(12) STANDARD PATENT (11) Application No. AU 2013345176 B2
(19) AUSTRALIAN PATENT OFFICE

(54) Title
Liquefaction of natural gas

(51) International Patent Classification(s)
F25J 1/00 (2006.01)

(21) Application No: **2013345176** (22) Date of Filing: **2013.11.01**

(87) WIPO No: **WO14/078092**

(30) Priority Data

(31) Number	(32) Date	(33) Country
61/727,577	2012.11.16	US

(43) Publication Date: **2014.05.22**
(44) Accepted Journal Date: **2016.12.22**

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(56) Related Art
EP 1092931 A1
US 2009/0277217 A1

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 May 2014 (22.05.2014)

(10) International Publication Number
WO 2014/078092 A1

(51) International Patent Classification:
F25J 1/00 (2006.01)

(21) International Application Number:
PCT/US2013/067919

(22) International Filing Date:
1 November 2013 (01.11.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/727,577 16 November 2012 (16.11.2012) US

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

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(54) **Title**: LIQUEFACTION OF NATURAL GAS

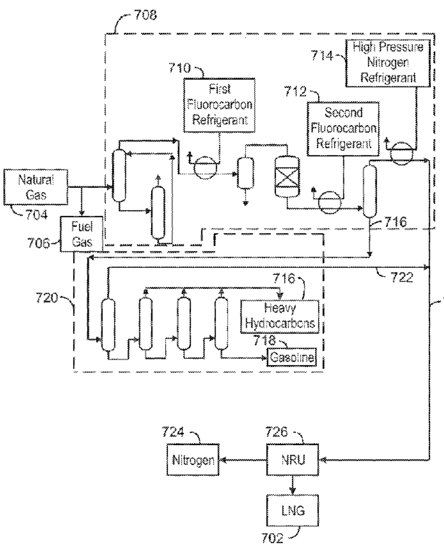

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FIG. 7

(57) **Abstract**: Systems and a method for the formation of a liquefied natural gas (LNG) are disclosed herein. The system includes a first fluorocarbon refrigeration system configured to chill a natural gas using a first fluorocarbon refrigerant and a second fluorocarbon refrigeration system configured to further chill the natural gas using a second fluorocarbon refrigerant. The system also includes a nitrogen refrigeration system configured to cool the natural gas using a nitrogen refrigerant to produce LNG and a nitrogen rejection unit configured to remove nitrogen from the LNG. As an alternative embodiment, the nitrogen refrigeration system can be replaced by a methane autorefrigeration system.

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Declarations under Rule 4.17:

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

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

Published:

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

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

LIQUEFACTION OF NATURAL GAS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application 61/727,577 filed November 16, 2012 entitled LIQUEFACTION OF NATURAL GAS, the entirety of which is incorporated by reference herein.

FIELD OF THE INVENTION

[0002] The present techniques relate generally to the field of hydrocarbon recovery and treatment processes and, more particularly, to a method and systems for forming liquefied natural gas (LNG) via a refrigeration process that includes two fluorocarbon refrigeration cycles upstream of a nitrogen refrigeration cycle or a methane autorefrigeration cycle.

BACKGROUND

[0003] This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present techniques. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present techniques. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0004] Many low temperature refrigeration systems that are used for natural gas processing and liquefaction rely on the use of refrigerants including hydrocarbon components and nitrogen to provide external refrigeration. Such hydrocarbon components may include methane, ethane, ethylene, propane, and the like. However, in many cases, it is desirable to implement a refrigeration system that uses nonflammable refrigerants.

[0005] U.S. Patent No. 6,412,302 to Foglietta et al. describes a process for producing a liquefied natural gas stream. The process includes cooling at least a portion of a pressurized natural gas feed stream by heat exchange contact with first and second expanded refrigerants that are used in independent refrigeration cycles. The first expanded refrigerant is selected from methane, ethane, and treated and pressurized natural gas, while the second expanded refrigerant is nitrogen. However, as discussed herein, it may be desirable to produce a LNG stream within a refrigeration system that uses nonflammable refrigerants.

SUMMARY

[0006] An embodiment provides a hydrocarbon processing system for the formation of a liquefied natural gas (LNG). The hydrocarbon processing system includes a first fluorocarbon refrigeration system configured to chill a natural gas using a first fluorocarbon refrigerant and a second fluorocarbon refrigeration system configured to further chill the natural gas using a second fluorocarbon refrigerant. The hydrocarbon processing system also includes a nitrogen refrigeration system configured to cool the natural gas using a nitrogen refrigerant to produce LNG and a nitrogen rejection unit configured to remove nitrogen from the LNG.

[0007] Another embodiment provides a method for the formation of LNG. The method includes cooling a natural gas in a first fluorocarbon refrigeration system, cooling the natural gas in a second fluorocarbon refrigeration system, liquefying the natural gas to form LNG in a nitrogen refrigeration system, and removing nitrogen from the LNG in a nitrogen rejection unit.

[0008] Another embodiment provides a hydrocarbon processing system for the formation of LNG. The hydrocarbon processing system includes a first refrigeration system configured to cool a natural gas using a first fluorocarbon refrigerant, wherein the first refrigeration system includes a number of first heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the first fluorocarbon refrigerant. The hydrocarbon processing system includes a second refrigeration system configured to chill the natural gas using a second fluorocarbon refrigerant, wherein the second refrigeration system includes a number of second heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the second fluorocarbon refrigerant. The hydrocarbon processing system also includes a third refrigeration system configured to form LNG from the natural gas using a nitrogen refrigerant, wherein the third refrigeration system includes a number of third heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the nitrogen refrigerant. The hydrocarbon processing system further includes a nitrogen rejection unit configured to remove nitrogen from the LNG.

[0009] Another embodiment provides a hydrocarbon processing system for the formation of LNG. The hydrocarbon processing system includes a first fluorocarbon refrigeration system configured to chill a natural gas using a first fluorocarbon refrigerant, a second fluorocarbon refrigeration system configured to further chill the natural gas using a second fluorocarbon refrigerant, and a methane autorefrigeration system configured to cool the natural gas to produce LNG.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The advantages of the present techniques are better understood by referring to the following detailed description and the attached drawings, in which:

[0011] Fig. 1 is a process flow diagram of a single stage refrigeration system;

[0012] Fig. 2 is a process flow diagram of a two stage refrigeration system including an economizer;

[0013] Fig. 3 is a process flow diagram of a single stage refrigeration system including a heat exchanger economizer;

[0014] Fig. 4 is a process flow diagram of a cascade cooling system including a first refrigeration system and a second refrigeration system;

[0015] Fig. 5 is process flow diagram of an expansion refrigeration system for hydrocarbon dew point control;

[0016] Fig. 6 is a process flow diagram of an expansion refrigeration system for NGL production;

[0017] Fig. 7 is a process flow diagram of a LNG production system;

[0018] Figs. 8A and 8B are process flow diagrams of a cascade fluorocarbon with nitrogen refrigeration cooling system;

[0019] Fig. 9 is a process flow diagram of a system including a NRU;

[0020] Figs. 10A and 10B are process flow diagrams of another cascade fluorocarbon with nitrogen refrigeration cooling system;

[0021] Fig. 10C is a process flow diagram of an alternative embodiment of the cascade fluorocarbon with nitrogen refrigeration cooling system with a simplified nitrogen refrigeration system;

[0022] Figs. 11A and 11B are process flow diagrams of another cascade cooling system;

[0023] Fig. 11C is a process flow diagram of an autorefrigeration system that is implemented within the same hydrocarbon processing system as the cascade cooling system of Figs. 11A and 11B;

[0024] Fig. 12 is a process flow diagram of a method for the formation of LNG from a natural gas stream; and

[0025] Fig. 13 is a process flow diagram of another method for the formation of LNG from a natural gas stream.

DETAILED DESCRIPTION

[0026] In the following detailed description section, specific embodiments of the present techniques are described. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the techniques are not limited to the specific embodiments described herein, but rather, include all alternatives, modifications, and equivalents falling within the spirit and scope of the appended claims.

[0027] At the outset, for ease of reference, certain terms used in this application and their meanings as used in this context are set forth. To the extent a term used herein is not defined herein, 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. Further, the present techniques are not limited by the usage of the terms shown herein, as all equivalents, synonyms, new developments, and terms or techniques that serve the same or a similar purpose are considered to be within the scope of the present claims.

[0028] As used herein, "autorefrigeration" refers to a process whereby a portion of a product stream is used for refrigeration purposes. This is achieved by extracting a fraction of the product stream prior to final cooling for the purpose of providing refrigeration capacity. This extracted stream is expanded in a valve or expander and, as a result of the expansion, the temperature of the stream is lowered. This stream is used for cooling the product stream in a heat exchanger. After exchanging heat, this stream is recompressed and blended with the feed gas stream. This process is also known as open cycle refrigeration.

[0029] Alternatively, "autorefrigeration" refers to a process whereby a fluid is cooled via a reduction in pressure. In the case of liquids, autorefrigeration refers to the cooling of the liquid by evaporation, which corresponds to a reduction in pressure. More specifically, a portion of the liquid is flashed into vapor as it undergoes a reduction in pressure while passing through a throttling device. As a result, both the vapor and the residual liquid are cooled to the saturation temperature of the liquid at the reduced pressure. For example, according to embodiments described herein, autorefrigeration of a natural gas may be performed by maintaining the natural gas at its boiling point so that the natural gas is cooled as heat is lost during boil off. This process may also be referred to as "flash evaporation."

[0030] As used herein, a "cascade cycle" refers to a system with two or more refrigerants, where a cold second refrigerant is condensed by a warmer first refrigerant. Thus, low temperatures may be "cascaded" down from one refrigerant to another. Each refrigerant in a cascade may have multiple levels of chilling based on staged evaporating pressures within economizers. Cascade cycles are considered to be beneficial for the production of LNG as compared to single refrigerant systems, since lower temperatures may be achieved within cascade cycles than single refrigerant systems.

[0031] A "compressor" or "refrigerant compressor" includes any unit, device, or apparatus able to increase the pressure of a refrigerant stream. This includes refrigerant compressors having a single compression process or step, or refrigerant compressors having multi-stage compressions or steps, more particularly multi-stage refrigerant compressors within a single casing or shell. Evaporated refrigerant streams to be compressed can be provided to a refrigerant compressor at different pressures. Some stages or steps of a hydrocarbon cooling process may involve two or more refrigerant compressors in parallel, series, or both. The present invention is not limited by the type or arrangement or layout of the refrigerant compressor or refrigerant compressors, particularly in any refrigerant circuit.

[0032] As used herein, "cooling" broadly refers to lowering and/or dropping a temperature and/or internal energy of a substance, such as by any suitable amount. Cooling may include a temperature drop of at least about 1 °C, at least about 5 °C, at least about 10 °C, at least about 15 °C, at least about 25 °C, at least about 50 °C, at least about 100 °C, and/or the like. The cooling may use any suitable heat sink, such as steam generation, hot water heating, cooling water, air, refrigerant, other process streams (integration), and combinations thereof. One or more sources of cooling may be combined and/or cascaded to reach a desired outlet temperature. The cooling step may use a cooling unit with any suitable device and/or equipment. According to one embodiment, cooling may include indirect heat exchange, such as with one or more heat exchangers. Heat exchangers may include any suitable design, such as shell and tube, brazed aluminum, spiral wound, and/or the like. In the alternative, the cooling may use evaporative (heat of vaporization) cooling, sensible heat cooling, and/or direct heat exchange, such as a liquid sprayed directly into a process stream.

[0033] "Cryogenic temperature" refers to a temperature that is about −50 °C or below.

[0034] As used herein, the terms "deethanizer" and "demethanizer" refer to distillation columns or towers that may be used to separate components within a natural gas stream. For example, a demethanizer is used to separate methane and other volatile components from ethane and heavier components. The methane fraction is typically recovered as purified gas that contains small amounts of inert gases such as nitrogen, CO_2, or the like.

[0035] "Fluorocarbons," also referred to as "perfluorocarbons" or "PFCs," are molecules including F and C atoms. Fluorocarbons have F-C bonds and, depending on the number of carbon atoms in the species, C-C bonds. An example of a fluorocarbon includes hexafluoroethane (C_2F_6). "Hydrofluorocarbons" or "HFCs" are a specific type of fluorocarbon including H, F, and C atoms. Hydrofluorocarbons have H-C and F-C bonds and, depending on the number of carbon atoms in the species, C-C bonds. Some examples of hydrofluorocarbons include fluoroform (CHF_3), pentafluoroethane (C_2HF_5), tetrafluoroethane ($C_2H_2F_4$), heptafluoropropane (C_3HF_7), hexafluoropropane ($C_3H_2F_6$), pentafluoropropane ($C_3H_3F_5$), and tetrafluoropropane ($C_3H_4F_4$), among other compounds of similar chemical structure.

[0036] The term "gas" is used interchangeably with "vapor," and is defined as a substance or mixture of substances in the gaseous state as distinguished from the liquid or solid state. Likewise, the term "liquid" means a substance or mixture of substances in the liquid state as distinguished from the gas or solid state.

[0037] A "heat exchanger" broadly means any device capable of transferring heat from one media to another media, including particularly any structure, e.g., device commonly referred to as a heat exchanger. Heat exchangers include "direct heat exchangers" and "indirect heat exchangers." Thus, a heat exchanger may be a shell-and-tube, spiral, hairpin, core, core-and-kettle, double-pipe, brazed aluminum, spiral wound, or any other type of known heat exchanger.

"Heat exchanger" may also refer to any column, tower, unit or other arrangement adapted to allow the passage of one or more streams there through, and to affect direct or indirect heat exchange between one or more lines of refrigerant, and one or more feed streams.

[0038] A "hydrocarbon" is an organic compound that primarily includes the elements hydrogen and carbon, although nitrogen, sulfur, oxygen, metals, or any number of other elements may be present in small amounts. As used herein, hydrocarbons generally refer to components found in natural gas, oil, or chemical processing facilities.

