In some embodiments not depicted herein, high pressure steam may also be employed as a coolant in the combustion process, either in place of or in addition to the 5 recycled exhaust gas. In such embodiments, the addition of steam would reduce power and size requirements in the EGR system (or eliminate the EGR system altogether), but would require the addition of a water recycle loop.

[0054] Additionally, in further embodiments not depicted herein, the compressed oxidant feed to the combustion chamber may comprise argon. For example, the oxidant may 10 comprise from about 0.1 to about 5.0 vol% argon, or from about 1.0 to about 4.5 vol% argon, or from about 2.0 to about 4.0 vol% argon, or from about 2.5 to about 3.5 vol% argon, or about 3.0 vol% argon. In such embodiments, the operation of the combustion chamber may be stoichiometric or non-stoichiometric. As will be appreciated by those skilled in the art, incorporating argon into the compressed oxidant feed may require the addition of a cross 15 exchanger or similar device between the main compressor and the combustion chamber configured to remove excess CO₂ from the recycle stream and return argon to the combustion chamber at the appropriate temperature for combustion.

[0055] As can be appreciated, specific temperatures and pressures achieved or experienced in the various components of any of the embodiments disclosed herein can 20 change depending on, among other factors, the purity of the oxidant used and the specific makes and/or models of expanders, compressors, coolers, etc. Accordingly, it will be appreciated that the particular data described herein is for illustrative purposes only and should not be construed as the only interpretation thereof. For example, in one exemplary embodiment herein, the HRSG **126** cools the exhaust gas stream **132** to approximately 25 200 °F. Exhaust gas stream **132** is boosted in pressure by the blower **142** in order to overcome the downstream pressure drop, resulting in a temperature increase such that cooled compressed exhaust gas stream **136** exits the blower **142** at approximately 229 °F. The exhaust gas is further cooled in the cooling unit **134**, and cooled recycle gas stream **140** exits the cooling unit **134** at approximately 100 °F.

30 [0056] Referring now to FIG. 2, depicted is an alternative embodiment of the power generation system **100** of FIG. 1, embodied and described as system **200**. As such, FIG. 2 may be best understood with reference to FIG. 1. Similar to the system **100** of FIG. 1, the

system **200** of FIG. 2 includes a gas turbine system **102** coupled to or otherwise supported by an exhaust gas recirculation (EGR) system **124**. The EGR system **124** in FIG. 2, however, can include a second HRSG **202** downstream of the blower **142** to recover the heat of compression associated with the blower **142**. In one or more embodiments exemplified by 5 the EGR system of FIG. 2, the first HRSG **126** is a triple pressure HRSG including high pressure (HP), intermediate pressure (IP) and low pressure (LP) boiler sections, while the second HRSG **202** includes LP boiler and economizer sections. In an exemplary method of operation of system **200**, the exhaust gas stream **132** exits the LP boiler section of HRSG **126** at a temperature of approximately 279 °F and is compressed in the blower **142**. Cooled 10 compressed exhaust gas stream **136** exits the blower **142** at a temperature of about 310 °F, and enters the second HRSG **202**. Recycle gas stream **138** then exits the second HRSG **202** at a temperature of approximately 200 °F. In this manner, the blower heat of compression is recovered by HRSG **202** and the cooling duty of the cooling unit **134** is reduced.

[0057] FIG. 3 depicts another embodiment of the low emission power generation system 15 **100** of FIG. 1, embodied as system **300**. As such, FIG. 3 may be best understood with reference to FIG. 1. Similar to the system **100** described in FIG. 1, the system **300** includes a gas turbine system **102** supported by or otherwise coupled to an EGR system **124**. The EGR system **124** in FIG. 3, however, employs psychrometric cooling to reduce power consumption 20 of the blower **142** and reduce the cooling duty of the cooling unit **134**. In one or more embodiments exemplified by the EGR system of FIG. 3, water is injected via stream **302** to saturate or nearly saturate and cool exhaust gas stream **132**, resulting in a saturated exhaust gas stream **304**. Saturated exhaust gas stream **304** may optionally be directed to a separator **306** to remove any water droplets that may be entrained therein. Separator **306** can be any device suitable for the removal of water droplets, such as for example a vane pack, mesh pad, 25 or other demisting device. The pressure of saturated exhaust gas stream **304** is increased in the blower **142**. Cooled compressed exhaust gas stream **136** exits the blower **142** and is directed to the cooling unit **134**. In the cooling unit, water condenses out of cooled compressed exhaust gas stream **136** as the stream is further cooled, and the water is recovered 30 in water stream **308**. In one or more embodiments of the invention, water stream **308** may be cooled in a heat exchanger **310** or other cooling device, resulting in cooled water stream **312**. Cooled water stream **312** may then be recycled via recycle water stream **314** to provide additional cooling of the exhaust gas in the cooling unit **134**, combined with water stream **302** to be injected into exhaust gas stream **132** upstream of the blower **142**, or both. While water

stream **302** may be employed at some points during operation of the system of FIG. 3, such as for example during start-up or when makeup water is needed in the system, it will be apparent to those skilled in the art that there may be times (for example during steady state operation) that the amount of water required for injection into exhaust gas stream **132** may be 5 supplied entirely by the recycle of cooled water stream **312**.

[0058] In an exemplary method of operation of system **300**, the exhaust gas stream **132** exits the HRSG **126** at a temperature of approximately 200 °F. The injection of water via stream **302** cools the exhaust gas, resulting in saturated exhaust gas stream **304** having a temperature of approximately 129 °F. Once compressed in the blower **142**, cooled 10 compressed exhaust gas stream **136** exits the blower **142** at a temperature of about 154 °F, and is cooled in the cooling unit **134** resulting in cooled recycle gas stream at a temperature of approximately 100 °F. In this manner, the blower adds less heat to the system and the cooling duty of the cooling unit **134** is reduced.

[0059] FIG. 4 depicts another embodiment of the low emission power generation system 15 **100** of FIG. 1, embodied as system **400**. FIG. 4 may be best understood with reference to FIGs. 1 and 3. Similar to the system **100** described in FIG. 1, the system **400** includes a gas turbine system **102** supported by or otherwise coupled to an EGR system **124**. The EGR system **124** in FIG. 4, however, employs cooling water coils in the HRSG to reduce the cooling duty of the cooling unit **134**. In one or more embodiments exemplified by the EGR 20 system of FIG. 3, cooling water coils **402** are employed within the HRSG **126** to provide additional cooling of exhaust gas stream **122**. The cooling water coils may be adapted to employ fresh cooling water or seawater. To use fresh cooling water, in some embodiments a closed fresh water system may be included in the design (not shown), with plate and frame exchangers that cool the fresh water against seawater to achieve maximum cooling. If 25 seawater coils are used in the HRSG, the HRSG tubes should be of sufficient metallurgy to handle both potential acidic water condensation and seawater. Cooled exhaust gas stream **132** exits the HRSG **126** and may optionally be directed to a separator **306** to remove any water droplets that may be entrained therein. Separator **306** can be any device suitable for the removal of water droplets, such as for example a vane pack, mesh pad, or other demisting 30 device. Once any entrained water droplets are removed by separator **306**, the cooled exhaust gas stream **132** is directed to the blower **142** and the EGR system downstream of the blower is as previously described with respect to FIG. 1.

[0060] In an exemplary method of operation of system **400**, cooled exhaust gas stream **132** exits the cooling water coils **402** of HRSG **126** at a temperature of approximately 118 °F, and compressed exhaust gas stream **136** exits the blower **142** at a temperature of approximately 140 °F. The exhaust gas is cooled in the cooling unit **134**, and cooled recycle gas stream **140** exits the cooling unit **134** at approximately 100 °F. Because the compressed exhaust gas stream **136** in the system **400** of FIG. 4 enters the cooling unit **134** at a lower temperature than in the previously described systems of FIGs. 1-3, the duty of the cooling unit is reduced with respect to those systems.

[0061] FIG. 5 depicts another embodiment of the low emission power generation system **100** of FIG. 1, embodied as system **500**. FIG. 5 may be best understood with reference to FIGs. 1 and 4. Similar to the system **100** described in FIG. 1, the system **500** includes a gas turbine system **102** supported by or otherwise coupled to an EGR system **124**. The EGR system **124** in FIG. 5 employs cooling water coils **402** in the HRSG **126** and a separator **306** upstream of the blower **142** as described in detail with respect to FIG. 4. FIG. 5, however, also employs an additional HRSG **502** downstream of the blower **142**, replacing the direct contact cooler (DCC) cooling unit described previously with respect to FIGS. 1-4. The HRSG **502** includes a cooling water section similar to the cooling water coils **402** contained within the first HRSG **126**. A separator section **504** is also included within the additional HRSG **502** to remove any condensed water droplets from the compressed exhaust gas stream **136**. Separator section **504** can be any device suitable for the removal of water droplets, such as for example a vane pack, mesh pad, or other demisting device. Once any water droplets are removed by separator section **504** within the additional HRSG **502**, cooled recycle gas stream **140** exits the HRSG **502** and is recycled directly to the main compressor **104**.

[0062] In an exemplary method of operation of system **500**, cooled exhaust gas stream **132** exits the cooling water coils **402** of the first HRSG **126** at a temperature of approximately 113 °F, and compressed exhaust gas stream **136** exits the blower **142** at a temperature of approximately 143 °F. The exhaust gas is further cooled in the second HRSG **502**, and cooled recycle gas stream **140** exits the separator section **504** of the second HRSG at approximately 113 °F. In one or more embodiments according to FIG. 5, the cooled recycle gas stream **140** entering the main compressor **104** is saturated with water.

[0063] In one or more of the embodiments depicted by FIGs. 1 through 5, the cooled recycle gas stream **140** may be saturated with water. Accordingly, there is a risk that acidic water droplets may form in the stream and cause erosion or corrosion of the blades of main

compressor **104**. FIG. 6 depicts another embodiment of the low emission power generation system **100** of FIG. 1, embodied as system **600**, which is configured to reduce or eliminate the formation of acidic water droplets by superheating the recycle gas stream entering the main compressor **104**. FIG. 6 may be best understood with reference to FIGs. 1, 4, and 5.

5 Similar to the system **100** described in FIG. 1, the system **600** includes a gas turbine system **102** supported by or otherwise coupled to an EGR system **124**. Similar to the system **400** described in FIG. 4, the EGR system **124** in FIG. 6 also employs cooling water coils **402** in the HRSG **126** and a separator **306** upstream of the blower **142**. The system of FIG. 6, however, eliminates the use of a cooling unit or other cooling device downstream of the 10 blower **142** and upstream of the main compressor **104**, instead directing compressed exhaust gas stream **136** directly from the blower **142** to the main compressor **104**.

[0064] In an exemplary method of operation of system **600**, cooled exhaust gas stream **132** exits the cooling water coils **402** of the first HRSG **126** at a temperature of approximately 113 °F. Exhaust gas stream **132** is superheated by the heat of compression of the blower **142**, 15 and compressed exhaust gas stream **136** exits the blower **142** at a temperature of approximately 144 °F. In this manner, the configuration of FIG. 6 achieves about 25 °F of superheating. As used herein, the term “superheating” refers to the extent to which the temperature of a gas is above the dew point temperature of that gas. Accordingly, 25 °F of superheating means that the temperature of a gas is 25 °F above its dew point temperature. 20 Compressed exhaust gas stream **136** is routed directly to the main compressor **104** without further cooling. If additional superheating of the gas stream is desired, such additional heating may be obtained by a variety of methods, such as for example by cross exchanging the blower discharge with flue gas upstream of the cooling water coils in the HRSG (not shown). Such a cross exchanger configuration would be similar to air preheaters that are 25 commonly installed with furnaces or incinerators and would decrease the required area of the cooling water coils but would add the additional expense of a large cross exchanger.

[0065] The configuration of system **600** in FIG. 6 is intended to reduce or eliminate the formation of acidic water droplets and prevent erosion or corrosion of the blades of the main compressor by superheating the recycle gas stream. FIGs. 7 through 9 depict alternative 30 embodiments of the present invention also intended to reduce or eliminate the formation of acidic water droplets in the recycle gas stream by dehydrating the recycle gas stream using glycol, such as for example triethylene glycol (TEG). In order for such glycol dehydration configurations to be cost effective, waste heat is used to regenerate the glycol. Waste heat

may be captured from a variety of sources in the system, such as from the back of one or more heat recovery steam generators (HRSGs) or from compression inter-cooling.

[0066] FIG. 7A depicts an embodiment of a portion of the EGR system 124 of a low emission power generation system such as that depicted in FIG. 1, embodied as system 700, which is configured to reduce or eliminate the formation of acidic water droplets by dehydrating the recycle gas stream entering the main compressor using a glycol contactor section within the cooling unit and regenerating the glycol in a separate glycol vacuum regeneration system. FIG. 7A may be best understood with reference to FIG. 1. In the system 700, cooled exhaust gas stream 132 flows from the HRSG 126 and is directed to the blower 142, where the stream is compressed. Compressed exhaust gas stream 136 exits the blower 142 and is directed to the cooling unit 134, which in one or more embodiments comprises a direct contact cooler (DCC) section utilizing water as the cooling medium. In one or more embodiments, the cooling unit 134 is considered herein to be a direct contact cooler (DCC), but may be any suitable cooling device such as a direct contact cooler, trim cooler, a mechanical refrigeration unit, or combinations thereof. Within the cooling unit 134, the compressed exhaust gas stream 136 is contacted with water to cool the stream. A water dropout stream 702 exits the cooling unit after contacting the gas stream. In one or more embodiments, a portion of water dropout stream 702 may be purged from the system 700, while the remaining portion of the water dropout stream may be cooled using a heat exchanger 720 and recycled to the cooling unit 134 to provide further cooling of the compressed exhaust gas stream 136. In one or more embodiments, the heat exchanger 720 utilizes seawater to provide the required cooling. In the same or other embodiments, additional cooling may be provided by a chilled water cooler (not shown) installed downstream of the heat exchanger 720 in order to counteract the temperature rise associated with dehydration that occurs within the cooling unit 134 when glycol dehydration is employed. The use of a chilled water cooler in this manner may be desirable because by lowering the temperature of the gas fed to the dehydration portion of the process, the recycled exhaust gas temperature is similarly lowered and the power consumption of the blower and main compressor are reduced. Persons of skill in the art will recognize that the use of a chilled water cooler may be desirable in any configuration employing glycol dehydration, including not only the configuration depicted by FIG. 7A but also those depicted in FIGs. 8 and 9 and in any other dehydration system.