[0039] "Liquefied natural gas" or "LNG" is natural gas generally known to include a high percentage of methane. However, LNG may also include trace amounts of other compounds. The other elements or compounds may include, but are not limited to, ethane, propane, butane, carbon dioxide, nitrogen, helium, hydrogen sulfide, or combinations thereof, that have been processed to remove one or more components (for instance, helium) or impurities (for instance, water and/or heavy hydrocarbons) and then condensed into a liquid at almost atmospheric pressure by cooling.

[0040] "Liquefied petroleum as" or "LPG" generally refers to a mixture of propane, butane, and other light hydrocarbons derived from refining crude oil. At normal temperature, LPG is a gas. However, LPG can be cooled or subjected to pressure to facilitate storage and transportation.

[0041] "Mixed refrigerant processes" may include, but are not limited to, a single refrigeration system using a mixed refrigerant, i.e., a refrigerant with more than one chemical component, a hydrocarbon pre-cooled mixed refrigerant system, and a dual mixed refrigerant system. In general, mixed refrigerants can include hydrocarbon and/or non-hydrocarbon components. Examples of suitable hydrocarbon components typically employed in mixed refrigerants can include, but are not limited to, methane, ethane, ethylene, propane, propylene, butane and butylene isomers, as well as pentanes. Non-hydrocarbon components generally employed in mixed refrigerants can include nitrogen. Mixed refrigerant processes employ at least one mixed component refrigerant, but can additionally employ one or more pure-component refrigerants as well.

[0042] "Natural gas" refers to a multi-component gas obtained from a crude oil well or from a subterranean gas-bearing formation. The composition and pressure of natural gas can vary significantly. A typical natural gas stream contains methane (CH_4) 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 (C_2H_6), higher molecular weight hydrocarbons (e.g., C_3-C_{20} hydrocarbons), one or more acid gases (e.g., carbon dioxide or hydrogen sulfide), or any combinations thereof. The natural gas can also contain minor amounts of contaminants such as water, nitrogen, iron sulfide, wax, crude oil, or any combinations thereof. The natural gas stream may be substantially purified prior to use in embodiments, so as to remove compounds that may act as poisons or freeze during the cooling process.

[0043] As used herein, “natural gas liquids” (NGLs) refer to mixtures of hydrocarbons whose components are, for example, typically heavier than methane and condensed from a natural gas. Some examples of hydrocarbon components of NGL streams include ethane, propane, butane, and pentane isomers, benzene, toluene, and other aromatic compounds.

[0044] A “nitrogen rejection unit” or “NRU” refers to any system or device configured to receive a natural gas feed stream and produce substantially pure products streams, *e.g.*, a salable methane stream and a nitrogen stream including about 30% to 99% N_2. Examples of types of NRU's include cryogenic distillation, pressure swing adsorption (PSA), membrane separation, lean oil absorption, and solvent absorption.

[0045] A “refrigerant component,” in a refrigeration system, will absorb heat at a lower temperature and pressure through evaporation and will reject heat at a higher temperature and pressure through condensation. Illustrative refrigerant components may include, but are not limited to, alkanes, alkenes, and alkynes having one to five carbon atoms, nitrogen, chlorinated hydrocarbons, fluorinated hydrocarbons, other halogenated hydrocarbons, noble gases, and mixtures or combinations thereof.

[0046] Refrigerant components often include single component refrigerants. A single component refrigerant with a single halogenated hydrocarbon has an associated “R-“ designation of two or three numbers, which reflects its chemical composition. Adding 90 to the number gives three digits that stand for the number of carbon, hydrogen, and fluorine atoms, respectively. The first digit of a refrigerant with three numbers is one unit lower than the number of carbon atoms in the molecule. If the molecule contains only one carbon atom, the first digit is omitted. The second digit is one unit greater than the number of hydrogen atoms in the molecule. The third digit is equal to the number of fluorine atoms in the molecule. Remaining bonds not accounted for are occupied by chlorine atoms. A suffix of a lower-case letter “a,” “b,” or "c" indicates increasingly unsymmetrical isomers. As a special case, the R-400 series is made up of zeotropic blends, and the R-500 series is made up of so-called azeotropic blends. The rightmost digit is assigned arbitrarily by ASHRAE, an industry organization.

[0047] "Substantial" when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to an amount that is sufficient to provide an effect that the material or characteristic was intended to provide. The exact degree of deviation allowable may depend, in some cases, on the specific context.

Overview

[0048] Embodiments described herein provide a hydrocarbon processing system. The hydrocarbon processing system includes a refrigeration system, such as a cascade cooling system, for producing LNG from a natural gas. The refrigeration system includes two fluorocarbon refrigeration systems and a nitrogen or methane refrigeration system. The fluorocarbon refrigeration systems and the nitrogen or methane refrigeration system are used to cool the natural gas, producing LNG. In addition, the hydrocarbon processing system may include a NRU, which may be used to remove nitrogen from the produced LNG.

[0049] Hydrocarbon processing systems include any number of systems known to those skilled in the art. Hydrocarbon production and treatment processes include, but are not limited to, chilling natural gas for NGL extraction, chilling natural gas for hydrocarbon dew point control, chilling natural gas for CO_2 removal, LPG production storage, condensation of reflux in deethanizers / demethanizers, and natural gas liquefaction to produce LNG.

[0050] Although many refrigeration cycles have been used to process hydrocarbons, one cycle that is used in LNG liquefaction plants is the cascade cycle, which uses multiple single component refrigerants in heat exchangers arranged progressively to reduce the temperature of the gas to a liquefaction temperature. Another cycle that is used in LNG liquefactions plants is the multi-component refrigeration cycle, which uses a multi-component refrigerant in specially designed exchangers. In addition, another cycle that is used in LNG liquefaction plants is the expander cycle, which expands gas from feed gas pressure to a low pressure with a corresponding reduction in temperature. Natural gas liquefaction cycles may also use variations or combinations of these three cycles.

[0051] LNG is prepared from a feed gas by refrigeration and liquefaction technologies. Optional steps include condensate removal, CO_2 removal, dehydration, mercury removal, nitrogen stripping, H_2S removal, and the like. After liquefaction, LNG may be stored or loaded on a tanker for sale or transport. Conventional liquefaction processes can include: APCI Propane pre-cooled mixed refrigerant; C3MR; DUAL MR; Phillips Optimized Cascade; Prico single mixed refrigerant; TEAL dual pressure mixed refrigerant; Linde/Statoil multi fluid cascade; Axens dual mixed refrigerant, DMR; and the Shell processes C3MR and DMR.

[0052] Carbon dioxide removal, i.e., separation of methane and lighter gases from CO_2 and heavier gases, may be achieved with cryogenic distillation processes, such as the Controlled Freeze Zone technology available from ExxonMobil Corporation.

[0053] While the method and systems described herein are discussed with respect to the formation of LNG from natural gas, the method and systems may also be used for a variety of other purposes. For example, the method and systems described herein may be used to chill natural gas for hydrocarbon dew point control, perform natural gas liquid (NGL) extraction, separate methane and lighter gases from carbon dioxide and heavier gases, prepare hydrocarbons for LPG production, or condense a reflux stream in deethanizers and/or demethanizers, among others.

Refrigerants

[0054] The refrigerants that are utilized according to embodiments described herein may be one or more single component refrigerants, or refrigerant mixtures including multiple components. Refrigerants may be imported and stored on-site or, alternatively, some of the components of the refrigerant may be prepared on-site, typically by a distillation process integrated with the hydrocarbon processing system. Commercially available refrigerants including fluorocarbons (FCs) or hydrofluorocarbons (HFCs) are used in various applications. Exemplary refrigerants are commercially available from DuPont Corporation, including the ISCEON® family of refrigerants, the SUVA® family of refrigerants, the OPTEON® family of refrigerants, and the FREON® family of refrigerants.

[0055] Multicomponent refrigerants are commercially available. For example, R-401A is a HCFC blend of R-32, R-152a, and R-124. R-404A is a HFC blend of 52 wt.% R-143a, 44 wt.% R-125, and 4 wt.% R-134a. R-406A is a blend of 55 wt.% R-22, 4 wt.% R-600a, and 41 wt.% R-142b. R-407A is a HFC blend of 20 wt.% R-32, 40 wt.% R-125, and 40 wt.% R-134a. R-407C is a hydrofluorocarbon blend of R-32, R-125, and R-134a. R-408A is a HCFC blend of R-22, R-125, and R-143a. R-409A is a HCFC blend of R-22, R-124, and R-142b. R-410A is a blend of

R-32 and R-125. R-500 is a blend of 73.8 wt.% R-12 and 26.2 wt.% of R-152a. R-502 is a blend of R-22 and R-115. R-508B is a blend of R-23 and R-116.

[0056] In various embodiments, any of a number of different types of hydrocarbon processing systems can be used with any of the refrigeration systems described herein. In addition, the refrigeration systems described herein may utilize any of the refrigerants described herein.

Refrigeration Systems

[0057] Hydrocarbon systems and methods often include refrigeration systems that utilize mechanical refrigeration, valve expansion, turbine expansion, or the like. Mechanical refrigeration typically includes compression systems and absorption systems, such as ammonia absorption systems. Compression systems are used in the gas processing industry for a variety of processes. For example, compression systems may be used for chilling natural gas for NGL extraction, chilling natural gas for hydrocarbon dew point control, LPG production storage, condensation of reflux in deethanizers or demethanizers, natural gas liquefaction to produce LNG, or the like.

[0058] Fig. 1 is a process flow diagram of a single stage refrigeration system 100. In various embodiments, the single stage refrigeration system 100 utilizes a refrigerant such as a fluorocarbon. Further, in various embodiments, the single stage refrigeration system 100 is implemented upstream of a nitrogen refrigeration or methane autorefrigeration system including a NRU. Multiple single stage refrigeration systems 100 may also be implemented in series upstream of such a nitrogen refrigeration system or a methane autorefrigeration system.

[0059] The single stage refrigeration system 100 includes an expansion valve 102, a chiller 104, a compressor 106, a condenser 108, and an accumulator 110. A saturated liquid refrigerant 112 may flow from the accumulator 110 to the expansion valve 102, and may expand across the expansion valve 102 isenthalpically. On expansion, some vaporization occurs, creating a chilled refrigerant mixture 114 that includes both vapor and liquid. The refrigerant mixture 114 may enter the chiller 104, also known as the evaporator, at a temperature lower than the temperature to which a process stream 116, such as a natural gas, is to be cooled. The process stream 116 flows through the chiller 104 and exchanges heat with the refrigerant mixture 114. As the process stream 116 exchanges heat with the refrigerant mixture 114, the process stream 116 is cooled, while the refrigerant mixture 114 vaporizes, creating a saturated vapor refrigerant 118.

[0060] After leaving the chiller 104, the saturated vapor refrigerant 118 is compressed within the compressor 106, and is then flowed into the condenser 108. Within the condenser 108, the saturated vapor refrigerant 118 is converted to a saturated, or slightly sub-cooled, liquid refrigerant 120. The liquid refrigerant 120 may then be flowed from the condenser 108 to the accumulator 110. The accumulator 110, which is also known as a surge tank or receiver, may serve as a reservoir for the liquid refrigerant 120. The liquid refrigerant 120 may be stored within the accumulator 110 before being expanded across the expansion valve 102 as the saturated liquid refrigerant 112.

[0061] It is to be understood that the process flow diagram of Fig. 1 is not intended to indicate that the single stage refrigeration system 100 is to include all the components shown in Fig. 1. Further, the single stage refrigeration system 100 may include any number of additional components not shown in Fig. 1, depending on the details of the specific implementation. For example, in some embodiments, a refrigeration system can include two or more compression stages. In addition, the refrigeration system 100 may include an economizer, as discussed further with respect to Fig. 2.

[0062] Fig. 2 is a process flow diagram of a two stage refrigeration system 200 including an economizer 202. Like numbered items are as described with respect to Fig. 1. In various embodiments, the two stage refrigeration system 200 utilizes a refrigerant such as a fluorocarbon. Further, in various embodiments, the two stage refrigeration system 200 is implemented upstream of a nitrogen refrigeration or a methane autorefrigeration system including a NRU. Multiple two stage refrigeration systems 200 may also be implemented in series upstream of such a nitrogen refrigeration system or a methane autorefrigeration system.

[0063] The economizer 202 may be any device or process modification that decreases the compressor power usage for a given chiller duty. Conventional economizers 202 include, for example, flash tanks and heat exchange economizers. Heat exchange economizers utilize a number of heat exchangers to transfer heat between process streams. This may reduce the amount of energy input into the two stage refrigeration system 200 by heat integrating process streams with each other.

[0064] As shown in Fig. 2, the saturated liquid refrigerant 112 leaving the accumulator 110 may be expanded across the expansion valve 102 to an intermediate pressure at which vapor and liquid may be separated. For example, as the saturated liquid refrigerant 112 flashes across the expansion valve 102, a vapor refrigerant 204 and a liquid refrigerant 206 are produced at a lower pressure and temperature than the saturated liquid refrigerant 112. The vapor refrigerant 204 and the liquid refrigerant 206 may then be flowed into the economizer 202. In various embodiments, the economizer 202 is a flash tank that effects the separation of the vapor refrigerant 204 and the liquid refrigerant 206. The vapor refrigerant 204 may be flowed to an intermediate pressure compressor stage, at which the vapor refrigerant 204 may be combined with saturated vapor refrigerant 118 exiting a first compressor 210, creating a mixed saturated vapor refrigerant 208. The mixed saturated vapor refrigerant 208 may then be flowed into a second compressor 212.

[0065] From the economizer 202, the liquid refrigerant 206 may be isenthalpically expanded across a second expansion valve 214. On expansion, some vaporization may occur, creating a refrigerant mixture 216 that includes both vapor and liquid, lowering the temperature and pressure. The refrigerant mixture 216 will have a higher liquid content than refrigerant mixtures in systems without economizers. The higher liquid content may reduce the refrigerant circulation rate and/or reduce the power usage of the first compressor 210.

[0066] The refrigerant mixture 216 enters the chiller 104, also known as the evaporator, at a temperature lower than the temperature to which the process stream 116 is to be cooled. The process stream 116 is cooled within the chiller 104, as discussed with respect to Fig. 1. In addition, the saturated vapor refrigerant 118 is flowed through the compressors 210 and 212 and the condenser 108, and the resulting liquid refrigerant 120 is stored within the accumulator 110, as discussed with respect to Fig. 1.

[0067] It is to be understood that the process flow diagram of Fig. 2 is not intended to indicate that the two stage refrigeration system 200 is to include all the components shown in Fig. 2. Further, the two stage refrigeration system 200 may include any number of additional components not shown in Fig. 2, depending on the details of the specific implementation. For example, the two stage refrigeration system 200 may include any number of additional economizers or other types of equipment not shown in Fig. 2. In addition, the economizer 202 may be a heat exchange economizer rather than a flash tank. The heat exchange economizer may also be used to decrease refrigeration circulation rate and reduce compressor power usage.

[0068] In some embodiments, the two stage refrigeration system 200 includes more than one economizer 202, as well as more than two compressors 210 and 212. For example, the two stage refrigeration system 200 may include two economizers and three compressors. In general, if the refrigeration system 200 includes X number of economizers, the refrigeration system 200 will include X +1 number of compressors. Such a refrigeration system 200 with multiple economizers may form part of a cascade refrigeration system.

[0069] Fig. 3 is a process flow diagram of a single stage refrigeration system 300 including a heat exchanger economizer 302. Like numbered items are as described with respect to Fig. 1. In various embodiments, the single stage refrigeration system 300 utilizes a refrigerant such as a fluorocarbon. Further, in various embodiments, the single stage refrigeration system 300 is implemented upstream of a nitrogen refrigeration system or a methane autorefrigeration system including a NRU. Multiple single stage refrigeration systems 300 may also be implemented in series upstream of such a nitrogen refrigeration system or a methane autorefrigeration system.

[0070] As shown in Fig. 3, the saturated liquid refrigerant 112 leaving the accumulator 110 may be expanded across the expansion valve 102 to an intermediate pressure at which vapor and liquid may be separated, producing the refrigerant mixture 114. The refrigerant mixture 114 may be flowed into the chiller 104 at a temperature lower than the temperature to which the process stream 116 is to be cooled. The process stream 116 may be cooled within the chiller 104, as discussed with respect to Fig. 1.

[0071] From the chiller 104, the saturated vapor refrigerant 118 may be flowed through the heat exchanger economizer 302. The cold, low-pressure saturated vapor refrigerant 118 may be used to subcool the saturated liquid refrigerant 112 within the heat exchanger economizer 302. The superheated vapor refrigerant 304 exiting the heat exchanger economizer 302 may then be flowed through the compressor 106 and the condenser 108, and the resulting liquid refrigerant 120 may be stored within the accumulator 110, as discussed with respect to Fig. 1.

[0072] It is to be understood that the process flow diagram of Fig. 3 is not intended to indicate that the single stage refrigeration system 300 is to include all the components shown in Fig. 3. Further, the single stage refrigeration system 300 may include any number of additional components not shown in Fig. 3, depending on the details of the specific implementation.

[0073] Fig. 4 is a process flow diagram of a cascade cooling system 400 including a first refrigeration system 402 and a second refrigeration system 404. In various embodiments, the first refrigeration system 402 and the second refrigeration system 404 utilize fluorocarbon refrigerants. For example, the first refrigeration system 402 may utilize R-410A, and the second refrigeration system 404 may utilize R-508B. In addition, the refrigerants in either refrigeration system 402 or 404 may include mixtures. The cascade cooling system 400 may be used for instances in which a higher degree of cooling than that provided by the refrigeration systems 100, 200, or 300 is desired. The cascade cooling system 400 may provide cooling at very low temperatures, e.g., below -40 °C. Further, in some embodiments, the cascade cooling system 400 is implemented upstream of a nitrogen refrigeration system or a methane autorefrigeration system.

[0074] Within the first refrigeration system 402, a vapor/liquid refrigerant stream 406 may be flowed from an accumulator 408 through a first expansion valve 410 and a first heat exchanger 412, which chills a product stream 413. The resulting vapor stream is separated in a first flash drum 414. A portion of the vapor/liquid refrigerant stream 406 may be flowed directly into the first flash drum 414 via a bypass valve 416.

[0075] From the first flash drum 414, a liquid refrigerant stream 418 may be flowed through a second expansion valve 420, and flashed into a second heat exchanger 422, which may be used to further chill the product stream 413. A gas accumulator 424 feeds the resulting vapor refrigerant stream 426 to a first stage compressor 428. The resulting medium pressure vapor refrigerant stream 430 is combined with the vapor refrigerant stream 432 from the first flash drum 414, and the combined stream is fed to a second stage compressor 434. The high pressure vapor stream 436 from the second stage compressor 434 is passed through a condenser 438, which may use cooling from the second refrigeration system 404. Specifically, the condenser 438 may cool the high pressure vapor stream 436 to produce a liquid refrigerant stream 406 using a low temperature refrigerant stream 440 from the second refrigeration system 404. The liquid refrigerant stream 406 from the condenser 438 is then stored in the accumulator 408. A control valve 442 may be used to control the flow of the low temperature refrigerant stream 440 through the condenser 438. From the condenser 438, the resulting vapor refrigerant stream 444 may be flowed back to the second refrigeration system 404.

[0076] Within the second refrigeration system 404, a liquid refrigerant stream 448 may be flowed from an accumulator 450 through a heat exchanger 452 that is configured to cool the liquid refrigerant stream 448 via a chilling system 454. The chilling system 454 may be, for example, performed by heat exchange with various process streams, such as a natural gas stream coming from a final flash drum that separates NGL from the gas.

[0077] The resulting low temperature refrigerant stream 456 may be flowed through a first expansion valve 458 and a first heat exchanger 460, which chills the product stream 413. The resulting vapor/liquid refrigerant stream is separated in a first flash drum 462. A portion of the low temperature refrigerant stream 456 may be flowed directly into the first flash drum 462 via a bypass valve 464, which may be a level control valve for controlling fluid entering flash drum 462.

[0078] From the first flash drum 462, a liquid refrigerant stream 466 may be flowed through a second expansion valve 468, and flashed into a second heat exchanger 470, which may be used to further chill the product stream 413. The resulting vapor/liquid refrigerant stream is separated in a second flash drum 472. A portion of the liquid refrigerant stream 466 may be flowed directly into the second flash drum 472 via a bypass valve 474, which can be used to control the temperature of the liquid in the second flash drum 472, as well as the amount of cooling in the second heat exchanger 470.

[0079] From the second flash drum 472, a liquid refrigerant stream 476 may be flowed through a third expansion valve 478, and flashed into a third heat exchanger 480, which may be used to further chill the product stream 413. A gas accumulator 482 feeds the resulting vapor refrigerant stream 484 to a first stage compressor 486. The resulting medium pressure vapor refrigerant stream 488 is combined with the vapor refrigerant stream 490 from the second flash drum 472, and the combined stream is fed to a second stage compressor 492. The resulting high pressure vapor refrigerant stream 494 is combined with the vapor refrigerant mixture 496 from the first flash drum 462, and the combined stream is fed to a third stage compressor 497. The resulting high pressure vapor refrigerant stream 498 is flowed through a heat exchanger 499, in which it may be further cooled through indirect heat exchange with cooling water. The resulting liquid refrigerant stream 448 may then be flowed into the accumulator 450.

[0080] It is to be understood that the process flow diagram of Fig. 4 is not intended to indicate that the cascade cooling system 400 is to include all the components shown in Fig. 4. Further, the cascade cooling system 400 may include any number of additional components not shown in Fig. 4, depending on the details of the specific implementation.

[0081] Fig. 5 is process flow diagram of an expansion refrigeration system 500 for hydrocarbon dew point control. Condensation of heavy hydrocarbons, e.g., C_3-C_6, in natural gas within pipes may result in liquid slugging on pipelines and disruption of gas receiving facilities.

Therefore, the hydrocarbon dew point may be reduced using the expansion refrigeration system 500 in order to prevent such condensation.

[0082] As shown in Fig. 5, a dehydrated natural gas feed stream 502 may be flowed into a gas/gas heat exchanger 504. Within the gas/gas heat exchanger 504, the dehydrated natural gas feed stream 502 may be cooled through indirect heat exchange with a low temperature natural gas stream 506. The resulting natural gas stream 508 may be flowed into a first separator 510, which may remove some amount of heavy hydrocarbons 512 from the natural gas stream 508. In various embodiments, removing the heavy hydrocarbons 512 from the natural gas stream 508 decreases the dew point of the natural gas stream 508. The removed heavy hydrocarbons 512 may be flowed out of the expansion refrigeration system 500 through a first outlet valve 514. For example, the heavy hydrocarbons 512 may be flowed from the expansion refrigeration system 500 to a stabilizer (not shown).

[0083] The natural gas stream 508 may then be flowed into an expander 516. In various embodiments, the expander 516 is a turbo-expander, which is a centrifugal or axial flow turbine. The expansion of the natural gas stream 508 within the expander 516 may provide energy for driving a compressor 518, which is coupled to the expander 516 via a shaft 520.

[0084] From the expander 516, the resulting low temperature natural gas stream 506 may be flowed into a second separator 522, which may remove any remaining heavy hydrocarbons 512 from the low temperature natural gas stream 506. In various embodiments, removing the heavy hydrocarbons 512 from the low temperature natural gas stream 506 further decreases the dew point of the low temperature natural gas stream 506. The removed heavy hydrocarbons 512 may then be flowed out of the expansion refrigeration system 500 through a second outlet valve 524.

[0085] The low temperature natural gas stream 506 may be flowed from the second separator 522 to the gas/gas heat exchanger 504, which may increase the temperature of the low temperature natural gas stream 506, producing a high temperature natural gas stream 526. The high temperature natural gas stream 526 may then be flowed through the compressor 518, which may return the pressure of the natural gas stream 526 to acceptable sales gas pressure. The final, decreased dew point natural gas stream 528 may then be flowed out of the expansion refrigeration system 500.

[0086] In an embodiment, a cooling system, for example, using a fluorocarbon refrigerant and a nitrogen refrigerant, may be used to add further cooling to the process. This cooling may be implemented by placing a heat exchanger 530 in the natural gas stream 508 or the low temperature natural gas stream 506, upstream of the second separator 522. A refrigerant liquid 532 may be flashed across an expansion valve 534, through the chiller 530. The resulting refrigerant vapor 536 can then be returned to the refrigerant system. The chilling may allow for the removal of a much higher amount of condensable hydrocarbons, such as C_3s and higher. Further, in some embodiments, the heat exchanger 530 is placed upstream of the expander 516, with a separator located between the heat exchanger 530 and the expander 516 to prevent liquids from flowing into the expander 516.

[0087] It is to be understood that the process flow diagram of Fig. 5 is not intended to indicate that the expansion refrigeration system 500 is to include all the components shown in Fig. 5. Further, the expansion refrigeration system 500 may include any number of additional components not shown in Fig. 5, depending on the details of the specific implementation. For example, in some embodiments, the expansion refrigeration system 500 is implemented within a cascade cooling system including two fluorocarbon refrigeration systems upstream of a nitrogen refrigeration system. In such embodiments, the refrigerant liquid 532 that is flashed across an expansion valve 534 and flowed through the chiller 530 is a fluorocarbon refrigerant from one of the fluorocarbon refrigeration systems or a nitrogen refrigerant from the nitrogen refrigeration system.

[0088] Fig. 6 is a process flow diagram of an expansion refrigeration system 600 for NGL production. In various embodiments, NGL extraction may be performed to recover NGLs, which include any number of different heavy hydrocarbons, from a natural gas stream. NGL extraction may be desirable due to the fact that NGLs are often of greater value for purposes other than as a gaseous heating fuel.

[0089] A dry natural gas feed stream 602 may be flowed into a gas/gas heat exchanger 604 from a dehydration system. Within the gas/gas heat exchanger 604, the dry natural gas feed stream 602 may be cooled through indirect heat exchange with a low temperature natural gas stream 606. The resulting natural gas stream 608 may be flowed into a separator 610, which may remove a portion of NGLs 612 from the natural gas stream 608. The removed NGLs 612 may be flowed from the separator 610 to a deethanizer or demethanizer 614.

[0090] The natural gas stream 608 may then be flowed into an expander 616. In various embodiments, the expander 616 is a turbo-expander. The expansion of the natural gas stream 608 within the expander 616 may provide energy for driving a compressor 618, which is coupled to the expander 616 via a shaft 620. In addition, the temperature of the natural gas stream 608 may be reduced via adiabatic expansion across a Joule-Thomson valve 622.

[0091] From the expander 616, the resulting low temperature natural gas stream 606 may be flowed into the deethanizer or demethanizer 614. Within the deethanizer or demethanizer 614, NGLs may be separated from the natural gas stream 606 and may be flowed out of the deethanizer or demethanizer 614 as an NGL product stream 624. The NGL product stream 624 may then be pumped out of the expansion refrigeration system 600 via a pump 626.

[0092] The deethanizer or demethanizer 614 may be coupled to a heat exchanger 628. In some embodiments, the heat exchanger 628 is a reboiler 628 that may be used to heat a portion of a bottoms stream 630 from the deethanizer or demethanizer 614 via indirect heat exchange within a high temperature fluid 632. The heated bottoms stream 630 may then be reinjected into the deethanizer or demethanizer 614.

[0093] The separation of the NGL product stream 624 from the natural gas stream 606 within the deethanizer or demethanizer 614 may result in the production of a low temperature natural gas stream that may be flowed out of the deethanizer or demethanizer 614 as an overhead stream 634. The overhead stream 634 may be flowed into a heat exchanger 636, which may decrease the temperature of the overhead stream 634 through indirect heat exchange with a refrigerant 638, such as a fluorocarbon refrigerant or a nitrogen refrigerant. The decrease in temperature can lead to condensation of some of the vapors. The overhead stream 634 may then be separated within a separation vessel 640 to produce the low temperature natural gas stream 606 and a liquid bottoms stream 642. The bottoms stream 642 may be pumped back into the deethanizer or demethanizer 614, via a pump 644, forming a recycle stream.