[0067] The cooling unit 134 further comprises a glycol absorption section 710. In one or more embodiments, the glycol absorption section is an absorption column such as a tray column or a packed column. Once the compressed exhaust gas stream has been cooled with water, the gas enters the glycol absorption section 710 of the cooling unit 134, where water vapor in the exhaust gas is absorbed by the glycol. The resulting cooled recycle gas stream 140, which has been at least partially dehydrated by the glycol, exits the cooling unit 134 and is directed to the main compressor 104. Once the glycol has absorbed the water from the exhaust gas, it is withdrawn from the glycol absorption section 710 via rich glycol stream 712 and is directed to a vacuum regeneration system 750.

[0068] Within the vacuum regeneration system 750, rich glycol stream 712 is heated in a cross exchanger 722 and fed to a glycol regeneration column 730, where the glycol is thermally regenerated. Regenerator overhead stream 736 exits the top of glycol regeneration column 730, while the regenerated glycol stream 732 exits the bottom of the column and is directed to a reboiler 734. From the reboiler 734, a glycol vapor stream 733 is returned to the glycol regeneration column and lean glycol stream 714 is directed through the cross exchanger 722 and optionally one or more heat exchangers 720 before being returned to the glycol absorption section 710. Regenerator overhead stream 736, which comprises water vapor and some residual exhaust gases, is cooled in a pre-condensing cooling unit 760 and directed to a first separator 740, where a substantial amount of the water in the overhead stream is removed and exits the system via a water purge stream 742. Exhaust gases exit the first separator 740 via stream 744 and are directed to a steam ejector 770. Within the steam ejector 770, steam at an elevated pressure creates a vacuum that draws in exhaust gas stream 744. The steam ejector 770 may use low pressure, intermediate pressure, or high pressure steam, and may be a single stage or multiple stage ejector. Alternately, in one or more embodiments not depicted in FIG. 7A, a vacuum pump may be used in place of a steam ejector to create the desired level of vacuum in the vacuum regeneration system 750.

[0069] Ejector outlet stream 762, comprising exhaust gases and water vapor, exits the ejector 770 and is cooled in an after-cooler cooling unit 760 before being separated in a second separator 740 to remove the motive steam from the ejector and any other residual water from the stream. The cooling units 760 may be air or water coolers, depending upon the temperature requirements and other parameters of the vacuum regeneration system 750. In one or more embodiments herein, the pressure drop across the pre-condenser cooling unit and the after-cooler cooling unit is less than or equal to about 2 psi, or less than or equal to

about 1.5 psi, or less than or equal to about 1 psi, or less than or equal to about 0.5 psi. The separators **740** may be any type of separation unit designed to remove water from the exhaust gases, such as for example a condenser, gravity separator, reflux drum, or the like. Water removed from the ejector outlet gases in the second separator **740** is removed from the 5 system via a water purge stream **742**, while the resulting dry exhaust gas exits the separator and is recycled to a point upstream of the blower **142** via stream **748**. In one or more embodiments, water purge streams **742** each have a glycol concentration of less than 0.5, or less than 0.25, or less than 0.1 parts per million by volume (ppmv).

[0070] At atmospheric operating pressure, the temperature requirement to reboil the 10 regenerated glycol stream **732** exceeds 300 °F. Accordingly, in one or more embodiments, it is desirable to operate the regeneration system **750**, and particularly the glycol regeneration column **730**, under vacuum conditions. In this manner, low level waste heat may be used to regenerate the glycol rather than steam. As the pressure in the glycol regeneration column **730** is lowered, the reboiler temperature required to vaporize water out of the glycol also 15 drops, while the heat duty remains relatively constant. Therefore, the vacuum pressure can be selected based upon the temperature of the available external heat source (within the limitations of the column design), the parameters of the vacuum generating device, and the available overhead cooling temperature.

[0071] FIG. 7B shows the correspondence between the pressure of a TEG regeneration 20 column and the temperature of the external reboiler heat source, assuming an 18 °F heat exchanger approach temperature. FIG. 7C demonstrates the relationship between the external heat source temperature and the column vacuum pressure and how that relates to the steam load of the ejector for two different pre-condenser overhead cooling temperatures, again assuming an 18 °F heat exchanger approach temperature. The “expected optimums” 25 indicated in FIG. 7C indicate a balance between the external heat source temperature and the ejector steam required to reach the necessary vacuum. By moving further left along the curves, a lower heat source temperature may be used, but more ejector steam would be required at the same overhead cooling temperature.

[0072] FIG. 8 depicts another embodiment of the low emission power generation system 30 **100** of FIG. 1, embodied as system **800**. FIG. 8 may be best understood with reference to FIGs. 1 and 7. Similar to the system **700** described in FIG. 7A, the system **800** incorporates glycol dehydration to reduce or eliminate the formation of acidic water droplets in the recycled exhaust gas stream. Instead of a separate vacuum regeneration system, however, the

system **800** of FIG. 8 incorporates a glycol regeneration section **730** within the cooling unit **134**, using the superheat of the compressed exhaust gas stream **136** to regenerate the glycol. In this manner, the external heating duty of the system **800** is reduced, although some additional heating via heat exchangers **720** may still be required.

5 [0073] While using the superheated inlet gas to the cooling unit to regenerate the glycol reduces the external heating duty in the system **800**, it also leads to potentially unacceptable glycol losses. Vaporized glycol in the regeneration section **730** is carried directly into the cooling section of the cooling unit **134**, where it may be condensed and removed in the water dropout stream **702**. The resulting costs associated with supplying make-up glycol may make
10 the configuration depicted in FIG. 8 undesirable in some situations. One way to address these potential glycol losses is shown in FIG. 9, which depicts another embodiment of the low emission power generation system **100** of FIG. 1, embodied as system **900**. FIG. 9 may be best understood with reference to FIGs. 1, 7, and 8. Similar to the system **800** described in FIG. 8, the system **900** incorporates glycol dehydration to reduce or eliminate the formation
15 of acidic water droplets in the recycled exhaust gas stream and includes a glycol regeneration section **730** within the cooling unit **134**. Additionally, however, the system **900** of FIG. 9 incorporates a desuperheating section **910** between the glycol regeneration section **730** and the cooling section in the cooling unit **134**. The desuperheating section **910** cools the exhaust gas to or near water saturation temperature and condenses most of the glycol, which is
20 removed from the desuperheating section **910** via condensed glycol stream **912** and added to lean glycol stream **714**. In such configurations, the desuperheating section **910** should be controlled so that large quantities of water do not condense along with the glycol. In one or more embodiments of the present invention, the total pressure drop from the blower **142** to the inlet of the main compressor **104** in the system **900** depicted in FIG. 9 is less than or equal
25 to about 2.0 psi, or less than or equal to about 1.5 psi, or less than or equal to about 1.0 psi.

30 [0074] It should be appreciated by those skilled in the art that, although glycol dehydration is exemplified and described with reference to FIGs. 7A, 8, and 9, any suitable dehydration method may be employed herein and is considered to be within the scope of the invention. For example, dehydration methods employing mole sieves or methanol may be used in place of the glycol dehydration described herein.

[0075] A further configuration that may be effective for reducing or eliminating the formation of acidic water droplets in the recycled exhaust gas stream is illustrated in FIG. 10, which depicts another embodiment of the low emission power generation system **100** of FIG.

1, embodied as system **1000**. FIG. 10 may be best understood with reference to FIG. 1. Unlike the configurations of FIGS. 7 through 9, the system **1000** of FIG. 10 does not employ dehydration of the exhaust gas but rather incorporates a feed/effluent exchanger **50** across the cooling unit **134** to achieve a desired dew point margin for the temperature of the cooled 5 recycle gas stream **140**. In one or more embodiments, the desired dew point margin of the cooled recycle gas stream may be about 50 °F, or about 45 °F, or about 40 °F, or about 35 °F, or about 30 °F, or about 25 °F, or about 20 °F, or about 15 °F above the dew point of the gas. The configuration depicted in FIG. 10 may result in an increase in the power consumption of 10 the blower **142** and the main compressor **104** due to a higher exhaust gas temperature compared to embodiments that use glycol dehydration. A benefit of the system **1000**, however, is that the configuration reduces the amount of required equipment, which accordingly results in lower capital costs and less complexity in the system.

EXAMPLES

Example 1

15 [0076] A study was performed to vary the exhaust gas recycle circuit of a low emission turbine. Several configurations corresponding to FIGS. 1-6 were simulated, and the results are reported in Table 1. The simulations and corresponding results are based on a single train case utilizing a frame 9FB combustion turbine generator (CTG) with air as the oxidant. The main air compressor (MAC) was assumed to be a single axial machine.

20 [0077] The following assumptions were used in all of the simulations of Example 1. The polytropic efficiency of the MAC was assumed to be 91% (no compressor curves used in simulation) and the polytropic efficiency of the exhaust gas blower was assumed to be 88.6%. The combustor outlet temperature and the expander inlet temperature were assumed to be 3200 °F and 2600 °F, respectively. The minimum DCC outlet temperature was assumed to 25 be 100 °F. The flue gas battery limit pressure was assumed to be 1900 psig.

[0078] CTG performance was predicted using correlations based on recycle compressor pressure ratio and recycle compressor exit volume. To ensure the predicted performance was within the known capabilities of the CTG, the following CTG limitations were maintained: maximum expander power = 588.5 MW, maximum shaft coupling torque (expander power – 30 compressor power) = 320 MW, maximum expander outlet Mach number = 0.8, maximum compressor inlet Mach number = 0.6, minimum compressor outlet flow = 126,500 actual

cubic feet per minute (acfm) to prevent stalling (compressor exit flow rate after coolant removed).

[0079] The simulation results are provided in Table 1 below.

Table 1

Configuration	FIG. 1	FIG. 2	FIG. 3	FIG. 4	FIG. 5	FIG. 6 (with 25 °F superheat)	FIG. 6 (with 40 °F superheat)
Heat rate (Btu/net kWh)	10,623	10,622	10,615	10,564	10,595	10,577	10,577
Fuel gas rate (MSCFD)	74	74	74	74	75	74	74
Fuel gas rate (MMBtu/hr)	2,994	3,004	3,004	3,004	3,047	3,011	2,992
Fuel gas, higher heating value (Btu/SCF)	975	975	975	975	975	975	975
Fuel gas, lower heating value (Btu/SCF)	878	878	878	878	878	878	878
Oxidant total flow rate (MSCFD)	695	698	698	698	708	700	695
CTG gross power production (MW)	580.5	580.5	580.5	580.6	594.5	592.8	593.0
Comb. turbine gen. loss and aux. load (MW)	6.9	6.9	6.9	6.9	7.1	7.1	7.1
STG gross power production (MW)	187.2	189.5	187.2	187.5	192.2	196.8	198.9
Exhaust gas recycle compression (MW)	263.4	263.3	263.3	263.4	274.0	282.2	286.9
Inert gas compression power req. (MW)	71.4	71.7	71.7	71.6	72.1	71.5	71.0
Air compression (MW)	126.9	126.7	126.7	126.7	129.6	127.8	127.1
Exhaust blower (MW)	11.6	13.1	10.6	9.9	11.8	12.2	13.0
Boiler feed water pump, est. (MW)	2.8	2.8	2.8	2.8	2.8	2.8	2.8
DCC Pump (MW)	2.6	2.5	2.5	2.0	1.3	1.1	1.1
Dehydration power req. (MW)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Net power export (MW)	281.9	282.8	283.0	284.4	287.6	284.7	282.8

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[0080] As shown in Table 1, the following results were observed, using the configuration of FIG. 1 as the base case for comparison. The configuration of FIG. 2 increases power production in the steam turbine generator (STG) by approximately 2 MW. However, this benefit may be offset by the higher power consumption of the EGR blower associated with a

10 higher suction temperature. The heat rate, power export and inert gas product are essentially identical to FIG. 1. The configuration of FIG. 3 reduces the EGR blower power consumption by approximately 1 MW. In the configuration of FIG. 4, the suction temperature to the EGR blower, and therefore blower power consumption, are reduced by cooling the flue gas against

cooling water in the HRSG. DCC water circulation is also lower as the cooling duty is reduced. The net effect is <1% reduction in the system heat rate. Due to the addition of cooling water coils to the back of the HRSG, higher metallurgy materials may be employed to handle the acidic water that condenses. In one or more embodiments, the HRSG may 5 include a drain for condensed liquids.

[0081] In the configurations of FIGs. 5 and 6, the suction temperature to the EGR blower, and therefore the relative blower power consumption, are reduced by cooling the flue gas against seawater in the HRSG. The power associated with pumping water to cool the exhaust gas is also reduced compared to FIG. 1. The net effect is <0.5% reduction in the system heat 10 rate. In the case of FIG. 6, the use of superheated gas entering the main compressor provides a potential cost savings for the DCC.

[0082] The overall results shown in Table 1 indicate that the options depicted by FIGs. 1 through 6 have a minor impact on the system heat rate. However, the options that consider elimination of the DCC may provide substantial capital cost savings. In particular, any 15 option that eliminates the DCC while still providing a superheated gas to the main compressor may save substantial capital cost. The opportunity for cost savings is improved if the superheat provided by blower compression (about 25 °F) is acceptable. Otherwise the addition of a large, low pressure gas heat exchanger may be utilized to achieve a 40 °F margin from the gas dew point.

20 *Example 2*

[0083] A second study was performed to vary the exhaust gas recycle circuit of a low emission turbine. Several configurations corresponding to FIGS. 7-10 were simulated, and the results are reported in Table 3, along with comparison to a base case having the configuration of FIG. 1. The simulations and corresponding results are based on a single 25 train case utilizing a frame 9FB combustion turbine generator (CTG) with air as the oxidant. The main air compressor (MAC) was assumed to be a single axial machine.

[0084] The following additional assumptions set forth in Table 2 were used in all of the simulations of Example 2.

Table 2

Polytropic efficiency of main compressor	86.14%
Polytropic efficiency of centrifugal booster	85.6%
Polytropic efficiency of EGR compressor (no compressor curves used in simulation)	92.5%
Polytropic efficiency of exhaust gas blower	88.6%
Combustor outlet temperature	3200 °F
Expander inlet temperature	2600 °F
Polytropic efficiency of expander	84.2%
Minimum DCC outlet temperature	100 °F
TEG absorber column pressure drop	0.4 psi
Total pressure drop from exhaust blower to main compressor	1 psi
Temperature approach for external heat source and cross exchangers	18 °F
Temperature of lean TEG returned to TEG absorption column (assuming 5 °F approach with seawater cooling)	98 °F
HRSG low pressure boiler approach temperature	22 °F
HRSG intermediate pressure boiler approach temperature	26 °F
HRSG high pressure boiler approach temperature	26 °F
HRSG high pressure economizer approach temperature	15 °F
For vacuum regeneration cases (Fig. 7a):	
Target reflux ratio of TEG regeneration column	0.1
Regeneration column pressure drop	0.2 psi
Temperature of overhead TEG regeneration gas recycled to exhaust gas blower	136 °F
Pressure drop of overhead TEG regeneration gas air coolers	1 psi

[0085] In addition to the above assumptions, in the vacuum regeneration cases it was also assumed that condensable gases were removed by cooling and separation before the steam 5 ejector and that the steam ejector was a single stage ejector with no interstage condenser. Rates for the steam ejector were based on design curves published by *DeFrate and Hoerl, Chem. Eng. Prog.*, 55, Symp. Ser. 21, 46 (1959).

[0086] After modifying the case specific variables, the fuel gas and air flow rates, diluent flow rates, and DCC outlet temperature/pressure were adjusted to achieve the EGR

compressor and expander volume limitations of 1.122×10^6 acfm and 3.865×10^6 acfm, respectively. Following this, the steam flow rates were adjusted to achieve consistent HRSG temperature approaches and a flue gas outlet temperature from the HRSG of about 200 °F.

[0087] The integrated regeneration dehydration cases with and without a desuperheater 5 were solved by adjusting the inlet temperature of the rich TEG to the regeneration section until the desired dew point was achieved for the specific TEG rate. In cases with a desuperheater, the desuperheater outlet temperature was controlled to be 5 °F above the dew point using cooling water flow. Numerous iterations are required to integrate the dehydrated gas return to the EGR compressor as the recycled exhaust gas composition changes.

[0088] The vacuum regeneration dehydration cases (i.e. cases with a separate regeneration column) were solved by selecting a starting reboiler temperature and then adjusting the vacuum pressure to achieve the desired dew point for the specific TEG rate. Alternately, a starting vacuum pressure may be selected and then the reboiler temperature adjusted to achieve the desired dew point. Once the vacuum pressure is determined, the 15 amount of steam required to achieve that vacuum must be calculated. Using the design curves for optimum single-stage ejectors, the steam entrainment ratio is determined to achieve the desired compression. This steam flow is incorporated into the simulation as a debit from the HRSG and a credit to the overhead flow. Numerous iterations are required to integrate both the non-condensed regeneration overhead back to the EGR booster and the 20 dehydrated gas return to the EGR compressor as the recycled exhaust gas composition changes.

[0089] The simulation results are provided in Table 3.

Table 3

Configuration	FIG. 1	FIG. 8	FIG. 8	FIG. 9	FIG. 8	FIG. 7A	FIG. 7A
Dew point suppression (°F)	--	40	40	40	30	40	40
TEG rate (gpm/lb H ₂ O)	--	5	2	2	2	3.5	2
Fuel gas rate, higher heating value (MMBtu/hr)	6,543	6,495	6,461	6,461	6,483	6,495	6,464
Heat rate, higher heating value (Btu/net kWh)	16,331	16,133	16,332	16,337	16,310	16,107	16,339
Annual TEG cost at \$9.47/gal (\$MM)	--	57.1	46.8	2.0	21.0	2.4	3.6
Flue gas (MSCFD)	1,337	1,327	1,320	1,320	1,325	1,327	1,321
Low pressure steam to desalination (1000 lb/hr)	3,247	3,216	3,247	3,247	3,247	3,220	3,245
Combustion turbine generator gross power production (MW)	1,148.6	1,140.0	1,149.8	1,149.8	1,149.7	1,148.4	1,150.2
Steam turbine generator gross power production (MW)	255.5	255.1	257.3	257.3	256.9	255.0	257.0
Exhaust gas recycle compression (MW)	538.0	528.8	549.2	549.2	546.2	537.0	548.9
Flue gas compression power requirement (MW)	146.0	146.6	142.7	142.7	143.5	145.2	142.8
Exhaust blower (MW)	16.8	14.7	19.8	19.8	18.8	16.2	19.9
Net power export (MW)	400.7	402.6	395.6	395.5	397.5	403.2	395.6

[0090] The overall simulation is generally unchanged by the specific vacuum pressure of the regeneration tower as long as the overhead cooling temperature and steam ejector are properly selected. As such, the power cycle data found in Table 3 applies regardless of the regeneration overhead cooling and external heat source temperatures. The selection of the 5 vacuum pressure, external heat source temperature and overhead cooling temperature is performed separately.

[0091] As shown in Table 3, the system heat rates are largely unaffected by the use of TEG dehydration in all of the evaluated configurations. Except for the case of FIG. 7A incorporating chilled water used to cool the cooling unit overhead, the heat rate of all of the 10 evaluated dehydration configurations varies less than about 1.4% from the base case (FIG. 1) without dehydration. The largest variation is found in the cases with higher TEG rates.

[0092] The overall effects of dehydration and the associated TEG flow rate are summarized in Table 4

Table 4

Trends	Temperature to EGR Compressor	Blower Power	Fuel Gas, Air, and Purge Rates	Water Removal / Working Fluid Density [*]	CTG Power	EGR Power	STG Power
Addition of Dehydration	↑	↑*	↓	↑	↑*	↑*	↑*
Increasing TEG Rate	↓	↓	↑	↑	↓	↓	↓

15

* general trend, some exceptions

[0093] In cases incorporating TEG dehydration, the gas temperature rise across the dehydration absorber increases the inlet temperature to the main compressor, resulting in additional power consumption and higher inlet actual cubic feet per minute (acf m). In order 20 to meet the main compressor inlet acf m limit, a higher inlet pressure is required. This increases the power consumption of the exhaust blower providing this pressure.

[0094] While the power consumption is increased to recycle warmer exhaust gas, it is counterbalanced by the removal of water from the exhaust gas prior to compression, as well as by lower fuel gas firing in the combustor. Water removal increases the density of the 25 circulating fluid, which increases the combustion turbine generator (CTG) power and the heat

recovery steam generator (HRSG) duty. The increase in density also lowers the inlet acfm to the main compressor, which then must be balanced by providing the gas at a higher inlet temperature or at a lower inlet pressure if the temperature rise alone is insufficient. Since the recycled exhaust gas is warmer, less fuel gas is required to reach temperature in the 5 combustor. Less fuel gas leads to lower compression power of both the combustion air compressor and the flue gas compressor, but also leads to about 1% lower flue gas production. This reduced power use as well as the lower fuel gas rate helps compensate for the higher power consumption in recycling the exhaust gas. Taken together, these effects result in TEG dehydration causing no substantial change in the system heat rate.

10 [0095] In the TEG dehydration configurations, dew point suppression is achieved by the TEG removing water from the exhaust gas stream. Additionally, there is also a temperature rise across the absorber which helps suppress the dew point at the outlet. In cases with higher TEG flows, a larger portion of heat is absorbed by the TEG itself, resulting in a lower gas temperature rise across the absorber. This means that less dew point suppression is provided 15 by the temperature rise and therefore additional water must be absorbed by the TEG. Accordingly, the system heat rate improves as the benefits of water removal increase, while the additional power required for the higher main compressor inlet temperature is mitigated. Power generation changes are minimal, but there is generally a small increase in both CTG and steam turbine generator (STG) power production. The increase in CTG power generation 20 is the result of higher inlet density and thus more mass flow through the expander. The density increase is explained in part by the lower water content, but it is also influenced by a higher pressure from the recycle compressor.

25 [0096] The increases in STG power generation at lower TEG rates are due to higher steam production in both the HRSG and purge gas waste heat boilers. The HRSG duty increases due to the higher temperature and mass flow of the flue gas to the HRSG. The combined purge gas boiler duties increase due to the higher purge gas temperature, which overcomes the lower flow. These increased duties offset the reduced duty in the combustion air boilers as well as any ejector steam used in the vacuum regeneration cases. However, as the TEG rate increases, ejector steam use increases while the flue and purge gas temperatures 30 decrease. Therefore, the STG power starts to decrease at higher TEG rates. The additional power involved in pumping the TEG at 2 gal TEG/ lb H₂O is approximately 0.7 MW, and at 5 gal TEG/ lb H₂O the additional power is approximately 1.7 MW. However, this power consumption does not have a significant impact on the heat rate.

[0097] To evaluate the differential cost associated with a specific dew point, dew point margins of 30 °F and 40 °F were evaluated for the configurations of FIGs. 7A and 8 at a TEG rate of 2 gal TEG/ lb H₂O. When the dew point margin is lowered, less water must be removed from the circulating TEG, reducing the reboiler duty and the overhead flow. The 5 resulting reboiler duty of the vacuum regeneration tower is decreased by 13% (38 MMBtu/hr) and the required external heating temperature decreases by 19 °F. The tower overhead cooling duty is decreased by 19.8% (39 MMBtu/hr) and the lean TEG cooling duty is decreased by 10.8% (26 MMBtu/hr). There is also a small (3.3%) decrease in the ejector steam load. Additionally, as less water is removed in the absorber, the gas temperature rise in 10 the absorber is also lower. With a lower gas temperature in the absorber overhead, less TEG is vaporized and carried on to the DCC. Therefore, TEG losses are reduced by 31%.

[0098] A higher TEG rate (gpm/lb H₂O) reduces the overhead temperature from the dehydration absorber and reduces the unrecoverable loss of TEG from the absorber overhead, but increases the external waste heat and cooling requirements. A higher TEG rate also 15 increases the ejector steam duty and waste water purge rates as more water is being removed. Additionally, in cases without a separate regeneration tower, TEG is vaporized in the DCC integrated regeneration section. Therefore, it may be preferable to minimize the TEG rate.

[0099] When TEG dehydration is employed, it is possible that the TEG may degrade in the presence of unreacted oxygen found in the recirculating gas leading to organic acid 20 formation, which lowers the pH of the TEG. As a result, there is the potential for accelerated corrosion of carbon steel components resulting from this pH decrease. For example, entrained TEG from the DCC overhead may be introduced into the main compressor. Without oxygen degradation, the TEG droplets typically have a pH of about 6.1. If oxygen degradation of the TEG occurs, the pH of the droplets will be reduced. Therefore, in one or 25 more embodiments of the present invention, an inhibited or buffered TEG (such as Norkool Desitherm, available commercially from The Dow Chemical Co.) may be used in order to reduce or eliminate the potential for corrosion as a result of this mechanism.

[0100] While the present disclosure may be susceptible to various modifications and alternative forms, the exemplary embodiments discussed above have been shown only by way of example. Any features or configurations of any embodiment described herein may be combined with any other embodiment or with multiple other embodiments (to the extent 5 feasible) and all such combinations are intended to be within the scope of the present invention. Additionally, it should be understood that the disclosure is not intended to be limited to the particular embodiments disclosed herein. Indeed, the present disclosure includes all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

CLAIMS

What is claimed is:

1. An integrated system comprising:

5 a gas turbine system comprising a combustion chamber configured to combust one or more oxidants and one or more fuels in the presence of a compressed recycle stream, wherein the combustion chamber directs a first discharge stream to an expander to generate a gaseous exhaust stream and at least partially drive a main compressor; and

an exhaust gas recirculation system, wherein the main compressor compresses the gaseous exhaust stream and thereby generates the compressed recycle stream;

10 wherein the exhaust gas recirculation system comprises at least one cooling unit configured to receive and cool the gaseous exhaust stream and at least one blower configured to receive and increase the pressure of the gaseous exhaust stream before directing a cooled recycle gas to the main compressor.

2. The system of claim 1, wherein the at least one cooling unit is a heat recovery steam generator (HRSG) configured to receive and cool the gaseous exhaust stream before introduction to the at least one blower.

3. The system of claim 2, wherein the exhaust gas recirculation system further comprises a second cooling unit configured to receive the gaseous exhaust stream from the at least one blower and further cool the gaseous exhaust stream to generate the cooled recycle gas.

20 4. The system of claim 3, wherein the second cooling unit comprises a direct contact cooler (DCC) section.