[0094] The low temperature natural gas stream 606 may then be flowed through the gas/gas heat exchanger 604. The temperature of the low temperature natural gas stream 506 may be increased within the gas/gas heat exchanger 604, producing a high temperature natural gas stream 646. The high temperature natural gas stream 646 may then be flowed through the compressor 618, which may increase the pressure of the natural gas stream 646. In some embodiments, the high temperature natural gas stream 646 is also flowed through a second compressor 648, which may increase the pressure of the natural gas stream 646 to acceptable sales gas pressure. The natural gas product stream 650 may then be flowed out of the expansion refrigeration system 600.

[0095] It is to be understood that the process flow diagram of Fig. 6 is not intended to indicate that the expansion refrigeration system 600 is to include all the components shown in Fig. 6. Further, the expansion refrigeration system 600 may include any number of additional components not shown in Fig. 6, depending on the details of the specific implementation. For example, in some embodiments, the expansion refrigeration system 600 is implemented within a cascade cooling system including two fluorocarbon refrigeration systems upstream of a nitrogen refrigeration system. In such embodiments, the refrigerant 638 that is utilized within the heat exchanger 636 is a fluorocarbon refrigerant from one of the fluorocarbon refrigeration systems or a nitrogen refrigerant from the nitrogen refrigeration system.

[0096] Fig. 7 is a process flow diagram of a LNG production system 700. As shown in Fig. 7, LNG 702 may be produced from a natural gas stream 704 using a number of different refrigeration systems. As shown in Fig. 7, a portion of the natural gas stream 704 may be separated from the natural gas stream 704 prior to entry into the LNG production system 700, and may be used as a fuel gas stream 706. The remaining natural gas stream 704 may be flowed into an initial natural gas processing system 708. Within the natural gas processing system 708, the natural gas stream 704 may be purified and cooled. For example, the natural gas stream 704 may be cooled using a first fluorocarbon refrigerant 710, a second fluorocarbon refrigerant 712, and a high-pressure nitrogen refrigerant 714. The cooling of the natural gas stream 704 may result in the production of the LNG 702.

[0097] Within the LNG production system 700, heavy hydrocarbons 716 may be removed from the natural gas stream 704, and a portion of the heavy hydrocarbons 716 may be used to produce gasoline 718 within a heavy hydrocarbon processing system 720. In addition, any residual natural gas 722 that is separated from the heavy hydrocarbons 716 during the production of the gasoline 718 may be returned to the natural gas stream 704.

[0098] The produced LNG 702 may include some amount of nitrogen 724. Therefore, the LNG 702 may be flowed through a NRU 726. The NRU 726 separates the nitrogen 724 from the LNG 702, producing the final LNG product.

[0099] It is to be understood that the process flow diagram of Fig. 7 is not intended to indicate that the LNG production system 700 is to include all the components shown in Fig. 7. Further, the LNG production system 700 may include any number of additional components not shown in Fig. 7 or different locations for the fluorocarbon refrigerant chillers within the process, depending on the details of the specific implementation. For example, any number of alternative refrigeration systems may also be used to produce the LNG 702 from the natural gas stream 704. In addition, any number of different refrigeration systems may be used in combination to produce the LNG 702.

Systems for the Production of LNG

[0100] Figs. 8A and 8B are process flow diagrams of a cascade cooling system 800. The cascade cooling system 800 may be used for the production of LNG, and may be implemented within a hydrocarbon processing system. The cascade cooling system 800 may operate at low temperatures, e.g., below about -18 °C, or below about -29 °C, or below about -40 °C. In addition, the cascade cooling system 800 may employ more than one refrigerant and provide refrigeration at multiple temperatures.

[0101] The cascade cooling system 800 may include a first fluorocarbon refrigeration system 802, as shown in Fig. 8A, which may utilize a first fluorocarbon refrigerant, such as R-410A. The cascade cooling system 800 may also include a second fluorocarbon refrigeration system 804, as shown in Fig. 8B, which may utilize a second fluorocarbon refrigerant, such as R-508B. In addition, the cascade cooling system 800 may include a nitrogen refrigeration system 806, as shown in Fig. 8B.

[0102] A natural gas stream 808 may be flowed through a chiller 810, which pre-cools the natural gas stream 808 via indirect heat exchange with a cooling fluid. The natural gas stream 808 may then be flowed into a pipe joint 812 within the cascade cooling system 800. The pipe joint 812 may be configured to split the natural gas stream 808 into three separate natural gas streams. A first natural gas stream may be flowed into the first fluorocarbon refrigeration system 802 via line 814, while a second natural gas stream and a third natural gas stream may be flowed into the system discussed with respect to Fig. 9 via lines 816 and 818, respectively.

[0103] The natural gas stream may be flowed into the first fluorocarbon refrigeration system 802 in preparation for cooling of the natural gas stream. The natural gas stream may be cooled by being passed through a series of heat exchangers 820, 822, and 824 within the first fluorocarbon refrigeration system 802. The heat exchangers 820, 822, and 824 may also be referred to as evaporators, chillers, or cold boxes. The natural gas stream may be cooled within each of the heat exchangers 820, 822, and 824 through indirect heat exchange with a circulating fluorocarbon refrigerant. The fluorocarbon refrigerant may be a hydrofluorocarbon, such as R-410A or R-404A, or any other suitable type of fluorocarbon refrigerant.

[0104] The fluorocarbon refrigerant may be continuously circulated through the first fluorocarbon refrigeration system 802, which may continuously prepare the fluorocarbon refrigerant for entry into each of the heat exchangers 820, 822, and 824. The fluorocarbon refrigerant may exit the first heat exchanger 820 via line 826 as a vapor fluorocarbon refrigerant. The vapor fluorocarbon refrigerant can be combined with additional vapor fluorocarbon refrigerant within two pipe joints 828 and 829. The vapor is then flowed through a compressor 830 to increase the pressure of the vapor fluorocarbon refrigerant, producing a superheated vapor fluorocarbon refrigerant. The superheated vapor fluorocarbon refrigerant is flowed through a condenser 832, which may cool and condense the superheated vapor fluorocarbon refrigerant, producing a liquid fluorocarbon refrigerant.

[0105] The liquid fluorocarbon refrigerant may be flowed through an expansion valve 834, which lowers the temperature and pressure of the liquid fluorocarbon refrigerant. This may result in the flash evaporation of the liquid fluorocarbon refrigerant, producing a mixture of the liquid fluorocarbon refrigerant and a vapor fluorocarbon refrigerant. The liquid fluorocarbon refrigerant and the vapor fluorocarbon refrigerant may be flowed into a first flash drum 836 via line 838. Within the first flash drum 836, the liquid fluorocarbon refrigerant may be separated from the vapor fluorocarbon refrigerant.

[0106] The vapor fluorocarbon refrigerant may be flowed from the first flash drum 836 to the pipe joint 828 via line 839. The liquid fluorocarbon refrigerant may be flowed into a pipe joint 840, which may split the liquid fluorocarbon refrigerant into two separate liquid fluorocarbon refrigerant streams. One liquid fluorocarbon refrigerant stream may be flowed through the first heat exchanger 820, partly or completely flashed to vapor, and returned to the pipe joint 828 via line 826. The other liquid fluorocarbon refrigerant stream may be flowed to a second flash drum 842 via line 844. The line 844 may also include an expansion valve 846 that throttles the liquid fluorocarbon refrigerant stream to control the flow of the liquid fluorocarbon refrigerant stream into the second flash drum 842. The throttling of the liquid fluorocarbon refrigerant stream within the expansion valve 846 may result in the flash evaporation of the liquid fluorocarbon refrigerant stream, producing a mixture of both vapor and liquid fluorocarbon refrigerant.

[0107] The second flash drum 842 may separate the vapor fluorocarbon refrigerant from the liquid fluorocarbon refrigerant. The vapor fluorocarbon refrigerant may be flowed into a pipe joint 848 via line 850. The pipe joint 848 may combine the vapor fluorocarbon refrigerant with vapor fluorocarbon refrigerant recovered from the second heat exchanger 822. The vapor fluorocarbon refrigerant may then be flowed into another pipe joint 852. The pipe joint 852 may combine the vapor fluorocarbon refrigerant with vapor fluorocarbon refrigerant recovered from the third heat exchanger 824. The combined vapor fluorocarbon refrigerant may be compressed within a compressor 854 and flowed into the pipe joint 829 via line 856 to be combined with the vapor from the flash drum 836 and the heat exchanger 820.

[0108] The liquid fluorocarbon refrigerant may be flowed from the second flash drum 842 to a pipe joint 858, which may split the liquid fluorocarbon refrigerant into two separate liquid fluorocarbon refrigerant streams. One liquid fluorocarbon refrigerant stream may be flowed through the second heat exchanger 822 and returned to the pipe joint 848 via line 860. The other liquid fluorocarbon refrigerant stream may be flowed through the third heat exchanger 824 via line 862. The line 862 may also include an expansion valve 864 that allows the liquid fluorocarbon refrigerant to flash, and, thus, lowers the pressure and temperature, of the liquid fluorocarbon refrigerant stream as it flows into the third heat exchanger 824. From the third heat exchanger 824, the liquid fluorocarbon refrigerant stream may be compressed within a compressor 866 and sent to the pipe joint 852 via line 868.

[0109] In various embodiments, a fluorocarbon refrigerant of the second fluorocarbon refrigeration system 804 is precooled within the first fluorocarbon refrigeration system 802. For example, the fluorocarbon refrigerant of the second fluorocarbon refrigerant may be precooled by being flowed through the first heat exchanger 820. The fluorocarbon refrigerant may be a hydrofluorocarbon, such as R-508B, or any other suitable type of fluorocarbon. The fluorocarbon refrigerant may be flowed from the second fluorocarbon refrigeration system 804 to the first heat exchanger 820 via line 870.

[0110] After the natural gas stream has been progressively chilled within each of the heat exchangers 820, 822, and 824, it is flowed into the second fluorocarbon refrigeration system 804, as shown in Fig. 8B, via line 874. The second fluorocarbon refrigeration system 804 may include a fourth heat exchanger 876 and a fifth heat exchanger 878, which may further cool the natural gas stream using the fluorocarbon refrigerant.

[0111] The fluorocarbon refrigerant may be continuously circulated through the second refrigeration system 804, which prepares the fluorocarbon refrigerant for entry into each of the heat exchangers 876 and 878. The fluorocarbon refrigerant may exit the fourth heat exchanger 876 as a vapor fluorocarbon refrigerant stream. The vapor fluorocarbon refrigerant stream may be combined with another vapor fluorocarbon refrigerant stream within a pipe joint 880, and may be combined with yet another vapor fluorocarbon refrigerant stream from the fifth heat exchanger 878 within another pipe joint 882. The vapor fluorocarbon refrigerant stream may then be flowed through a compressor 884, which may increase the pressure of the vapor fluorocarbon refrigerant stream, producing a superheated fluorocarbon refrigerant stream. The superheated fluorocarbon refrigerant stream may be flowed through a pipe joint 886 and another compressor 888, which may further increase the pressure of the superheated fluorocarbon refrigerant stream.

[0112] The superheated fluorocarbon refrigerant stream may be flowed through a gas cooler 890. The gas cooler 890 may cool the superheated fluorocarbon refrigerant stream, producing a cool vapor fluorocarbon refrigerant stream. In some cases, if the vapor fluorocarbon refrigerant stream is below ambient temperature, the vapor fluorocarbon refrigerant stream may not be flowed through the gas cooler 890. The liquid fluorocarbon refrigerant stream may then be flowed through the first heat exchanger 820 within the first fluorocarbon refrigeration system 802 via the line 870.

[0113] Once the fluorocarbon refrigerant stream has passed through the first heat exchanger 820, the fluorocarbon refrigerant stream may enter a third flash drum 892 within the second fluorocarbon refrigeration system 804 via line 894. Line 894 may include an expansion valve 896 that controls the flow of the fluorocarbon refrigerant stream into the third flash drum 892. The expansion valve 896 may reduce the temperature and pressure of the fluorocarbon refrigerant stream, resulting in the flash evaporation of the fluorocarbon refrigerant stream into both a vapor fluorocarbon refrigerant stream and a liquid fluorocarbon refrigerant stream.

[0114] The vapor fluorocarbon refrigerant stream and the liquid fluorocarbon refrigerant stream may be flashed into the third flash drum 892, which may separate the vapor fluorocarbon refrigerant stream from the liquid fluorocarbon refrigerant stream. The vapor fluorocarbon refrigerant stream may be flowed into the pipe joint 886 via line 898. The liquid fluorocarbon refrigerant stream may be flowed from the third flash drum 892 to a fourth flash drum 904 via line 906. Line 906 may include an expansion valve 908 that controls the flow of the fluorocarbon refrigerant stream into the fourth flash drum 904. The expansion valve 908 may further reduce the temperature and pressure of the fluorocarbon refrigerant stream, resulting in the flash evaporation of the fluorocarbon refrigerant stream into both a vapor fluorocarbon refrigerant stream and a liquid fluorocarbon refrigerant stream.

[0115] The liquid fluorocarbon refrigerant stream may be flowed from the fourth flash drum 904 to a pipe joint 910, which may split the liquid fluorocarbon refrigerant stream into two separate liquid fluorocarbon refrigerant streams. One liquid fluorocarbon refrigerant stream may be flowed through the fourth heat exchanger 876 and returned to the pipe joint 880 via line 912. The other liquid fluorocarbon refrigerant stream may be flowed through the fifth heat exchanger 878 via line 914. Line 914 may also include an expansion valve 916 that controls the flow of the liquid fluorocarbon refrigerant stream into the fifth heat exchanger 878, e.g., by allowing the fluorocarbon refrigerant stream to flash, lowering the temperature and creating a vapor fluorocarbon refrigerant stream and a liquid fluorocarbon refrigerant stream. From the fifth heat exchanger 878, the resulting vapor fluorocarbon refrigerant stream may be compressed within a compressor 918 and then flowed into the pipe joint 882 to be recirculated.

[0116] After the natural gas stream has been cooled within the heat exchangers 876 and 878 through indirect heat exchange with the fluorocarbon refrigerant stream, the natural gas stream may be flowed into the nitrogen refrigeration system 806 via line 920. In various embodiments, a nitrogen refrigerant stream of the nitrogen refrigeration system 806 is precooled by being flowed through each of the heat exchangers 820, 822, 824, and 876. The nitrogen refrigerant stream may be flowed from the nitrogen refrigeration system 806 to the heat exchangers 820, 822, 824, and 876 via line 921.

[0117] Within the nitrogen refrigeration system 806, the natural gas stream may be cooled within a sixth heat exchanger 922 via indirect heat exchange with the nitrogen refrigerant stream. The nitrogen refrigerant stream may be continuously circulated through the nitrogen refrigeration system 806, which prepares the nitrogen refrigerant stream for entry into the sixth heat exchanger 922. The nitrogen refrigerant may be flowed through the sixth heat exchanger 922 as two separate nitrogen refrigerant streams. From the sixth heat exchanger 922, the nitrogen refrigerant streams may be combined within a pipe joint 924.

[0118] The combined nitrogen refrigerant stream may be flowed through a seventh heat exchanger 926 via line 928. Within the seventh heat exchanger 926, the nitrogen refrigerant stream may provide cooling for a high pressure nitrogen refrigerant stream that is flowing in the opposite direction. From the seventh heat exchanger 926, the nitrogen refrigerant stream may be compressed within a first compressor 930, cooled within a first chiller 932, compressed within a second compressor 934, and cooled within a second chiller 936. The resulting high pressure nitrogen refrigerant stream may then be flowed into a pipe joint 938, which may split the high pressure nitrogen refrigerant stream into two separate high pressure nitrogen refrigerant streams.

[0119] From the pipe joint 938, one high pressure nitrogen refrigerant stream may be flowed through the heat exchangers 820, 822, 824, and 876 via the line 921. Upon exiting the fourth heat exchanger 876, the nitrogen refrigerant stream may be expanded within an expander 940, generating power, and flowed through the sixth heat exchanger 922 to provide cooling for the natural gas stream.

[0120] The other high pressure nitrogen refrigerant stream may be flowed from the pipe joint 938 through a third compressor 942, a third chiller 944, and the seventh heat exchanger 926. The high pressure nitrogen refrigerant stream may then be expanded within an expander 946, generating power, and flowed through the sixth heat exchanger 922 to provide cooling for the natural gas stream. The power generated in expanders 940 and 946 may be used to generate electricity or to drive all, some (or part) of the compressors 930, 934, or 942.

[0121] Fig. 9 is a process flow diagram of a system 900 including a NRU 902. The system 900 may be located downstream of the cascade cooling system 800, and may be implemented within the same hydrocarbon processing system as the cascade cooling system 800.

[0122] Once the natural gas stream has been cooled within the nitrogen refrigeration system 806, the natural gas stream may be in the form of LNG. The LNG stream may be flowed into the system 900 via line 948. Specifically, the LNG stream may be flowed into a pipe joint 950, which may combine the LNG stream from line 948 with the natural gas stream from line 816. Initial cooling of the natural gas stream from line 816 may be performed within an eighth heat exchanger 952 prior to flowing the natural gas stream into the pipe joint 950.

[0123] From the pipe joint 950, the LNG stream may be flowed into the NRU 902 to remove excess nitrogen from the LNG stream. Specifically, the LNG stream may be flowed into a reboiler 954, which may decrease the temperature of the LNG stream. The cooled LNG stream may be expanded within a hydraulic expansion turbine 956 and then flowed through an expansion valve 958, which lowers the temperature and pressure of the LNG stream.

[0124] The LNG stream may be flowed into a cryogenic fractionation column 960, such as an NRU tower, within the NRU 902. In addition, heat may be transferred to the cryogenic fractionation column 960 from the reboiler 954 via line 962. The cryogenic fractionation column 960 may separate nitrogen from the LNG stream via a cryogenic distillation process. An overhead stream may be flowed out of the cryogenic fractionation column 960 via line 964. The overhead stream may include primarily methane, nitrogen, and other low boiling point or non-condensable gases, such as helium, which have been separated from the LNG stream.

[0125] In some embodiments, the overhead stream is flowed into an overhead condenser (not shown), which may separate any liquid within the overhead stream and return it to the cryogenic fractionation column 960 as reflux. This may result in the production of one vapor stream, a fuel stream including primarily methane and another vapor stream including primarily low boiling point gases. The fuel stream may be flowed through the eighth heat exchanger 952 via line 964. Within the eighth heat exchanger 952, the temperature of the vapor fuel stream may be increased via indirect heat exchange with the natural gas stream, producing a vapor fuel stream. The vapor fuel stream may be combined with other vapor fuel streams within a pipe joint 966. The combined vapor fuel stream may then be compressed and cooled within a series of compressors 968, 970, and 972 and chillers 974, 976, 978. The resulting vapor fuel stream may be combined with the natural gas stream from line 818, which may be a vapor fuel stream from the natural gas stream 808, within a pipe joint 980. The vapor fuel stream may then be flowed out of the system 900 as fuel 982 via line 984.

[0126] The bottoms stream that is produced within the cryogenic fractionation column 960 includes primarily LNG with traces of nitrogen. The LNG stream may be flowed into LNG tank 986 via line 988. The line 988 may include a valve 990 that is used to control the flow of the LNG stream into the LNG tank 986. The LNG tank 986 may store the LNG stream for any period of time. Boil-off gas generated within the LNG tank 986 may be flowed to the pipe joint 966 via line 992. At any point in time, the final LNG stream 994 may be transported to a LNG tanker 996 using a pump 998, for transport to markets. Additional boil-off gas 999 generated while loading the final LNG stream 944 into the LNG tanker 996 may be recovered in the cascade cooling system 800.

[0127] It is to be understood that the process flow diagrams of Figs. 8A, 8B, and 9 are not intended to indicate that the cascade cooling system 800 or the system 900 is to include all the components shown in Figs. 8A, 8B, or 9. Further, the cascade cooling system 800 or the system 900 may include any number of additional components not shown in Figs. 8A, 8B, or 9, respectively, depending on the details of the specific implementation. In various embodiments, the heat exchangers 820, 822, 824, 876, 878, and 922 include high convection rate type tubes. The use of such high convection rate type tubes may reduce the size of the equipment and the inventory of refrigerant that is used to provide cooling within the heat exchangers 820, 822, 824, 876, 878, and 922. In addition, any of the heat exchangers 820, 822, 824, 876, 878, 922, or 926 may be included within a spiral wound type unit or a brazed aluminum type unit.

[0128] In various embodiments, the compressors 830, 854, 866, 888, 884, 918, 930, 934, 942, 968, 972, and 976 are centrifugal type compressors. In order to reduce the loss of refrigerant to the atmosphere, each compressor 830, 854, 866, 888, 884, 918, 930, 934, 942, 968, 972, and 976 may also include a reclaimer or a seal leak gas recovery system.

[0129] Figs. 10A and 10B are process flow diagrams of another cascade cooling system 1000. The cascade cooling system 1000 may be a modified version of the cascade cooling system 800 of Figs. 8A and 8B. Like numbered items are as described with respect to Figs. 8A and 8B. The cascade cooling system 1000 may be implemented within a hydrocarbon processing system.

[0130] The cascade cooling system 1000 may include a first fluorocarbon refrigeration system 1002, as shown in Fig. 10A, which may utilize a first fluorocarbon refrigerant, such as R-410A. The cascade cooling system 1000 may also include a second fluorocarbon refrigeration system 1004, as shown in Fig. 10B, which may utilize a second fluorocarbon refrigerant, such as R-508B. In addition, the cascade cooling system 1000 may include a nitrogen refrigeration system 1006, as shown in Fig. 10B.

[0131] The first fluorocarbon refrigeration system 1002 of Fig. 10A may be similar to the first fluorocarbon refrigeration system 802 of Fig. 8A. However, the first fluorocarbon refrigeration system 1002 of Fig. 10A may include a second heat exchanger 1008 and a third heat exchanger 1010 in place of the heat exchangers 822 824 within the first fluorocarbon refrigeration system 802 of Fig. 8A.

[0132] Within the first fluorocarbon refrigeration system 1002, a fluorocarbon refrigerant of the second fluorocarbon refrigeration system 1004 is precooled, condensed, and sub-cooled by being flowed through the heat exchangers 820, 1008, and 1010 respectively. The fluorocarbon refrigerant may be a hydrofluorocarbon, such as R-508B, or any other suitable type of fluorocarbon. The fluorocarbon refrigerant may be flowed from the second fluorocarbon refrigeration system 1004 to the heat exchangers 820, 1008, and 1010 within the first fluorocarbon refrigeration system 1002 via line 870. Thus, the first fluorocarbon refrigeration system 1002 of Fig. 10A may provide for a greater degree of precooling and less compression of the second fluorocarbon refrigerant than the first fluorocarbon refrigeration system 802 of Fig. 8A, since the fluorocarbon refrigerant is flowed through all three heat exchangers 802, 1008, and 1010.

[0133] The natural gas stream is progressively chilled within each of the heat exchangers 820, 1008, and 1010. The chilled natural gas stream is then flowed into the second fluorocarbon refrigeration system 1004, as shown in Fig. 10B, via line 874. The second fluorocarbon refrigeration system 1004 may include the fourth heat exchanger 876 and a fifth heat exchanger 1012, which may further cool the natural gas stream using the fluorocarbon refrigerant.

[0134] The fluorocarbon refrigerant may be continuously circulated through the second refrigeration system 1004, which prepares the fluorocarbon refrigerant for entry into each of the heat exchangers 876 and 1012. The fluorocarbon refrigerant may exit the fourth heat exchanger 876 as a vapor fluorocarbon refrigerant stream. The vapor fluorocarbon refrigerant stream may be combined with another vapor fluorocarbon refrigerant stream within the pipe joint 880, and may be combined with another vapor fluorocarbon refrigerant stream from the fifth heat exchanger 1012 within the pipe joint 882. The vapor fluorocarbon refrigerant stream may then be flowed through a compressor 884, which may increase the pressure of the vapor fluorocarbon refrigerant stream. The vapor may then be flowed through the first heat exchanger 820 within the first fluorocarbon refrigeration system 1002 via the line 870.

[0135] Once the fluorocarbon refrigerant stream has passed through the heat exchangers 820, 1008, and 1010, the fluorocarbon refrigerant stream may enter a third flash drum 1013 within the second fluorocarbon refrigeration system 1004 via line 1014. Line 1014 may include the expansion valve 908, which controls the flow of the fluorocarbon refrigerant stream into the third flash drum 1013. The expansion valve 908 may reduce the temperature and pressure of the fluorocarbon refrigerant stream, resulting in the flash evaporation of the fluorocarbon refrigerant stream into both a vapor fluorocarbon refrigerant stream and a liquid fluorocarbon refrigerant stream.

[0136] The vapor fluorocarbon refrigerant stream and the liquid fluorocarbon refrigerant stream may be flashed into the third flash drum 1013, which may separate the vapor fluorocarbon refrigerant stream from the liquid fluorocarbon refrigerant stream. The vapor fluorocarbon refrigerant stream may be flowed into the pipe joint 880 via line 1016. The liquid fluorocarbon refrigerant stream may be flowed from the third flash drum 1013 to the pipe joint 910, which may split the liquid fluorocarbon refrigerant stream into two separate liquid fluorocarbon refrigerant streams. One liquid fluorocarbon refrigerant stream may be flowed through the fourth heat exchanger 876 and returned to the pipe joint 880 via line 912. The other liquid fluorocarbon refrigerant stream may be flowed through the fifth heat exchanger 1012 via line 914. Line 914 may also include an expansion valve 916 that controls the flow of the liquid fluorocarbon refrigerant stream into the fifth heat exchanger 1012, e.g., by allowing the fluorocarbon refrigerant stream to flash, lowering the temperature and creating a vapor fluorocarbon refrigerant stream and a liquid fluorocarbon refrigerant stream. From the fifth heat exchanger 1012, the resulting vapor fluorocarbon refrigerant stream may be compressed within the compressor 918 and then flowed into the pipe joint 882 to be recirculated.

[0137] After the natural gas stream has been cooled within the heat exchangers 876 and 878 through indirect heat exchange with the fluorocarbon refrigerant stream, the natural gas stream may be flowed into the nitrogen refrigeration system 1006 via line 920. In various embodiments, a nitrogen refrigerant stream of the nitrogen refrigeration system 1006 is precooled by being flowed through each of the heat exchangers 820, 1008, 1010, 876, and 1012. The nitrogen refrigerant stream may be flowed from the nitrogen refrigeration system 1006 to the heat exchangers 820, 1008, 1010, 876, and 1012 via line 921.

[0138] Within the nitrogen refrigeration system 1006, the natural gas stream may be cooled within a sixth heat exchanger 1018 via indirect heat exchange with the nitrogen refrigerant stream. The nitrogen refrigerant stream may be continuously circulated through the nitrogen refrigeration system 1006, which prepares the nitrogen refrigerant stream for entry into the sixth heat exchanger 1018.

[0139] From the sixth heat exchanger 1018, the nitrogen refrigerant stream may be combined with another nitrogen refrigerant stream within a pipe joint 1020. The combined nitrogen refrigerant stream may be flowed through the seventh heat exchanger 926 via line 928. Within the seventh heat exchanger 926, the nitrogen refrigerant stream may provide cooling for a high pressure nitrogen refrigerant stream that is flowing in the opposite direction. From the seventh heat exchanger 926, the nitrogen refrigerant stream may be compressed within the first compressor 930, cooled within the first chiller 932, compressed within the second compressor 934, cooled within the second chiller 936, compressed within a third compressor 1022, and cooled within a third chiller 1024. The resulting high pressure nitrogen refrigerant stream may then be flowed into a pipe joint 1026, which may split the high pressure nitrogen refrigerant stream into two separate high pressure nitrogen refrigerant streams.

[0140] From the pipe joint 1026, one high pressure nitrogen refrigerant stream may be flowed through the heat exchangers 820, 1008, 1010, 876, and 1012 via the line 921. Upon exiting the fifth heat exchanger 1012, the nitrogen refrigerant stream may be expanded within an expander 1028, generating power, and flowed into the pipe joint 1020 to be combined with the nitrogen refrigerant stream exiting the sixth heat exchanger 1018.