5. The system of claim 3, wherein the second cooling unit comprises a HRSG.

6. The system of claim 5, wherein the exhaust gas recirculation system further comprises a third cooling unit configured to receive the gaseous exhaust stream from the at least one blower and further cool the gaseous exhaust stream before introduction to the second cooling unit.

25 7. The system of claim 6, wherein the first cooling unit and the third cooling unit comprise HRSGs.

8. The system of claim 7, wherein the first cooling unit comprises a HRSG comprising a high pressure boiler section, an intermediate pressure boiler section, and a low pressure boiler section, and the third cooling unit comprises a HRSG comprising a low pressure boiler section and an economizer section.

5 9. The system of claim 2, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator configured to receive the gaseous exhaust stream from the cooling water coils of the HRSG and remove water droplets from the gaseous exhaust stream before introduction to the blower.

10. The system of claim 9 wherein the separator comprises a vane pack.

10 11. The system of claim 4, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator configured to receive the gaseous exhaust stream from the cooling water coils of the HRSG and remove water droplets from the gaseous exhaust stream before introduction to the blower.

12. The system of claim 11 wherein the separator comprises a vane pack.

15 13. The system of claim 3, wherein

the second cooling unit comprises a HRSG and each of the first and second cooling units further comprise cooling water coils; and

20 the exhaust gas recirculation system further comprises a first separator configured to receive the gaseous exhaust stream from the cooling water coils of the first cooling unit and remove water droplets from the gaseous exhaust stream before introduction to the blower and a second separator configured to receive the cooled recycle gas from the cooling water coils of the second cooling unit and remove water droplets from the cooled recycle gas before introduction to the main compressor.

14. The system of claim 13 wherein the first separator, the second separator, or both of
25 the first and second separators comprise a vane pack.

15. The system of claim 4, wherein the exhaust gas recirculation system employs psychrometric cooling of the gaseous exhaust stream.

16. The system of claim 15, wherein

30 water is added to the gaseous exhaust stream to saturate or nearly saturate the gaseous exhaust stream before introduction to the blower;

the exhaust gas recirculation system further comprises a separator configured to receive the saturated or nearly saturated gaseous exhaust stream and remove water droplets from the saturated or nearly saturated gaseous exhaust stream before introduction to the blower; and

5 the second cooling unit is further configured to remove water from the gaseous exhaust stream and recycle at least part of the water removed.

17. The system of claim 16, wherein a first portion of the water removed in the second cooling unit is recycled and added to the gaseous exhaust stream upstream of the separator and a second portion of the water removed in the second cooling unit is recycled to the 10 second cooling unit.

18. The system of claim 3, wherein the exhaust gas recirculation system further comprises a feed/effluent cross exchanger across the second cooling unit configured to adjust the temperature of the cooled recycle gas such that a dew point margin of at least about 20 °F is achieved.

15 19. The system of claim 18, wherein the dew point margin of the cooled recycle gas is at least about 30 °F.

20. The system of claim 4, wherein

the second cooling unit further comprises a glycol absorption section configured to receive the cooled recycle gas from the DCC section and at least partially dehydrate the 20 cooled recycle gas before introduction to the main compressor; and

the exhaust gas recirculation system further comprises a glycol regeneration system configured to receive rich glycol from the glycol absorption section of the second cooling unit, thermally regenerate the rich glycol in a glycol regeneration column to form regenerated lean glycol, and return the regenerated lean glycol to the glycol absorption section.

25 21. The system of claim 20, wherein the glycol regeneration system is operated under vacuum conditions.

22. The system of claim 20, wherein the second cooling unit comprises the glycol regeneration column and the glycol regeneration column is configured to receive the gaseous exhaust stream from the blower before introduction to the DCC section.

23. The system of claim 22, wherein the second cooling unit further comprises a desuperheating section positioned between the glycol regeneration column and the DCC section.

24. The system of claim 1, wherein the combustion chamber is configured to combust one or more oxidants and one or more fuels in the presence of a compressed recycle stream and a high pressure steam coolant stream.

25. A method of generating power, comprising:

combusting at least one oxidant and at least one fuel in a combustion chamber in the presence of a compressed recycle exhaust gas, thereby generating a discharge stream;

10 expanding the discharge stream in an expander to at least partially drive a main compressor and generate a gaseous exhaust stream; and

directing the gaseous exhaust stream to an exhaust gas recirculation system, wherein the main compressor compresses the gaseous exhaust stream and thereby generates the compressed recycle stream;

15 wherein the exhaust gas recirculation system comprises at least one cooling unit and at least one blower, such that the gaseous exhaust stream is cooled in at least one cooling unit and the pressure of the gaseous exhaust stream is increased in the at least one blower, thereby generating a cooled recycle gas directed to the main compressor.

26. The method of claim 25, wherein the at least one cooling unit is a heat recovery steam generator (HRSG) that cools the gaseous exhaust stream before the gaseous exhaust stream is introduced to the at least one blower.

27. The method of claim 26, wherein the exhaust gas recirculation system further comprises a second cooling unit that receives the gaseous exhaust stream from the at least one blower and further cools the gaseous exhaust stream, thereby generating the cooled recycle gas.

28. The method of claim 27, wherein the second cooling unit comprises a direct contact cooler (DCC) section.

29. The method of claim 27, wherein the second cooling unit comprises a HRSG.

30. The method of claim 29, wherein the exhaust gas recirculation system further comprises a third cooling unit that receives the gaseous exhaust stream from the at least one

blower and further cools the gaseous exhaust stream before the gaseous exhaust stream is introduced to the second cooling unit.

31. The method of claim 30, wherein the first cooling unit and the third cooling unit comprise HRSGs.

5 32. The method of claim 31, wherein the first cooling unit comprises a HRSG comprising a high pressure boiler section, an intermediate pressure boiler section, and a low pressure boiler section, and the third cooling unit comprises a HRSG comprising a low pressure boiler section and an economizer section.

10 33. The method of claim 26, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator that receives the gaseous exhaust stream from the cooling water coils of the HRSG and removes water droplets from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower.

34. The method of claim 33 wherein the separator comprises a vane pack.

15 35. The method of claim 29, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator that receives the gaseous exhaust stream from the cooling water coils of the HRSG and removes water droplets from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower.

20 36. The method of claim 35 wherein the separator comprises a vane pack.

37. The method of claim 27, wherein

the second cooling unit comprises a HRSG and each of the first and second cooling units further comprise cooling water coils; and

the exhaust gas recirculation system further comprises:

25 a first separator that receives the gaseous exhaust stream from the cooling water coils of the first cooling unit and removes water droplets from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower; and

30 a second separator that receives the cooled recycle gas from the cooling water coils of the second cooling unit and removes water droplets from the cooled recycle gas before the cooled recycle gas is introduced to the main compressor.

38. The method of claim 37 wherein the first separator, the second separator, or both of the first and second separators comprise a vane pack.

39. The method of claim 27, wherein the exhaust gas recirculation system employs psychrometric cooling to further cool the gaseous exhaust stream.

5 40. The method of claim 39, wherein

the gaseous exhaust stream is saturated or nearly saturated with water before the gaseous exhaust stream is introduced to the blower;

10 the exhaust gas recirculation system further comprises a separator that receives the saturated or nearly saturated gaseous exhaust stream and removes water droplets from the saturated or nearly saturated gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower; and

the second cooling unit removes water from the gaseous exhaust stream and at least part of the water removed by the second cooling unit is recycled.

15 41. The method of claim 40, wherein a first portion of the water removed by the second cooling unit is recycled and added to the gaseous exhaust stream upstream of the separator and a second portion of the water removed in the second cooling unit is recycled to the second cooling unit.

20 42. The method of claim 27, wherein a dew point margin of at least about 20 °F is achieved in the cooled recycle gas by modifying the temperature of the cooled recycle gas in a feed/effluent cross exchanger across the second cooling unit.

43. The method of claim 42, wherein the dew point margin of the cooled recycle gas is at least about 30 °F.

44. The method of claim 28, wherein

25 the second cooling unit further comprises a glycol absorption section that receives the cooled recycle gas from the DCC section and at least partially dehydrates the cooled recycle gas before the cooled recycle gas is introduced to the main compressor; and

30 the exhaust gas recirculation system further comprises a glycol regeneration system that receives rich glycol from the glycol absorption section of the second cooling unit, thermally regenerates the rich glycol in a glycol regeneration column to form regenerated lean glycol, and returns the regenerated lean glycol to the glycol absorption section.

45. The method of claim 44, wherein the glycol regeneration system is operated under vacuum conditions.

46. The method of claim 45, wherein the second cooling unit comprises the glycol regeneration column and the glycol regeneration column receives the gaseous exhaust stream 5 from the blower before the gaseous exhaust stream is introduced to the DCC section.

47. The method of claim 46, wherein the second cooling unit further comprises a desuperheating section receives the gaseous exhaust stream from the glycol regeneration column and cools the gaseous exhaust stream to a temperature sufficient to at least partially condense glycol from the gaseous exhaust stream before the gaseous exhaust stream is 10 introduced to the DCC section.

48. The method of claim 25, wherein the at least one oxidant and the at least one fuel are combusted in the combustion chamber in the presence of the compressed recycle exhaust gas and high pressure steam.

49. The system of claim 1, wherein the compressed recycle stream includes a steam 15 coolant, which supplements or replaces the gaseous exhaust stream.

50. The system of claim 49, further comprising a water recycle loop to provide the steam coolant.

51. The method of claim 25, further comprising adding a steam coolant to the compressed recycle stream to supplement or replace the gaseous exhaust stream.

20 52. The method of claim 51, further comprising a water recycle loop to provide the steam coolant.

AMENDED CLAIMS

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1. An integrated system comprising:

a gas turbine system comprising a combustion chamber configured to combust one or more oxidants and one or more fuels in the presence of a compressed recycle stream, wherein the combustion chamber directs a first discharge stream to an expander to generate a gaseous exhaust stream and at least partially drive a main compressor; and

an exhaust gas recirculation system, wherein the main compressor compresses the gaseous exhaust stream and thereby generates the compressed recycle stream;

wherein the exhaust gas recirculation system comprises at least one cooling unit configured to receive and cool the gaseous exhaust stream and at least one blower configured to receive and increase the pressure of the gaseous exhaust stream before directing a cooled recycle gas to the main compressor.

2. The system of claim 1, wherein the at least one cooling unit is a heat recovery steam generator (HRSG) configured to receive and cool the gaseous exhaust stream before introduction to the at least one blower.

3. The system of claim 2, wherein the exhaust gas recirculation system further comprises a second cooling unit configured to receive the gaseous exhaust stream from the at least one blower and further cool the gaseous exhaust stream to generate the cooled recycle gas.

4. The system of claim 3, wherein the second cooling unit comprises a direct contact cooler (DCC) section.

5. The system of claim 3, wherein the second cooling unit comprises a HRSG.

6. The system of claim 5, wherein the exhaust gas recirculation system further comprises a third cooling unit configured to receive the gaseous exhaust stream from the at least one blower and further cool the gaseous exhaust stream before introduction to the second cooling unit.

7. The system of claim 6, wherein the first cooling unit and the third cooling unit comprise HRSGs.

8. The system of claim 7, wherein the first cooling unit comprises a HRSG comprising a high pressure boiler section, an intermediate pressure boiler section, and a low pressure boiler section, and the third cooling unit comprises a HRSG comprising a low pressure boiler section and an economizer section.

9. The system of claim 2, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator configured to receive the gaseous exhaust stream from the cooling water coils of the HRSG and remove water droplets from the gaseous exhaust stream before introduction to the blower.
10. The system of claim 9 wherein the separator comprises a vane pack.
11. The system of claim 4, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator configured to receive the gaseous exhaust stream from the cooling water coils of the HRSG and remove water droplets from the gaseous exhaust stream before introduction to the blower.
12. The system of claim 11 wherein the separator comprises a vane pack.
13. The system of claim 3, wherein
 - the second cooling unit comprises a HRSG and each of the first and second cooling units further comprise cooling water coils; and
 - the exhaust gas recirculation system further comprises a first separator configured to receive the gaseous exhaust stream from the cooling water coils of the first cooling unit and remove water droplets from the gaseous exhaust stream before introduction to the blower and a second separator configured to receive the cooled recycle gas from the cooling water coils of the second cooling unit and remove water droplets from the cooled recycle gas before introduction to the main compressor.
14. The system of claim 13 wherein the first separator, the second separator, or both of the first and second separators comprise a vane pack.
15. The system of claim 4, wherein the exhaust gas recirculation system employs psychrometric cooling of the gaseous exhaust stream.
16. The system of claim 15, wherein
 - water is added to the gaseous exhaust stream to saturate or nearly saturate the gaseous exhaust stream before introduction to the blower;
 - the exhaust gas recirculation system further comprises a separator configured to receive the saturated or nearly saturated gaseous exhaust stream and remove water droplets from the saturated or nearly saturated gaseous exhaust stream before introduction to the blower; and

the second cooling unit is further configured to remove water from the gaseous exhaust stream and recycle at least part of the water removed.

17. The system of claim 16, wherein a first portion of the water removed in the second cooling unit is recycled and added to the gaseous exhaust stream upstream of the separator and a second portion of the water removed in the second cooling unit is recycled to the second cooling unit.

18. The system of claim 3, wherein the exhaust gas recirculation system further comprises a feed/effluent cross exchanger across the second cooling unit configured to adjust the temperature of the cooled recycle gas such that a dew point margin of at least about 20 °F is achieved.