[0141] The other high pressure nitrogen refrigerant stream may be flowed from the pipe joint 1026 through the seventh heat exchanger 926. The high pressure nitrogen refrigerant stream may then be expanded within an expander 1030, generating power, and flowed through the sixth heat exchanger 1018 to provide cooling for the natural gas stream. The power generated in expanders 1028 and 1030 may be used to generate electricity or to drive part of the compressors 930, 934 or 1022.

[0142] Once the natural gas stream has been cooled within the nitrogen refrigeration system 1006, the natural gas stream may be in the form of LNG. The LNG stream may be flowed into the system 900 of Fig. 9 via line 948. Within the system 900, nitrogen may be removed from the LNG within the NRU 902, and the final LNG stream 994 may be obtained, as discussed with respect to Fig. 9.

[0143] Fig. 10C is a process flow diagram of an alternative embodiment of the cascade cooling system 1000 with a simplified nitrogen refrigeration system 1032. As shown in Fig.

10C, the pipe joints 1020 and 1026, the seventh heat exchanger 926, the expander 1030, and the chillers 932 and 936 are not included within the nitrogen refrigeration system 1032. In addition, the first compressor 930 and the second compressor 934 are combined into a single unit, i.e., compressor 1134. In such embodiments, the entire nitrogen refrigerant stream is flowed through the heat exchangers 820, 1008, 1010, 876, and 1012 via the line 921. Thus, such an embodiment simplifies the design of the cascade cooling system 1000. The power generated in expander 1028 may be used to generate electricity or to drive part of the compressors 1022 or 1134.

[0144] It is to be understood that the process flow diagrams of Figs. 10A, 10B, and 10C are not intended to indicate that the cascade cooling system 1000 is to include all the components shown in Figs. 10A, 10B, and 10C. Further, the cascade cooling system 1000 may include any number of additional components not shown in Figs. 10A, 10B, and 10C, depending on the details of the specific implementation.

[0145] Figs. 11A and 11B are process flow diagrams of another cascade cooling system 1100. The cascade cooling system 1100 may be a modified version of the cascade cooling systems 800 and 1000 of Figs. 8A, 8B, 10A, 10B, and 10C, respectively. Like numbered items are as described with respect to Figs. 8A, 8B, 10A, 10B, and 10C. The cascade cooling system 1100 may be implemented within a hydrocarbon processing system.

[0146] The cascade cooling system 1100 may include a first fluorocarbon refrigeration system 1102, as shown in Fig. 11A, which may utilize a first fluorocarbon refrigerant, such as R-410A. The cascade cooling system 1100 may also include a second fluorocarbon refrigeration system 1104, as shown in Fig. 11B, which may utilize a second fluorocarbon refrigerant, such as R-508B.

[0147] Fig. 11C is a process flow diagram of an autorefrigeration system 1105 that is implemented within the same hydrocarbon processing system as the cascade cooling system 1100 of Figs. 11A and 11B. Like numbered items are as described with respect to Figs, 8A, 8B, 9, 10A, 10B, 10C, 11A, and 11B. The autorefrigeration system 1105 may be used to produce LNG from the natural gas stream. In addition, the autorefrigeration system 1105 may include a NRU 1106 for removing nitrogen from the natural gas stream.

[0148] A natural gas stream 808 may be flowed through the chiller 810, which pre-cools the natural gas stream 808 via indirect heat exchange with a cooling fluid. The natural gas stream 808 may then be flowed into the pipe joint 812 within the cascade cooling system 1100. The pipe joint 812 may be configured to split the natural gas stream 808 into three separate natural gas streams. A first natural gas stream may be flowed into a pipe joint 1107 via line 814, while a second natural gas stream and a third natural gas stream may be flowed into the autorefrigeration system 1105 via lines 816 and 818, respectively.

[0149] Within the pipe joint 1107, the natural gas stream may be combined with a methane recycle stream that is returned from the autorefrigeration system 1105 via line 1108. The combined natural gas stream may then be flowed into the first fluorocarbon refrigeration system 1102 in preparation for cooling of the natural gas stream. The natural gas stream may be cooled by being passed through a series of heat exchangers 1110, 822, and 824 within the first fluorocarbon refrigeration system 1102. The natural gas stream may be cooled within each of the heat exchangers 1110, 822, and 824 through indirect heat exchange with a circulating fluorocarbon refrigerant, as discussed with respect to Fig. 8A.

[0150] The cooled natural gas stream is then flowed into the second fluorocarbon refrigeration system 1104, as shown in Fig. 11B, via line 874. The second fluorocarbon refrigeration system 1104 may include a fourth heat exchanger 1112 and a fifth heat exchanger 1114, which may further cool the natural gas stream using the fluorocarbon refrigerant.

[0151] The fluorocarbon refrigerant may be continuously circulated through the second refrigeration system 1104, which prepares the fluorocarbon refrigerant for entry into each of the heat exchangers 1112 and 1114. The fluorocarbon refrigerant may exit the fourth heat exchanger 1112 as a vapor fluorocarbon refrigerant stream. The vapor fluorocarbon refrigerant stream may be combined with another vapor fluorocarbon refrigerant stream within the pipe joint 880, and may be combined with another vapor fluorocarbon refrigerant stream from the fifth heat exchanger 1114 within the pipe joint 882. The vapor fluorocarbon refrigerant stream may then be flowed through a compressor 884, which may increase the pressure of the vapor fluorocarbon refrigerant stream. The vapor may then be flowed through the first heat exchanger 1110 within the first fluorocarbon refrigeration system 1102 via the line 870.

[0152] Once the fluorocarbon refrigerant stream has passed through the heat exchangers 1110, 822, and 824, the fluorocarbon refrigerant stream may enter the third flash drum 1013 within the second fluorocarbon refrigeration system 1104 via line 1014. Line 1014 may include the expansion valve 908, which controls the flow of the fluorocarbon refrigerant stream into the third flash drum 1013. The expansion valve 908 may reduce the temperature and pressure of the fluorocarbon refrigerant stream, resulting in the flash evaporation of the fluorocarbon refrigerant stream into both a vapor fluorocarbon refrigerant stream and a liquid fluorocarbon refrigerant stream.

[0153] The vapor fluorocarbon refrigerant stream and the liquid fluorocarbon refrigerant stream may be flashed into the third flash drum 1013, which may separate the vapor fluorocarbon refrigerant stream from the liquid fluorocarbon refrigerant stream. The vapor fluorocarbon refrigerant stream may be flowed into the pipe joint 880 via line 1016. The liquid fluorocarbon refrigerant stream may be flowed from the third flash drum 1013 to the pipe joint 910, which may split the liquid fluorocarbon refrigerant stream into two separate liquid fluorocarbon refrigerant streams. One liquid fluorocarbon refrigerant stream may be flowed through the fourth heat exchanger 1112 and returned to the pipe joint 880 via line 912. The other liquid fluorocarbon refrigerant stream may be flowed through the fifth heat exchanger 1114 via line 914. Line 914 may also include an expansion valve 916 that controls the flow of the liquid fluorocarbon refrigerant stream into the fifth heat exchanger 1114, e.g., by allowing the fluorocarbon refrigerant stream to flash, lowering the temperature and creating a vapor fluorocarbon refrigerant stream and a liquid fluorocarbon refrigerant stream. From the fifth heat exchanger 1114, the resulting vapor fluorocarbon refrigerant stream may be compressed within the compressor 918 and then flowed into the pipe joint 882 to be recirculated.

[0154] After the natural gas stream has been cooled within the heat exchangers 1112 and 1114 through indirect heat exchange with the fluorocarbon refrigerant stream, the natural gas stream may be flowed into the autorefrigeration system 1105 via line 1116. More specifically, the natural gas stream may be flowed into a sixth heat exchanger 1118 within the autorefrigeration system 1105. Within the sixth heat exchanger 1118, the natural gas stream may be cooled via indirect heat exchange with a lower temperature natural gas stream flowing in the opposite direction.

[0155] From the sixth heat exchanger 1118, the natural gas stream may be flowed into a pipe joint 1120, which splits the natural gas stream into two separate natural gas streams. One natural gas stream may be flowed through an expansion valve 1122, which may lower the temperature and pressure of the natural gas stream. The low temperature natural gas stream may then be flowed into the sixth heat exchanger 1118 via line 1124, and may be used for cooling of the natural gas stream within the sixth heat exchanger 1118. From the sixth heat exchanger 1118, the natural gas stream may be flowed into a pipe joint 1126, in which it may be combined with another natural gas stream. The combined natural gas stream may be compressed within a compressor 1128 and then flowed into the pipe joint 1107 within the first fluorocarbon refrigeration system 1102.

[0156] From the pipe joint 1120, the other natural gas stream may be flowed into an additional pipe joint 1130, in which it may be combined with another natural gas stream. The combined natural gas stream may be flowed into the NRU 1106 to remove excess nitrogen from the natural gas stream. Specifically, the natural gas stream may be flowed into the reboiler 954, which may decrease the temperature of the natural gas stream. The cooled natural gas stream may be expanded within the hydraulic expansion turbine 986 and then flowed through expansion valve 988, which lowers the temperature and pressure of the natural gas stream.

[0157] The natural gas stream may be flowed into the cryogenic fractionation column 960 within the NRU 1106. In addition, heat may be transferred to the cryogenic fractionation column 960 from the reboiler 954 via line 962. The cryogenic fractionation column 960 may separate nitrogen from the natural gas stream via a cryogenic distillation process. An overhead stream may be flowed out of the cryogenic fractionation column 960 via line 964. The overhead stream may include primarily methane, nitrogen, and other low boiling point or non-condensable gases, such as helium, which have been separated from the natural gas stream.

[0158] In some embodiments, the overhead stream is flowed into an overhead condenser 1132, which may separate any liquid within the overhead stream and return it to the cryogenic fractionation column 960 as reflux via line 1134. This may result in the production of one vapor stream, a fuel stream including primarily methane and another vapor stream including primarily low boiling point gases. The fuel stream may be flowed through a seventh heat exchanger 1136 via line 964. Within the seventh heat exchanger 1136, the temperature of the vapor fuel stream may be increased via indirect heat exchange with the natural gas stream from line 816, producing a vapor fuel stream. The vapor fuel stream may be compressed and chilled within a series of compressors 1138 and 1140 and chillers 1142 and 1144. The resulting vapor fuel stream may be combined with the natural gas stream from line 818, which may be a vapor fuel stream from the natural gas stream 808, within the pipe joint 980. The vapor fuel stream may then be flowed out of the autorefrigeration system 1105 as fuel 982 via line 984.

[0159] The bottoms stream that is produced within the cryogenic fractionation column 960 includes primarily LNG with traces of nitrogen. The bottoms stream may be flowed through the overhead condenser 1132 via line 1146. Line 1146 may also include an expansion valve 1148 that controls the flow of the bottoms stream into the overhead condenser 1132. The bottoms stream may be used as refrigerant for the overhead condenser 1132.

[0160] From the overhead condenser 1132, the resulting mixed phase stream may be flowed into a first flash drum 1150 via line 1152. The first flash drum 1150 may separate the mixed phase stream into a vapor stream that includes primarily natural gas and a LNG stream. The vapor stream may be flowed into a pipe joint 1154. The pipe joint 1154 may combine the vapor stream with another vapor stream recovered from a second flash drum 1156. The combined vapor streams may be flowed into a compressor 1158 via line 1160. From the compressor 1158, the natural gas stream may be flowed into the pipe joint 1126.

[0161] From the first flash drum 1150, the LNG stream may be flowed into the second flash drum 1156 via line 1162. The line 1162 may include an expansion valve 1164 that controls the flow of the LNG stream into the second flash drum 1156, allowing a portion of the liquid from the LNG stream to flash, creating a mixed phase system that is flowed into the second flash drum 1156.

[0162] The second flash drum 1156 may separate the mixed phase stream into LNG and a vapor stream that includes natural gas. The vapor stream may be flowed into a pipe joint 1166 via line 1168. The pipe joint 1166 may combine the vapor stream with another vapor stream recovered from a third flash drum 1170. The combined vapor streams may be compressed within a compressor 1172 and flowed into the pipe joint 1154.

[0163] The LNG stream may then be flowed into the third flash drum 1170 via line 1174. The line 1174 may include an expansion valve 1176 that controls the flow of the LNG stream into the third flash drum 1170, allowing a portion of the liquid from the LNG to flash. The third flash drum 1170 may further reduce the temperature and pressure of the LNG stream such that the LNG stream approaches an equilibrium temperature and pressure. The produced vapor stream may be flowed into a pipe joint 1178, which may combine the vapor stream with boil-off gas recovered from a LNG tank 1180. The combined vapor streams may be compressed within a compressor 1182 and flowed into the pipe joint 1166.

[0164] The LNG stream may be flowed into a LNG tank 1180 via line 1184. The LNG tank 1180 may store the LNG stream for any period of time. Boil-off gas generated within the LNG tank 1180 may be flowed to the pipe joint 1178 via line 1186. At any point in time, the final LNG stream 994 may be transported to a LNG tanker 996 using a pump 998, for transport to markets. Additional boil-off gas 999 generated while loading the final LNG stream 944 into the LNG tanker 996 may be recovered in the cascade cooling system 1100.

[0165] It is to be understood that the process flow diagrams of Figs. 11A, 11B, and 912 are not intended to indicate that the cascade cooling system 1100 or the autorefrigeration system 1105 is to include all the components shown in Figs. 11A, 11B, or 11C. Further, the cascade cooling system 1100 or the autorefrigeration system 1105 may include any number of additional components not shown in Figs. 11A, 11B, or 11C, respectively, depending on the details of the specific implementation.

[0166] The pressures of the refrigerant streams within the cascade cooling systems 800, 1000, and 1100 of Figs. 8A and 8B; 10A, 10B, and 10C; 11A,and 11B, respectively, may vary considerably. In some embodiments, the lowest refrigerant pressure is slightly above the local atmospheric pressure, but may be at a vacuum. In other embodiments, the lowest refrigerant pressure is between around 7-9 psia. This lowers the refrigerant temperature, increasing the load on the fluorocarbon refrigeration systems, but reducing the load on the nitrogen refrigeration system or methane autorefrigeration system. In some embodiments, using sub-atmospheric pressures allows refrigerant power to be shifted between the different fluorocarbon refrigeration systems, allowing for load balancing and the use of more operable drivers. For example, in some cases, refrigerant drivers may be identical for all the fluorocarbon refrigeration systems and the nitrogen refrigeration system.

Method for LNG Formation

[0167] Fig. 12 is a process flow diagram of a method 1200 for the formation of LNG from a natural gas stream. The method 1200 may be implemented within any suitable type of hydrocarbon processing system. The method 1200 begins at block 1202, at which the natural gas stream is cooled in a first fluorocarbon refrigeration system. The first fluorocarbon refrigeration system may be a mechanical refrigeration system, valve expansion system, turbine expansion system, or the like. The first fluorocarbon refrigeration system uses a first fluorocarbon refrigerant to cool the natural gas stream. The first fluorocarbon refrigerant may be, for example, a hydrofluorocarbon refrigerant, such as R-410A, or any other suitable type of fluorocarbon refrigerant.

[0168] In various embodiments, the first fluorocarbon refrigerant is compressed to provide a compressed first fluorocarbon refrigerant, and the compressed first fluorocarbon refrigerant is cooled by indirect heat exchange with a cooling fluid. The compressed first fluorocarbon refrigerant may be expanded to cool the compressed first fluorocarbon refrigerant, thereby producing an expanded, cooled first fluorocarbon refrigerant. The expanded, cooled first fluorocarbon refrigerant may be passed to a heat exchange area, which may be any suitable type of heat exchanger, such as a chiller or evaporator. In addition, the natural gas stream may be compressed and cooled by indirect heat exchange with an external cooling fluid. The natural gas stream may then be chilled within the heat exchange area using the expanded, cooled first fluorocarbon refrigerant.

[0169] The first fluorocarbon refrigeration system may also include any number of additional refrigeration stages for cooling the natural gas stream. For example, the first fluorocarbon refrigeration system may be a three stage refrigeration system that includes three heat exchange areas for cooling the natural gas stream via indirect heat exchange with the first fluorocarbon refrigerant.

[0170] At block 1204, the natural gas stream is cooled in a second fluorocarbon refrigeration system. The second fluorocarbon refrigeration system may be a mechanical refrigeration system, valve expansion system, turbine expansion system, or the like. The second fluorocarbon refrigeration system uses a second fluorocarbon refrigerant to cool the natural gas stream. The second fluorocarbon refrigerant may be, for example, a hydrofluorocarbon refrigerant, such as R-508B, or any other suitable type of fluorocarbon refrigerant.

[0171] In various embodiments, the second fluorocarbon refrigerant is compressed to provide a compressed second fluorocarbon refrigerant, and the compressed second fluorocarbon refrigerant is cooled by indirect heat exchange with a cooling fluid. The compressed second fluorocarbon refrigerant may be expanded to cool the compressed second fluorocarbon refrigerant, thereby producing an expanded, cooled second fluorocarbon refrigerant. The expanded, cooled second fluorocarbon refrigerant may be passed to a heat exchange area, which may be any suitable type of heat exchanger, such as a chiller or evaporator. In addition, the natural gas stream may be compressed and cooled by indirect heat exchange with an external cooling fluid. The natural gas stream may then be chilled within the heat exchange area using the expanded, cooled second fluorocarbon refrigerant.

[0172] The second fluorocarbon refrigeration system may also include any number of additional refrigeration stages for cooling the natural gas stream. For example, the second fluorocarbon refrigeration system may be a two stage refrigeration system that includes two heat exchange areas for cooling the natural gas stream via indirect heat exchange with the second fluorocarbon refrigerant. In addition, the second fluorocarbon refrigerant may be precooled within the first fluorocarbon refrigeration system. This may be accomplished by flowing the second fluorocarbon refrigerant through the heat exchange areas within the first fluorocarbon refrigeration system, for example.

[0173] At block 1206, the natural gas stream is liquefied to form LNG in a nitrogen refrigeration system. A nitrogen refrigerant may be used to liquefy the natural gas stream within the nitrogen refrigeration system. The nitrogen refrigerant may be maintained in a gas phase within the nitrogen refrigeration system. In various embodiments, the nitrogen is compressed and cooled in a series of compressors and chillers, expanded within a hydraulic expansion turbine to generate power and reduce the temperature of the nitrogen refrigerant, and flowed through a heat exchanger. Within the heat exchanger, the nitrogen refrigerant may liquefy the natural gas stream to produce LNG via indirect heat exchange with the natural gas stream.

[0174] At block 1208, nitrogen is removed from the LNG in a NRU. The NRU may include a cryogenic fractionation column, such as a NRU tower. Nitrogen that is separated from the LNG may be flowed out of the cryogenic fractionation column as an overhead stream, while the LNG may be flowed out of the cryogenic fractionation column as a bottoms stream. In addition, a liquid feed from the bottom of the nitrogen rejection unit may be used to provide cooling to a reflux condenser at the top of the nitrogen rejection unit.

[0175] It is to be understood that the process flow diagram of Fig. 12 is not intended to indicate that the steps of the method 1200 are to be executed in any particular order, or that all of the steps are to be included in every case. Further, any number of additional steps may be included within the method 1200, depending on the details of the specific implementation.

[0176] Fig. 13 is a process flow diagram of another method 1300 for the formation of LNG from a natural gas stream. Like numbered items are as described with respect to Fig. 12. The method 1300 may be implemented within any suitable type of hydrocarbon processing system.

The method 1300 includes cooling a natural gas stream in a first fluorocarbon refrigeration system at block 1202, and cooling the natural gas stream in a second fluorocarbon refrigeration system at block 1204.

[0177] In addition, at block 1302, the natural gas stream is cooled to form LNG in a methane autorefrigeration system. The methane autorefrigeration system may include a number of expansion valves and flash drums for cooling the natural gas. In some embodiments, the methane autorefrigeration system is the autorefrigeration system 1105 discussed with respect to Fig. 11C. Further, in some embodiments, a nitrogen rejection unit is located upstream of the methane autorefrigeration system.

[0178] It is to be understood that the process flow diagram of Fig. 13 is not intended to indicate that the steps of the method 1300 are to be executed in any particular order, or that all of the steps are to be included in every case. Further, any number of additional steps may be included within the method 1300, depending on the details of the specific implementation.

Embodiments

[0179] Embodiments of the invention may include any combinations of the methods and systems shown in the following numbered paragraphs. This is not to be considered a complete listing of all possible embodiments, as any number of variations can be envisioned from the description herein.

1. A hydrocarbon processing system for formation of a liquefied natural gas (LNG), including:

a first fluorocarbon refrigeration system configured to chill a natural gas using a first fluorocarbon refrigerant;

a second fluorocarbon refrigeration system configured to further chill the natural gas using a second fluorocarbon refrigerant;

a nitrogen refrigeration system configured to cool the natural gas using a nitrogen refrigerant to produce LNG; and

a nitrogen rejection unit configured to remove nitrogen from the LNG.

2. The hydrocarbon processing system of paragraph 1, wherein the first fluorocarbon refrigeration system is configured to cool the second fluorocarbon refrigerant of the second fluorocarbon refrigeration system.

3. The hydrocarbon processing system of any of paragraphs 1 or 2, wherein the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, is configured to cool the nitrogen refrigerant of the nitrogen refrigeration system.

4. The hydrocarbon processing system of any of paragraphs 1-3, wherein the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, includes multiple cooling cycles.

5. The hydrocarbon processing system of any of paragraphs 1-4, wherein the nitrogen refrigeration system includes a number of heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the nitrogen refrigerant.

6. The hydrocarbon processing system of any of paragraphs 1-5, wherein the first fluorocarbon refrigeration system includes:

a compressor configured to compress the first fluorocarbon refrigerant to provide a compressed first fluorocarbon refrigerant;

a chiller configured to cool the compressed first fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

a valve configured to expand the compressed first fluorocarbon refrigerant to cool the compressed first fluorocarbon refrigerant, thereby producing a cooled first fluorocarbon refrigerant; and

a heat exchanger configured to cool the natural gas via indirect heat exchange with the cooled first fluorocarbon refrigerant.

7. The hydrocarbon processing system of any of paragraphs 1-6, wherein the second fluorocarbon refrigeration system includes:

a compressor configured to compress the second fluorocarbon refrigerant to provide a compressed second fluorocarbon refrigerant;

a chiller configured to cool the compressed second fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

a valve configured to expand the compressed second fluorocarbon refrigerant to cool the compressed second fluorocarbon refrigerant, thereby producing a cooled second fluorocarbon refrigerant; and a heat exchanger configured to cool the natural gas via indirect heat exchange with the cooled second fluorocarbon refrigerant.

8. The hydrocarbon processing system of any of paragraphs 1-7, wherein the first fluorocarbon refrigerant includes R-410A.

9. The hydrocarbon processing system of any of paragraphs 1-8, wherein the second fluorocarbon refrigerant includes R-508B.

10. The hydrocarbon processing system of any of paragraphs 1-9, wherein the first fluorocarbon refrigerant or the second fluorocarbon refrigerant, or both, includes a nontoxic, nonflammable refrigerant.

11. The hydrocarbon processing system of any of paragraphs 1-10, wherein the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, includes two or more chillers and two or more compressors.

12. The hydrocarbon processing system of any of paragraphs 1-11, wherein the first fluorocarbon refrigeration system and the second fluorocarbon refrigeration system are implemented in series.

13. The hydrocarbon processing system of any of paragraphs 1-12, wherein the nitrogen refrigerant is in a gas phase.

14. The hydrocarbon processing system of any of paragraphs 1-13, wherein the nitrogen refrigeration system includes two or more chillers, two or more expanders, and two or more compressors.

15. The hydrocarbon processing system of any of paragraphs 1-14, wherein the hydrocarbon processing system is configured to chill the natural gas for hydrocarbon dew point control.

16. The hydrocarbon processing system of any of paragraphs 1-15, wherein the hydrocarbon processing system is configured to chill the natural gas for natural gas liquid extraction.

17. The hydrocarbon processing system of any of paragraphs 1-16, wherein the hydrocarbon processing system is configured to separate methane and lighter gases from carbon dioxide and heavier gases.

18. The hydrocarbon processing system of any of paragraphs 1-17, wherein the hydrocarbon processing system is configured to prepare hydrocarbons for liquefied petroleum gas production storage.

19. The hydrocarbon processing system of any of paragraphs 1-18, wherein the hydrocarbon processing system is configured to condense a reflux stream.

20. A method for formation of a liquefied natural gas (LNG), including:

cooling a natural gas in a first fluorocarbon refrigeration system;

cooling the natural gas in a second fluorocarbon refrigeration system;

liquefying the natural gas to form LNG in a nitrogen refrigeration system; and

removing nitrogen from the LNG in a nitrogen rejection unit.

21. The method of paragraph 20, including cooling a second fluorocarbon refrigerant of the second fluorocarbon refrigeration system within the first fluorocarbon refrigeration system.

22. The method of any of paragraphs 20 or 21, including cooling a nitrogen refrigerant of the nitrogen refrigeration system within the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both.

23. The method of any of paragraphs 20-22, wherein cooling the natural gas in the first fluorocarbon refrigeration system includes:

compressing a first fluorocarbon refrigerant to provide a compressed first fluorocarbon refrigerant;

optionally cooling the compressed first fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

expanding the compressed first fluorocarbon refrigerant to cool the compressed first fluorocarbon refrigerant, thereby producing an expanded, cooled first fluorocarbon refrigerant;

passing said expanded, cooled first fluorocarbon refrigerant to a first heat exchange area;

optionally compressing the natural gas;

optionally cooling the natural gas by indirect heat exchange with an external cooling fluid; and

heat exchanging the natural gas with the expanded, cooled first fluorocarbon refrigerant.

24. The method of any of paragraphs 20-23, wherein cooling the natural gas in the second fluorocarbon refrigeration system includes:

compressing a second fluorocarbon refrigerant to provide a compressed second fluorocarbon refrigerant;

optionally cooling the compressed second fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

expanding the compressed second fluorocarbon refrigerant to cool the compressed second fluorocarbon refrigerant, thereby producing an expanded, cooled second fluorocarbon refrigerant;

passing said expanded, cooled second fluorocarbon refrigerant to a first heat exchange area;

optionally compressing the natural gas;

optionally cooling the natural gas by indirect heat exchange with an external cooling fluid; and

heat exchanging the natural gas with the expanded, cooled second fluorocarbon refrigerant.

25. The method of any of paragraphs 20-24, including maintaining a nitrogen refrigerant of the nitrogen refrigeration system in a gas phase using one or more expansion turbines.

26. The method of any of paragraphs 20-25, including chilling the natural gas in the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, using two or more refrigeration stages.

27. The method of any of paragraphs 20-26, including liquefying the natural gas in the nitrogen refrigeration system using one or more refrigeration stages.

28. The method of any of paragraphs 20-27, including cooling a first fluorocarbon refrigerant of the first fluorocarbon refrigeration system or a second fluorocarbon refrigerant of the second fluorocarbon refrigeration system, or both, using a heat exchanger.

29. The method of any of paragraphs 20-28, including cooling a nitrogen refrigerant of the nitrogen refrigeration system using a heat exchanger.

30. A hydrocarbon processing system for formation of a liquefied natural gas (LNG), including:

a first refrigeration system configured to cool a natural gas using a first fluorocarbon refrigerant, wherein the first refrigeration system includes a number of first heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the first fluorocarbon refrigerant;

a second refrigeration system configured to chill the natural gas using a second fluorocarbon refrigerant, wherein the second refrigeration system includes a number of second heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the second fluorocarbon refrigerant;

a third refrigeration system configured to form LNG from the natural gas using a nitrogen refrigerant, wherein the third refrigeration system includes a number of third heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the nitrogen refrigerant; and

a nitrogen rejection unit configured to remove nitrogen from the LNG.