19. The system of claim 18, wherein the dew point margin of the cooled recycle gas is at least about 30 °F.

20. The system of claim 4, wherein

the second cooling unit further comprises a glycol absorption section configured to receive the cooled recycle gas from the DCC section and at least partially dehydrate the cooled recycle gas before introduction to the main compressor; and

the exhaust gas recirculation system further comprises a glycol regeneration system configured to receive rich glycol from the glycol absorption section of the second cooling unit, thermally regenerate the rich glycol in a glycol regeneration column to form regenerated lean glycol, and return the regenerated lean glycol to the glycol absorption section.

21. The system of claim 20, wherein the glycol regeneration system is operated under vacuum conditions.

22. The system of claim 20, wherein the second cooling unit comprises the glycol regeneration column and the glycol regeneration column is configured to receive the gaseous exhaust stream from the blower before introduction to the DCC section.

23. The system of claim 22, wherein the second cooling unit further comprises a desuperheating section positioned between the glycol regeneration column and the DCC section.

24. The system of claim 1, wherein the combustion chamber is configured to combust one or more oxidants and one or more fuels in the presence of a compressed recycle stream and a high pressure steam coolant stream.

25. A method of generating power, comprising:

combusting at least one oxidant and at least one fuel in a combustion chamber in the presence of a compressed recycle exhaust gas, thereby generating a discharge stream;

expanding the discharge stream in an expander to at least partially drive a main compressor and generate a gaseous exhaust stream; and

directing the gaseous exhaust stream to an exhaust gas recirculation system, wherein the main compressor compresses the gaseous exhaust stream and thereby generates the compressed recycle stream;

wherein the exhaust gas recirculation system comprises at least one cooling unit and at least one blower, such that the gaseous exhaust stream is cooled in at least one cooling unit and the pressure of the gaseous exhaust stream is increased in the at least one blower, thereby generating a cooled recycle gas directed to the main compressor.

26. The method of claim 25, wherein the at least one cooling unit is a heat recovery steam generator (HRSG) that cools the gaseous exhaust stream before the gaseous exhaust stream is introduced to the at least one blower.

27. The method of claim 26, wherein the exhaust gas recirculation system further comprises a second cooling unit that receives the gaseous exhaust stream from the at least one blower and further cools the gaseous exhaust stream, thereby generating the cooled recycle gas.

28. The method of claim 27, wherein the second cooling unit comprises a direct contact cooler (DCC) section.

29. The method of claim 27, wherein the second cooling unit comprises a HRSG.

30. The method of claim 29, wherein the exhaust gas recirculation system further comprises a third cooling unit that receives the gaseous exhaust stream from the at least one blower and further cools the gaseous exhaust stream before the gaseous exhaust stream is introduced to the second cooling unit.

31. The method of claim 30, wherein the first cooling unit and the third cooling unit comprise HRSGs.

32. The method of claim 31, wherein the first cooling unit comprises a HRSG comprising a high pressure boiler section, an intermediate pressure boiler section, and a low pressure boiler section, and the third cooling unit comprises a HRSG comprising a low pressure boiler section and an economizer section.

33. The method of claim 26, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator that receives the gaseous exhaust stream from the cooling water coils of the HRSG and removes water droplets from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower.

34. The method of claim 33 wherein the separator comprises a vane pack.

35. The method of claim 29, wherein the HRSG further comprises cooling water coils and wherein the exhaust gas recirculation system further comprises a separator that receives the gaseous exhaust stream from the cooling water coils of the HRSG and removes water droplets from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower.

36. The method of claim 35 wherein the separator comprises a vane pack.

37. The method of claim 27, wherein

the second cooling unit comprises a HRSG and each of the first and second cooling units further comprise cooling water coils; and

the exhaust gas recirculation system further comprises:

a first separator that receives the gaseous exhaust stream from the cooling water coils of the first cooling unit and removes water droplets from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower; and

a second separator that receives the cooled recycle gas from the cooling water coils of the second cooling unit and removes water droplets from the cooled recycle gas before the cooled recycle gas is introduced to the main compressor.

38. The method of claim 37 wherein the first separator, the second separator, or both of the first and second separators comprise a vane pack.

39. The method of claim 27, wherein the exhaust gas recirculation system employs psychrometric cooling to further cool the gaseous exhaust stream.

40. The method of claim 39, wherein

the gaseous exhaust stream is saturated or nearly saturated with water before the gaseous exhaust stream is introduced to the blower;

the exhaust gas recirculation system further comprises a separator that receives the saturated or nearly saturated gaseous exhaust stream and removes water droplets from the saturated or nearly saturated gaseous exhaust stream before the gaseous exhaust stream is introduced to the blower; and

the second cooling unit removes water from the gaseous exhaust stream and at least part of the water removed by the second cooling unit is recycled.

41. The method of claim 40, wherein a first portion of the water removed by the second cooling unit is recycled and added to the gaseous exhaust stream upstream of the separator and a second portion of the water removed in the second cooling unit is recycled to the second cooling unit.

42. The method of claim 27, wherein a dew point margin of at least about 20 °F is achieved in the cooled recycle gas by modifying the temperature of the cooled recycle gas in a feed/effluent cross exchanger across the second cooling unit.

43. The method of claim 42, wherein the dew point margin of the cooled recycle gas is at least about 30 °F.

44. The method of claim 28, wherein

the second cooling unit further comprises a glycol absorption section that receives the cooled recycle gas from the DCC section and at least partially dehydrates the cooled recycle gas before the cooled recycle gas is introduced to the main compressor; and

the exhaust gas recirculation system further comprises a glycol regeneration system that receives rich glycol from the glycol absorption section of the second cooling unit, thermally regenerates the rich glycol in a glycol regeneration column to form regenerated lean glycol, and returns the regenerated lean glycol to the glycol absorption section.

45. The method of claim 44, wherein the glycol regeneration system is operated under vacuum conditions.

46. The method of claim 45, wherein the second cooling unit comprises the glycol regeneration column and the glycol regeneration column receives the gaseous exhaust stream from the blower before the gaseous exhaust stream is introduced to the DCC section.

47. The method of claim 46, wherein the second cooling unit further comprises a desuperheating section receives the gaseous exhaust stream from the glycol regeneration column and cools the gaseous exhaust stream to a temperature sufficient to at least partially condense glycol from the gaseous exhaust stream before the gaseous exhaust stream is introduced to the DCC section.

48. The method of claim 25, wherein the at least one oxidant and the at least one fuel are combusted in the combustion chamber in the presence of the compressed recycle exhaust gas and high pressure steam.

49. The system of claim 1, wherein the compressed recycle stream includes a steam coolant, which supplements or replaces the gaseous exhaust stream.

50. The system of claim 49, further comprising a water recycle loop to provide the steam coolant.

51. The method of claim 25, further comprising adding a steam coolant to the compressed recycle stream to supplement or replace the gaseous exhaust stream.

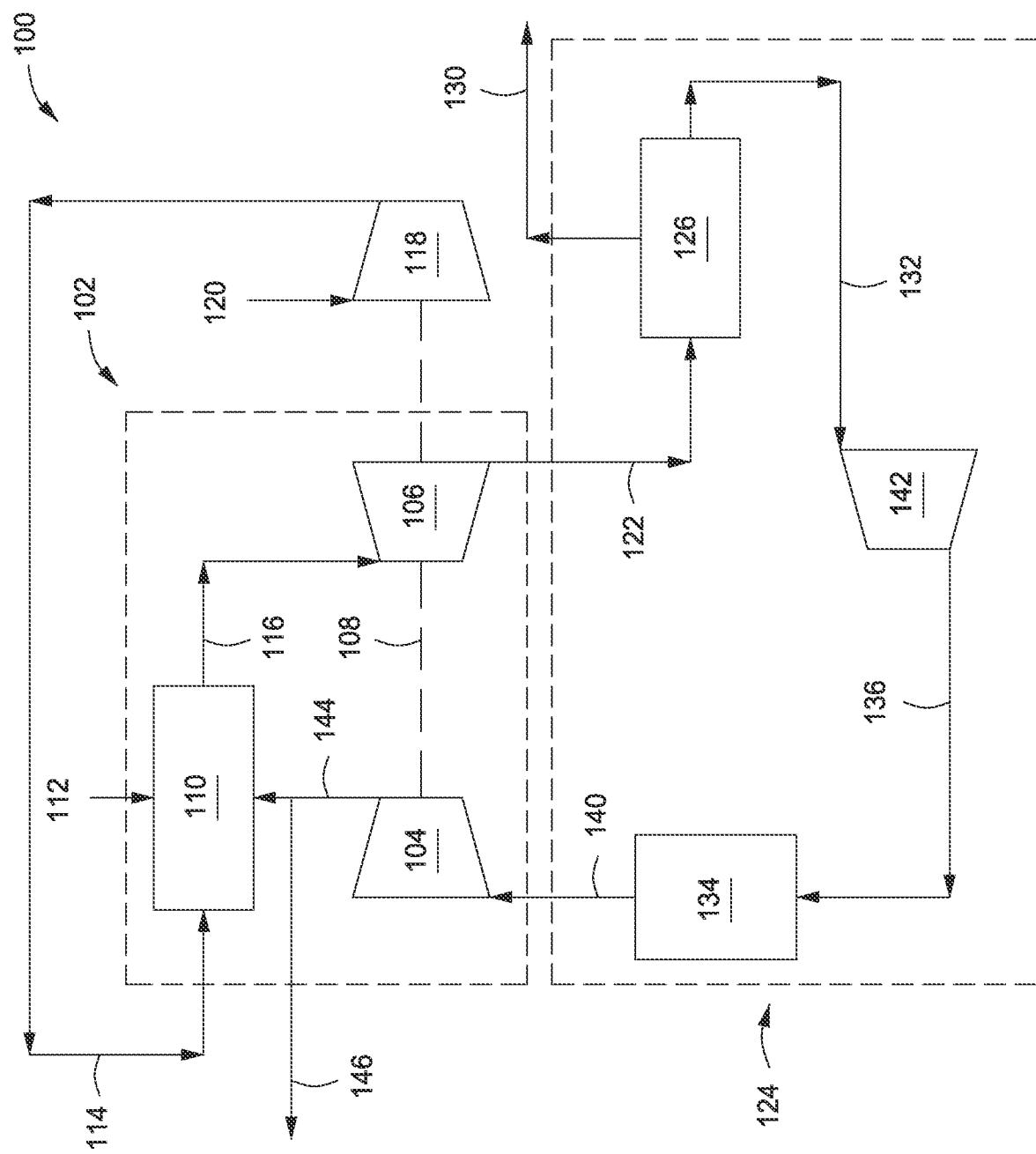
52. The method of claim 51, further comprising a water recycle loop to provide the steam coolant.

53. The integrated system of claim 1, wherein the one or more oxidants and the one or more fuels are combusted substantially stoichiometrically in a reaction having an equivalence ratio from about 0.9 : 1 to about 1.1 : 1.

54. The method of generating power of claim 25, wherein the at least one oxidant and at least one fuel are combusted substantially stoichiometrically in a reaction having an equivalence ratio from about 0.9 : 1 to about 1.1 : 1.

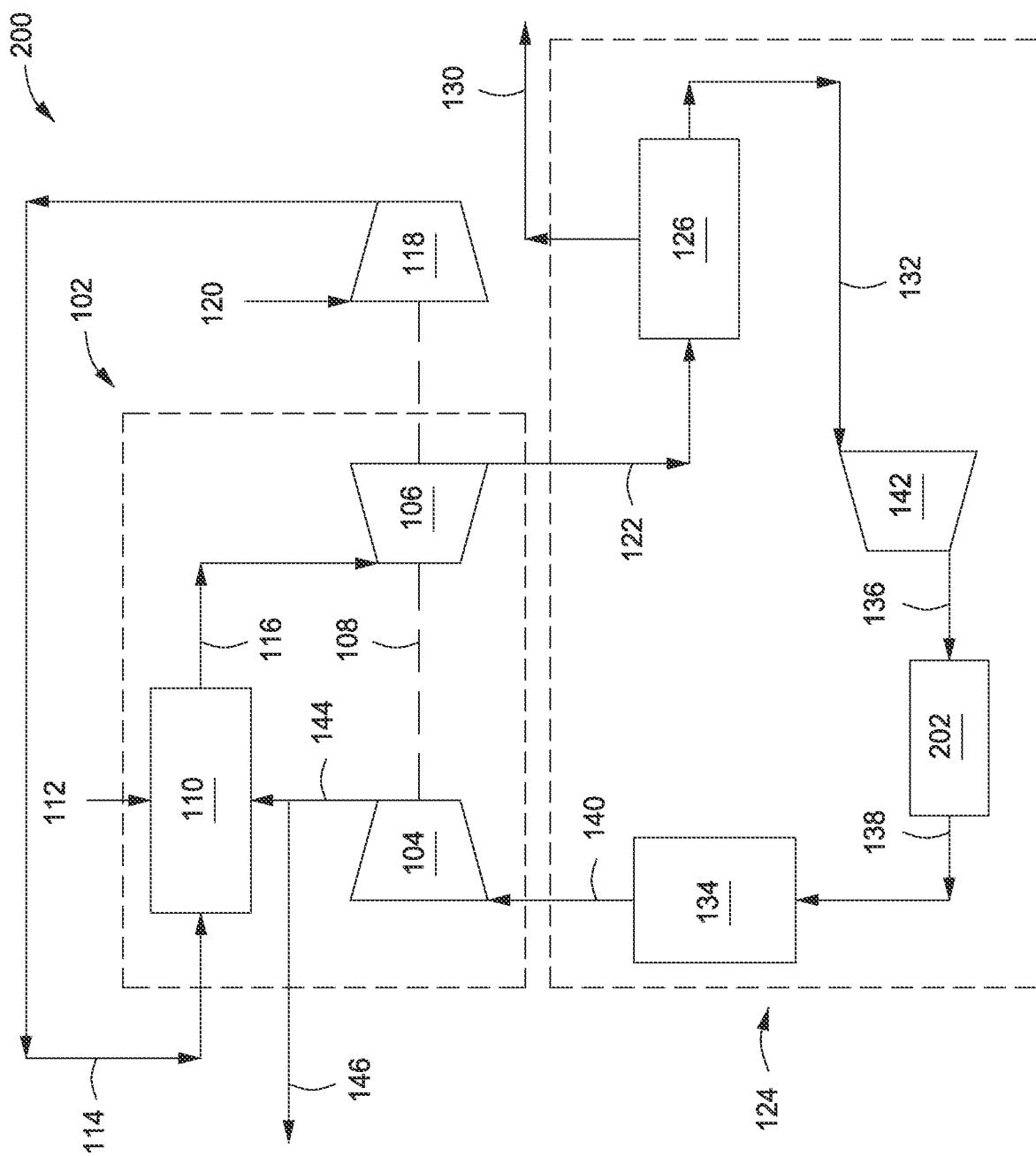
1/12

FIG. 1



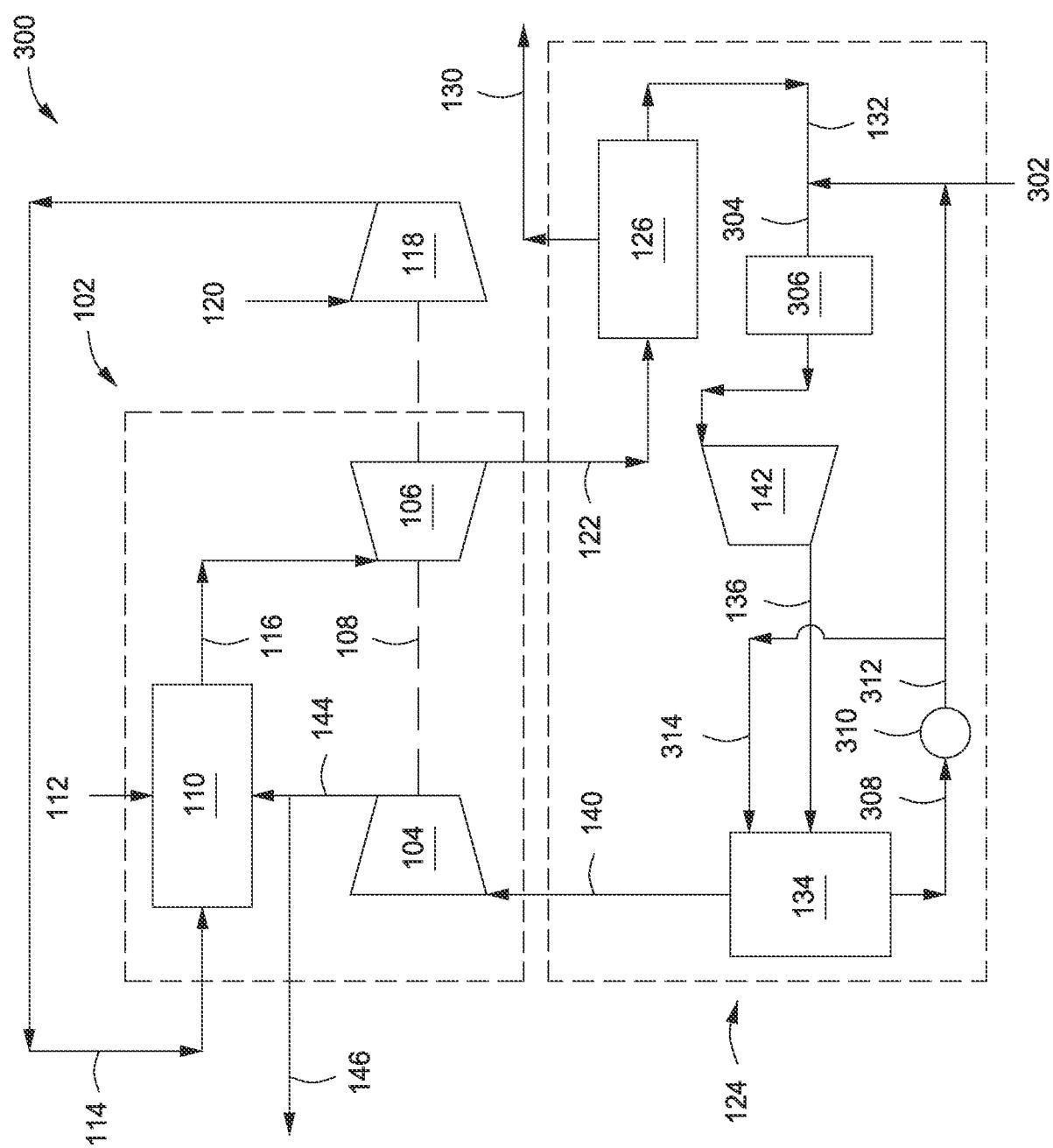
2/12

FIG. 2



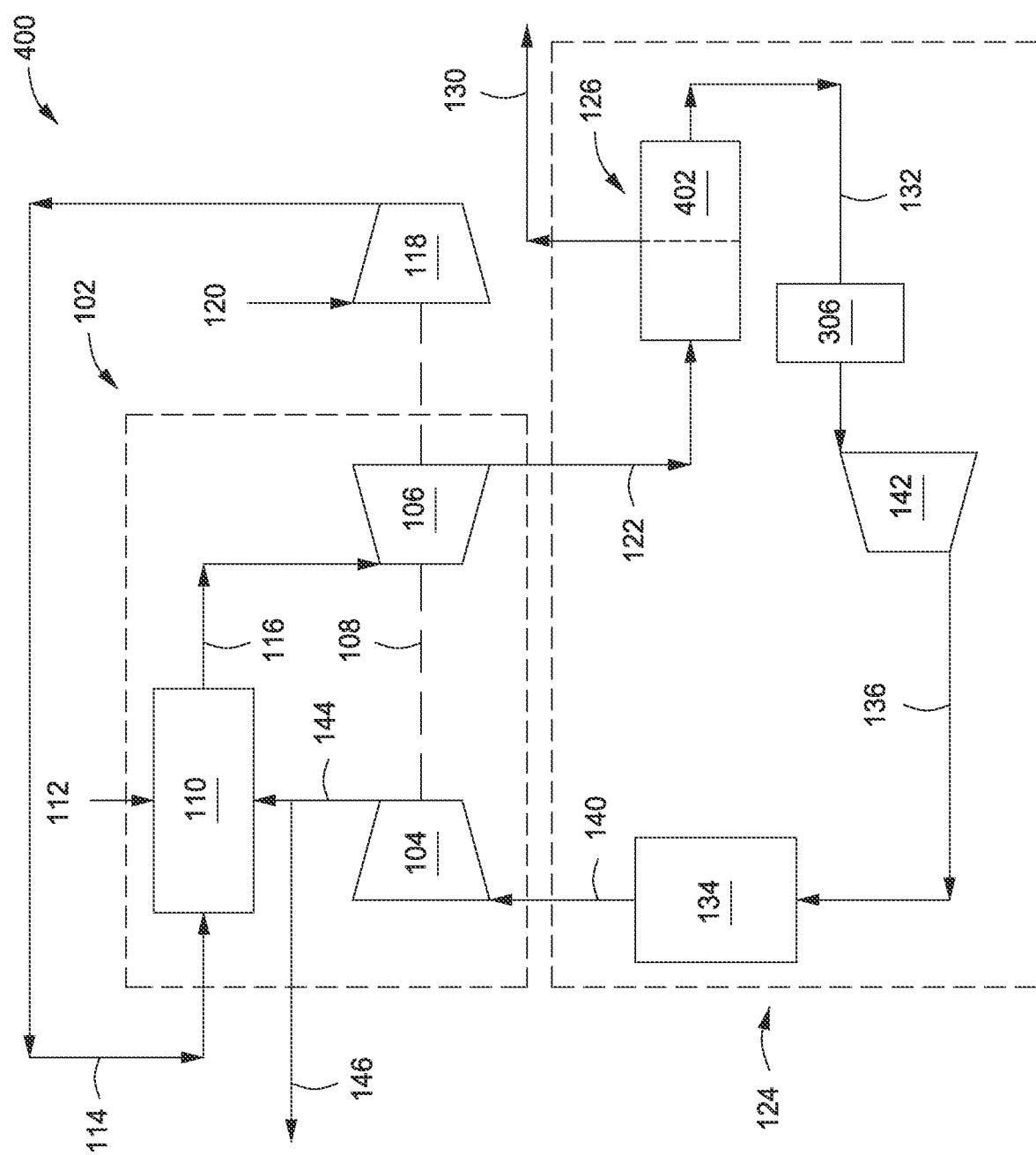
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FIG. 3



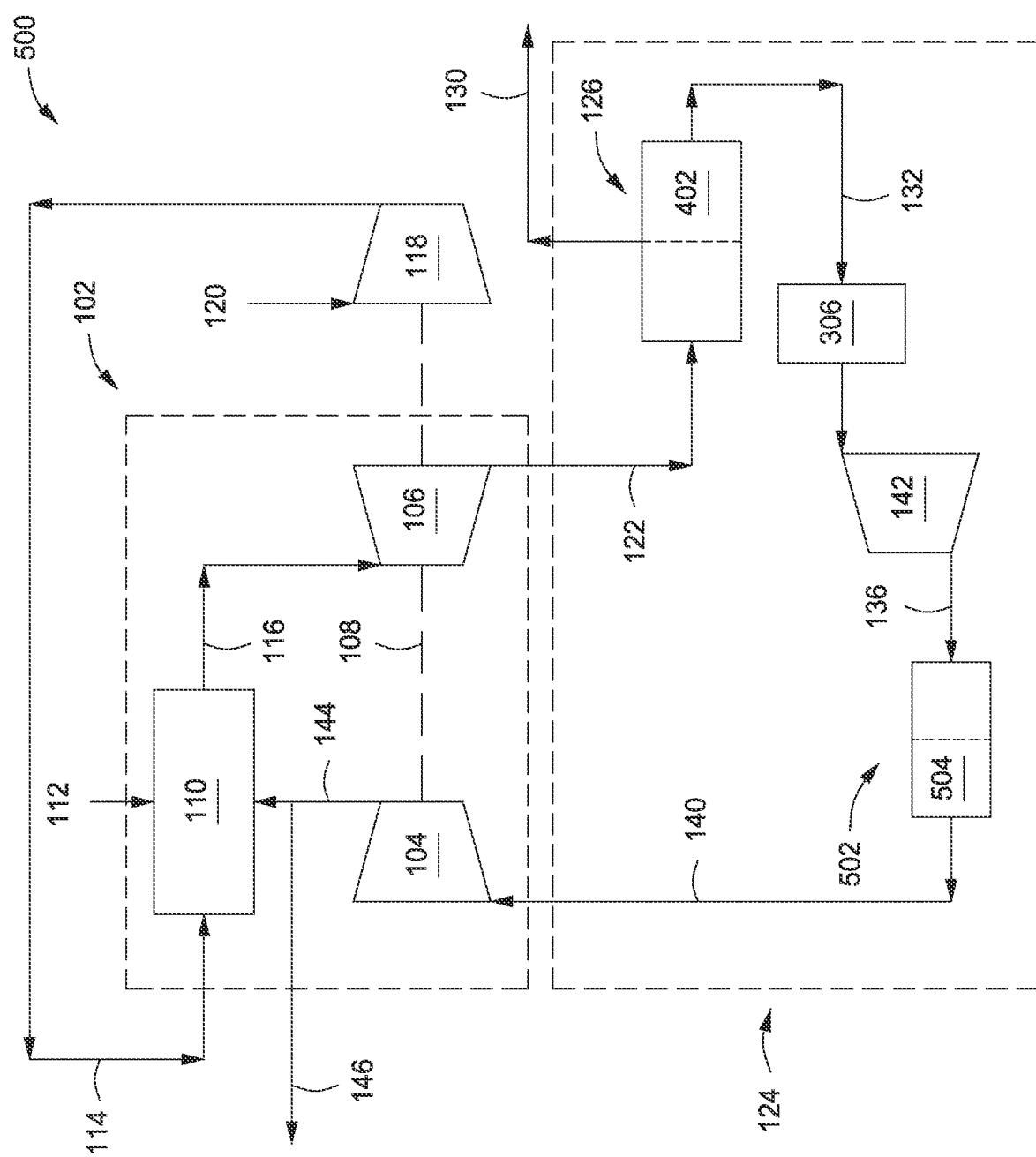
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FIG. 4



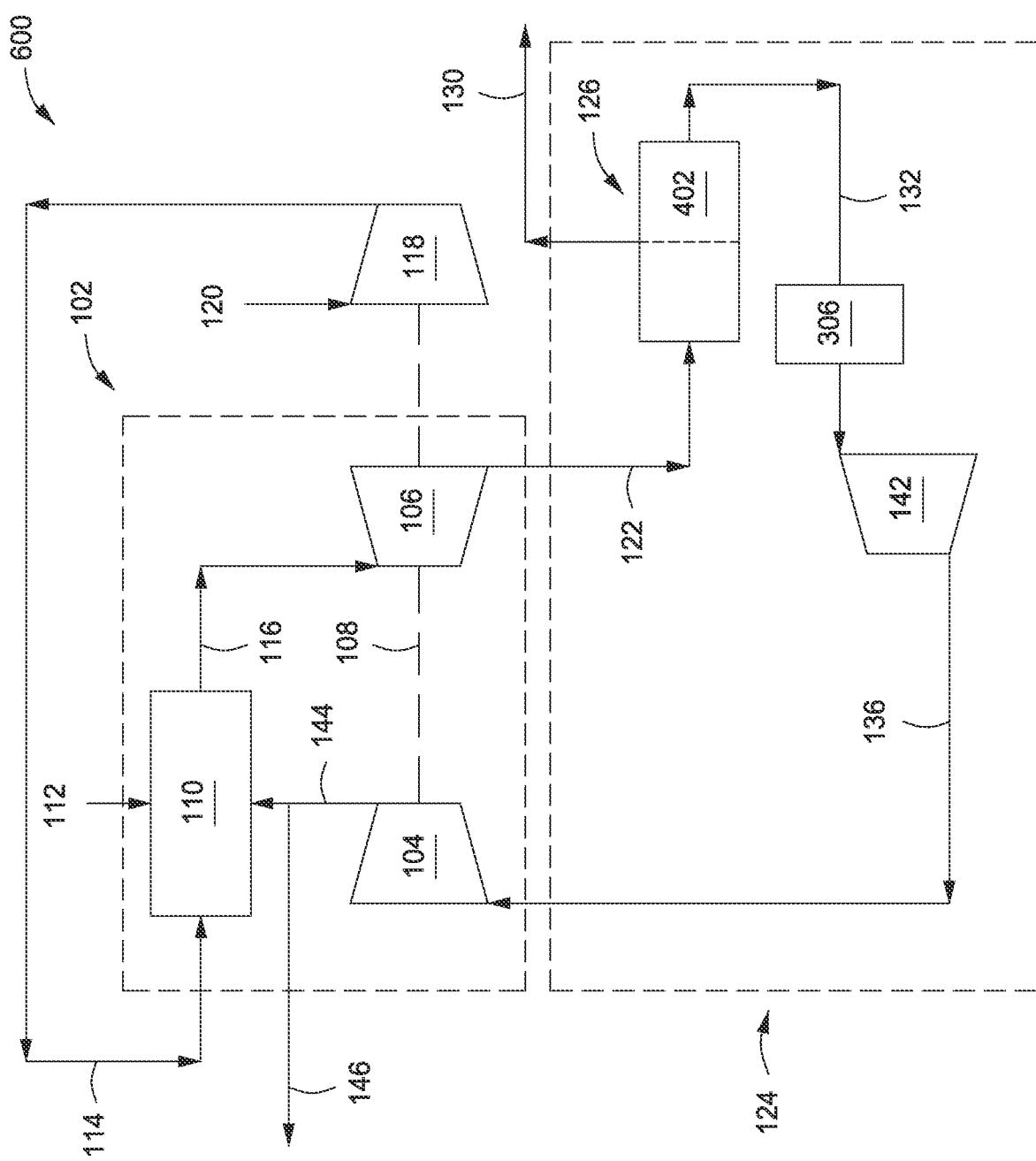
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FIG. 5



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FIG. 6



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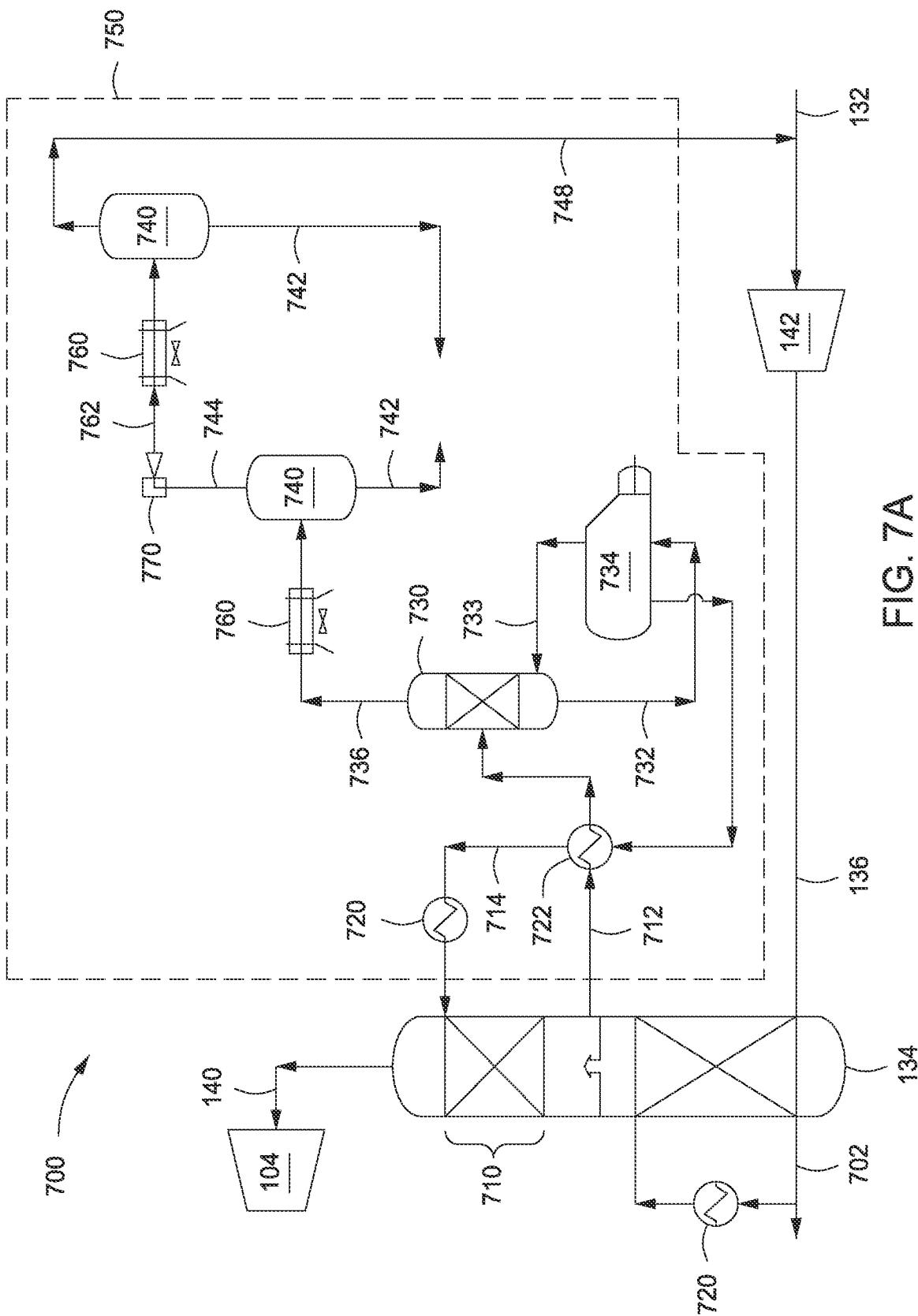


FIG. 7A

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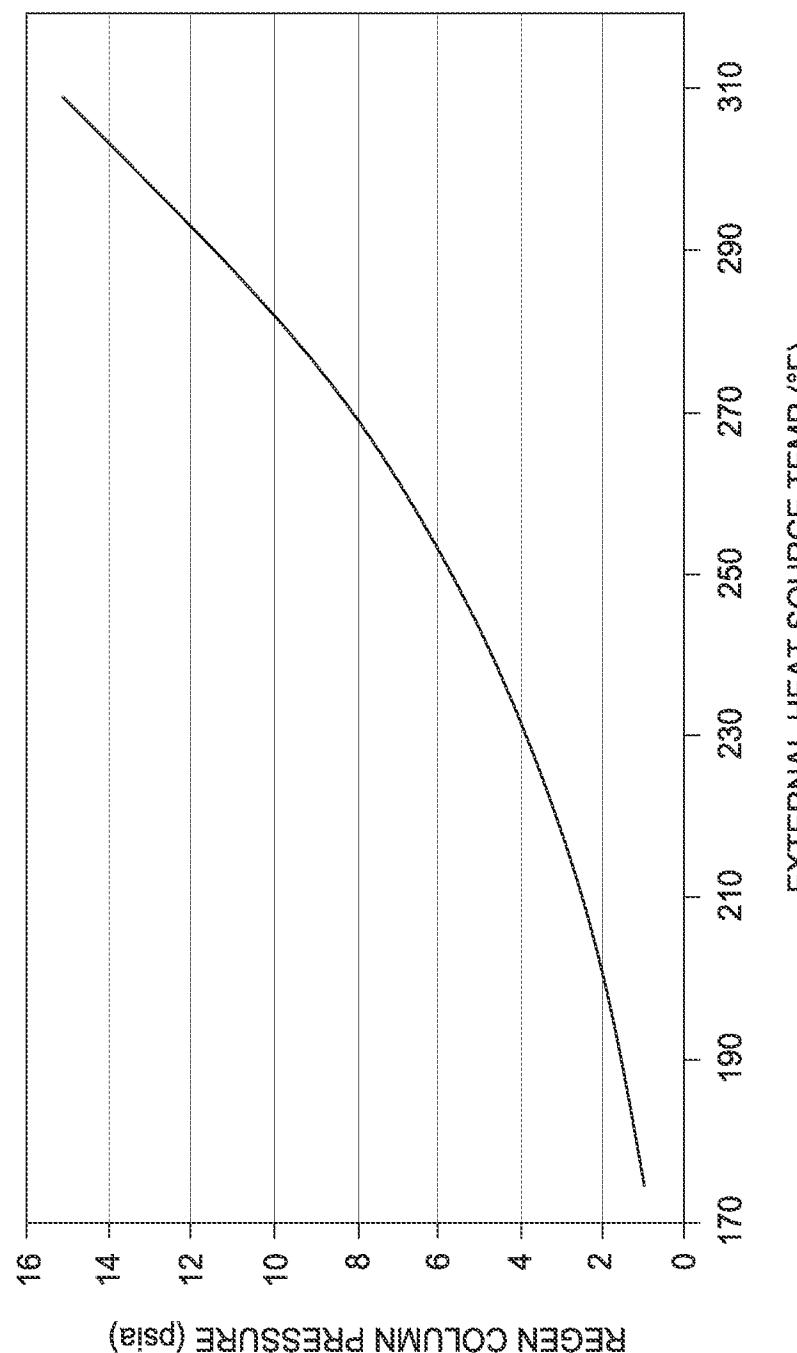


FIG. 7B

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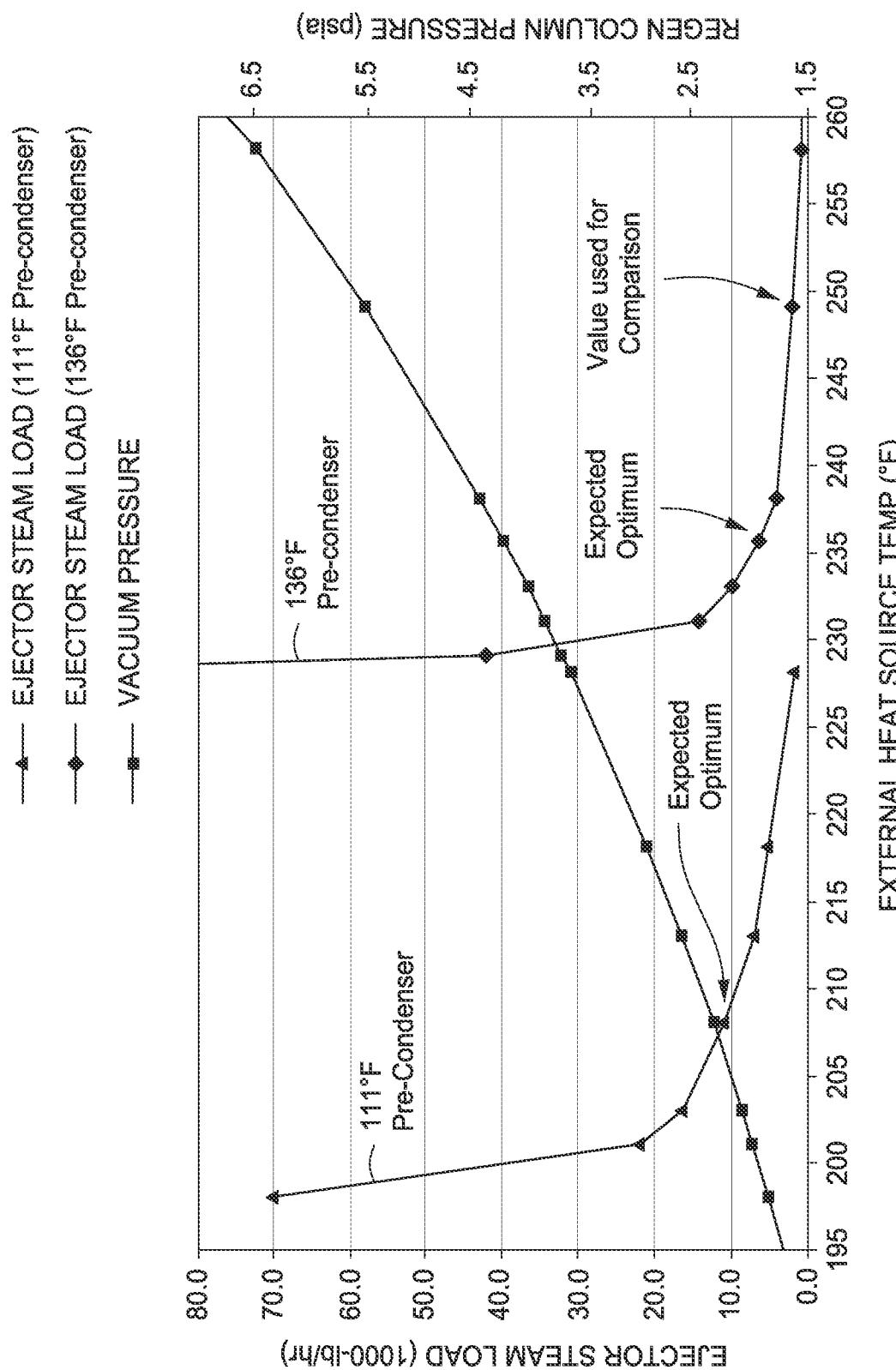


FIG. 7C

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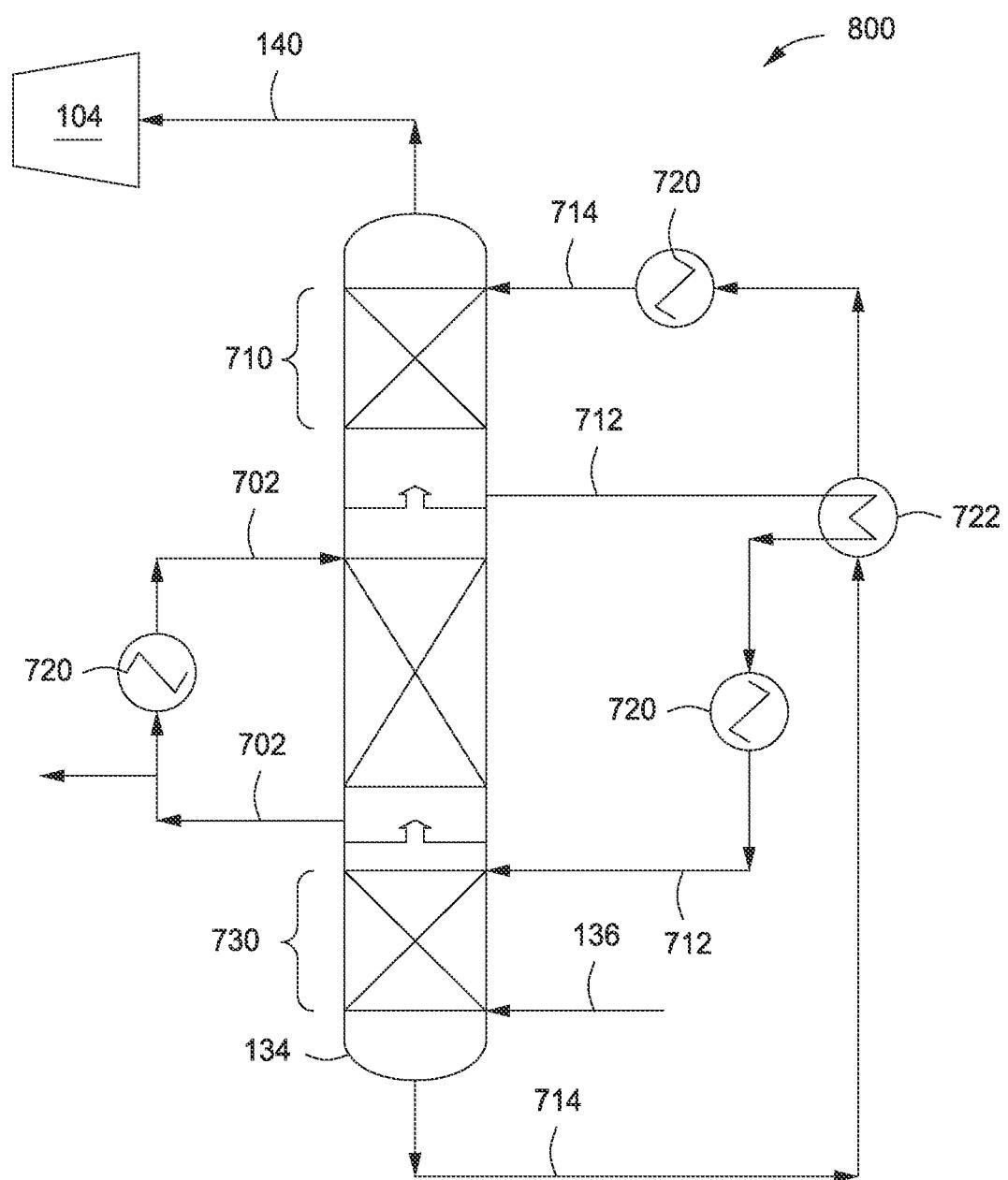


FIG. 8

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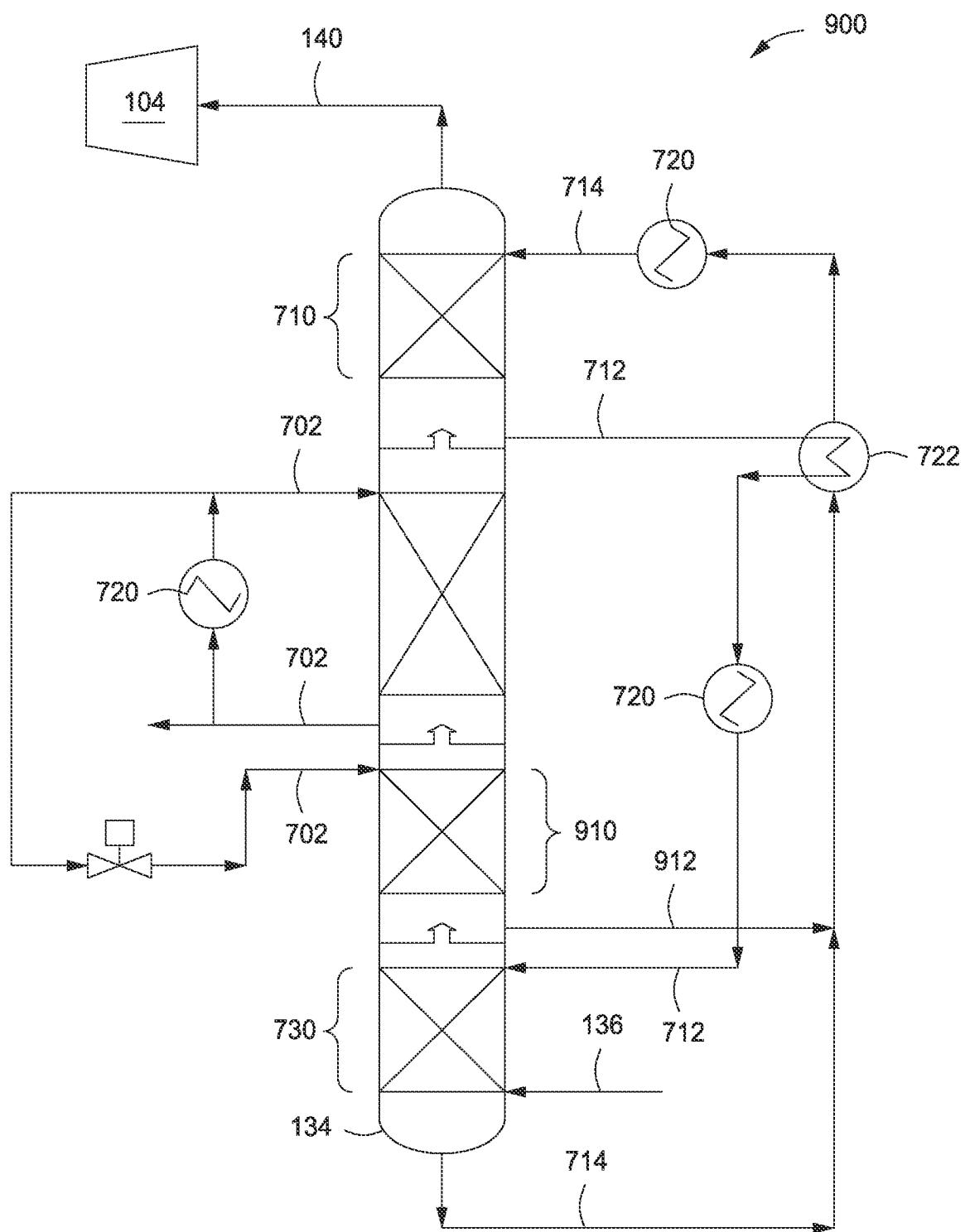


FIG. 9

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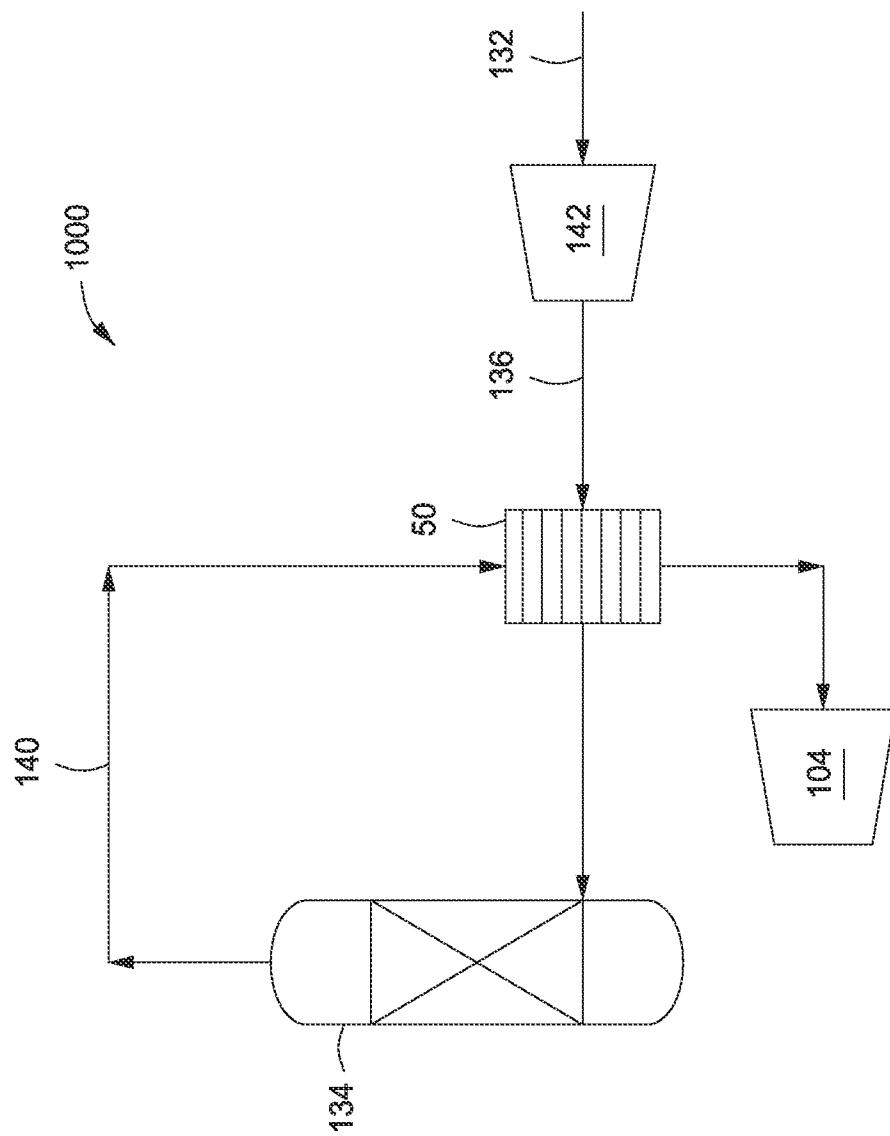


FIG. 10

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F02G 1/00 (2012.01)

USPC - 60/39.52

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)

USPC - 60/39.52

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

USPC - 123/568.11, 568.12, 568.15, 568.21, 568.22, 568.31;

60/39.01, 39.5, 39.52, 39.53

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 PubWEST - turbine, compressor, expander, carbon dioxide, CO₂, steam generator, psychrometric, glycol, feed, effluent, exchanger, heat recovery, powerplant
 Google Scholar - gas turbine power plant exhaust gas recirculation CO₂ recycle

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7,089,743 B2 (Frutschi et al.) 15 August 2006 (15.08.2006), fig. 6, col. 2, ln 63 - col. 3, ln 59, col. 4, ln 15 - col. 5, ln 20	1-3, 5-7, 25-27 and 29-31
Y		4, 8-24, 28 and 32-52
Y	US 7,536,873 B2 (Nohlen) 26 May 2009 (26.05.2009), abstract	4, 11, 12, 15-17, 20-23, 28, 35, 36, 39-41 and 44-47
Y	US 4,976,100 A (Lee) 11 December 1990 (11.12.1990), fig. 2, col. 2, ln 23-33 and col. 4, ln 29-38	8 and 32
Y	US 2011/0023488 A1 (Fong et al.) 03 February 2011 (03.02.2011), para [0963]	9-14, 16, 17, 33-38, 40 and 41
Y	US 5,141,049 A (Larsen et al.) 25 August 1992 (25.08.1992), col. 1, ln 12-24	18, 19, 42 and 43
Y	US 2011/0219777 A1 (Wijmans et al.) 15 September 2011 (15.09.2011), para [0006]	24 and 48-52
Y	US 3,841,382 A (Gravis et al.) 15 October 1974 (15.10.1974), col. 1, ln 19-35 and col. 2, ln 60-69	20-23 and 44-47
Y	US 5,444,971 A (Holenberger) 29 August 1995 (29.08.1995), col. 2, ln 18-36	15-17 and 39-41
Y	US 6,477,859 B2 (Wong et al.) 12 November 2002 (12.11.2002), col. 1, ln 34 - col. 5, ln 3, and col. 5, ln 49-53	23 and 47

Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

25 May 2012 (25.05.2012)

Date of mailing of the international search report

01 JUN 2012

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Lee W. Young

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 7,516,609 B2 (Agnew) 14 April 2009 (14.04.2009), abstract and figs. 2-5	1-52
A	US 2009/0199566 A1 (Lebas et al.) 13 August 2009 (13.08.2009), abstract and fig. 2	1-52