31. The hydrocarbon processing system of paragraph 30, wherein the nitrogen refrigerant is in a gas phase.

32. The hydrocarbon processing system of any of paragraphs 30 or 31, wherein the first heat exchangers include evaporators configured to cool the natural gas by at least partially vaporizing the first fluorocarbon refrigerant via a transfer of heat from the natural gas to the first fluorocarbon refrigerant.

33. The hydrocarbon processing system of any of paragraphs 30-32, wherein the second heat exchangers include evaporators configured to chill the natural gas by at least partially vaporizing the second fluorocarbon refrigerant via a transfer of heat from the natural gas to the second fluorocarbon refrigerant.

34. A hydrocarbon processing system for formation of a liquefied natural gas (LNG), including:

a first fluorocarbon refrigeration system configured to chill a natural gas using a first fluorocarbon refrigerant;

a second fluorocarbon refrigeration system configured to further chill the natural gas using a second fluorocarbon refrigerant; and

a methane autorefrigeration system configured to cool the natural gas to produce LNG.

35. The hydrocarbon processing system of paragraph 34, including a nitrogen rejection unit upstream of the methane autorefrigeration system.

36. The hydrocarbon processing system of any of paragraphs 34 or 35, wherein the methane autorefrigeration system includes a number of expansion valves and a number of flash drums.

[0180] While the present techniques may be susceptible to various modifications and alternative forms, the embodiments discussed herein have been shown only by way of example. However, it should again be understood that the techniques is not intended to be limited to the particular embodiments disclosed herein. Indeed, the present techniques include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A hydrocarbon processing system for formation of a liquefied natural gas (LNG), comprising:

a first fluorocarbon refrigeration system configured to chill a natural gas using a first fluorocarbon refrigerant;

a second fluorocarbon refrigeration system configured to further chill the natural gas using a second fluorocarbon refrigerant;

a nitrogen refrigeration system configured to cool the natural gas using a nitrogen refrigerant to produce LNG, wherein the nitrogen refrigerant is maintained in a gas phase in the nitrogen refrigeration system, and wherein the nitrogen refrigeration system comprises two or more chillers, two or more power-generating expanders, and two or more compressors; and

a nitrogen rejection unit configured to remove nitrogen from the LNG.

2. The hydrocarbon processing system of claim 1, wherein the first fluorocarbon refrigeration system is configured to cool the second fluorocarbon refrigerant of the second fluorocarbon refrigeration system.

3. The hydrocarbon processing system of claim 1, wherein the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, is configured to cool the nitrogen refrigerant of the nitrogen refrigeration system.

4. The hydrocarbon processing system of any one of claims 1 to 3, wherein the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, comprises multiple cooling cycles.

5. The hydrocarbon processing system of any one of claims 1 to 4, wherein the nitrogen refrigeration system comprises a plurality of heat exchangers configured to allow for cooling of the natural gas via an indirect exchange of heat between the natural gas and the nitrogen refrigerant.

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6. The hydrocarbon processing system of any one of claims 1 to 5, wherein the first fluorocarbon refrigeration system comprises:

a compressor configured to compress the first fluorocarbon refrigerant to provide a compressed first fluorocarbon refrigerant;

a chiller configured to cool the compressed first fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

a valve configured to expand the compressed first fluorocarbon refrigerant to cool the compressed first fluorocarbon refrigerant, thereby producing a cooled first fluorocarbon refrigerant; and

a heat exchanger configured to cool the natural gas via indirect heat exchange with the cooled first fluorocarbon refrigerant.

7. The hydrocarbon processing system of any one of claims 1 to 6, wherein the second fluorocarbon refrigeration system comprises:

a compressor configured to compress the second fluorocarbon refrigerant to provide a compressed second fluorocarbon refrigerant;

a chiller configured to cool the compressed second fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

a valve configured to expand the compressed second fluorocarbon refrigerant to cool the compressed second fluorocarbon refrigerant, thereby producing a cooled second fluorocarbon refrigerant; and

a heat exchanger configured to cool the natural gas via indirect heat exchange with the cooled second fluorocarbon refrigerant.

8. The hydrocarbon processing system of any one of claims 1 to 7, wherein the first fluorocarbon refrigerant comprises R-410A.

9. The hydrocarbon processing system of any one of claims 1 to 8, wherein the second fluorocarbon refrigerant comprises R-508B.

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10. The hydrocarbon processing system of any one of claims 1 to 7, wherein the first fluorocarbon refrigerant or the second fluorocarbon refrigerant, or both, comprises a nontoxic, nonflammable refrigerant.

11. The hydrocarbon processing system of any one of claims 1 to 10, wherein the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, comprises two or more chillers and two or more compressors.

12. The hydrocarbon processing system of any one of claims 1 to 11, wherein the first fluorocarbon refrigeration system and the second fluorocarbon refrigeration system are implemented in series.

13. A method for formation of a liquefied natural gas (LNG), comprising:

cooling a natural gas in a first fluorocarbon refrigeration system;

cooling the natural gas in a second fluorocarbon refrigeration system;

liquefying the natural gas to form LNG in a nitrogen refrigeration system;

maintaining a nitrogen refrigerant of the nitrogen refrigeration system in a gas phase using one or more expansion turbines; and

removing nitrogen from the LNG in a nitrogen rejection unit.

14. The method of claim 13, comprising cooling a second fluorocarbon refrigerant of the second fluorocarbon refrigeration system within the first fluorocarbon refrigeration system.

15. The method of claim 13, comprising cooling a nitrogen refrigerant of the nitrogen refrigeration system within the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both.

16. The method of any one of claims 13 to 15, wherein cooling the natural gas in the first fluorocarbon refrigeration system comprises:

compressing a first fluorocarbon refrigerant to provide a compressed first fluorocarbon refrigerant;

optionally cooling the compressed first fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

expanding the compressed first fluorocarbon refrigerant to cool the compressed first fluorocarbon refrigerant, thereby producing an expanded, cooled first fluorocarbon refrigerant;

passing said expanded, cooled first fluorocarbon refrigerant to a first heat exchange area;

optionally compressing the natural gas;

optionally cooling the natural gas by indirect heat exchange with an external cooling fluid; and

heat exchanging the natural gas with the expanded, cooled first fluorocarbon refrigerant.

17. The method of any one of claims 13 to 15, wherein cooling the natural gas in the second fluorocarbon refrigeration system comprises:

compressing a second fluorocarbon refrigerant to provide a compressed second fluorocarbon refrigerant;

optionally cooling the compressed second fluorocarbon refrigerant by indirect heat exchange with a cooling fluid;

expanding the compressed second fluorocarbon refrigerant to cool the compressed second fluorocarbon refrigerant, thereby producing an expanded, cooled second fluorocarbon refrigerant;

passing said expanded, cooled second fluorocarbon refrigerant to a first heat exchange area;

optionally compressing the natural gas;

optionally cooling the natural gas by indirect heat exchange with an external cooling fluid; and

heat exchanging the natural gas with the expanded, cooled second fluorocarbon refrigerant.

18. The method of any one of claims 13 to 17, comprising chilling the natural gas in the first fluorocarbon refrigeration system or the second fluorocarbon refrigeration system, or both, using two or more refrigeration stages.

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19. The method of any one of claims 13 to 18, comprising liquefying the natural gas in the nitrogen refrigeration system using one or more refrigeration stages.

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WATERMARK PATENT AND TRADE MARKS ATTORNEYS

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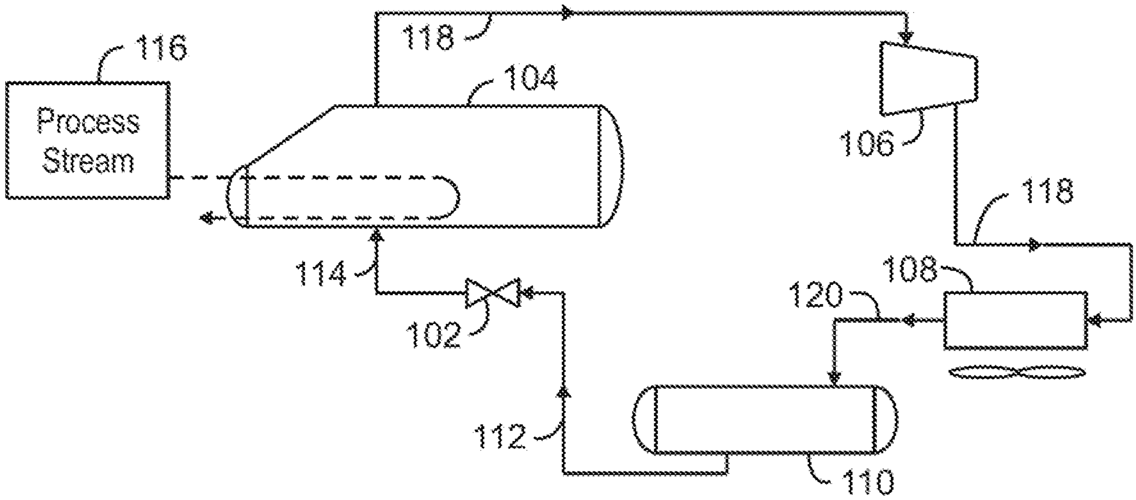
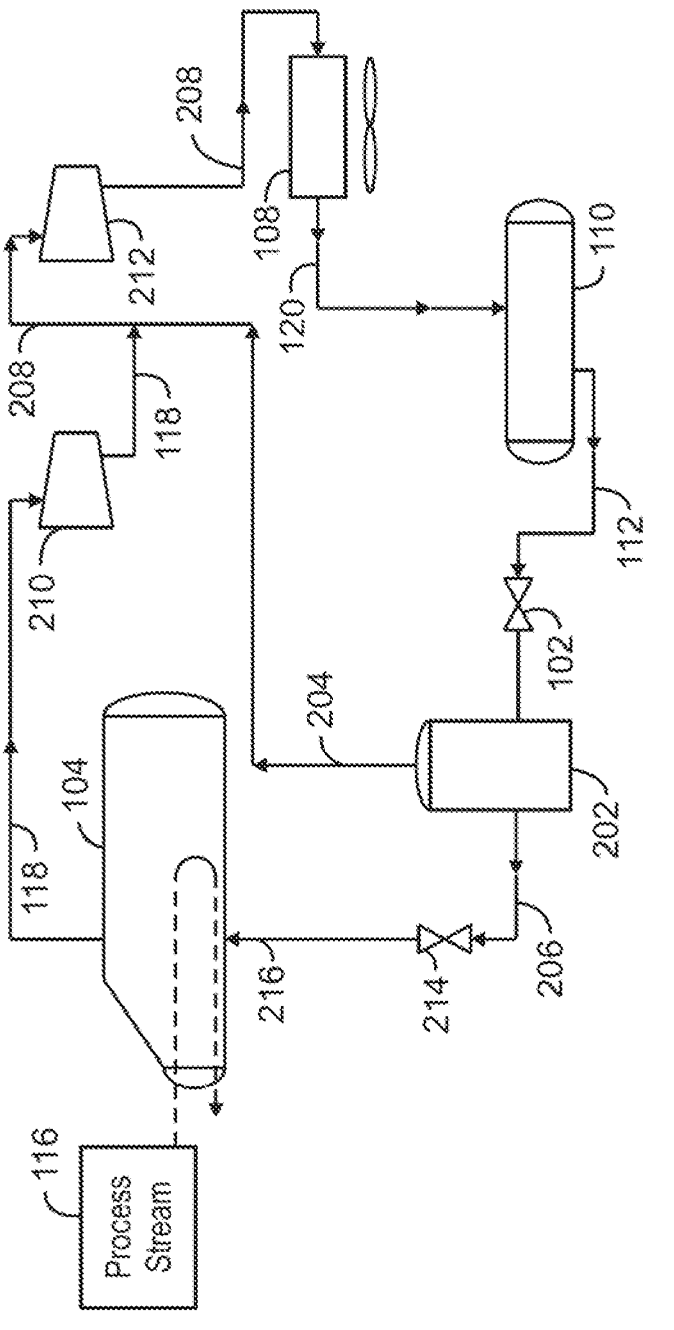
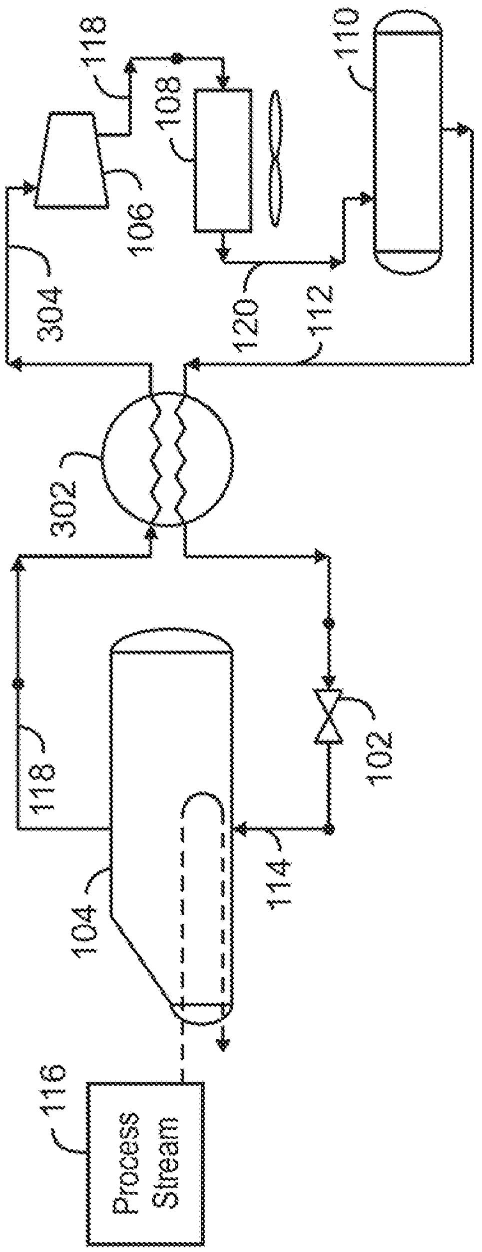


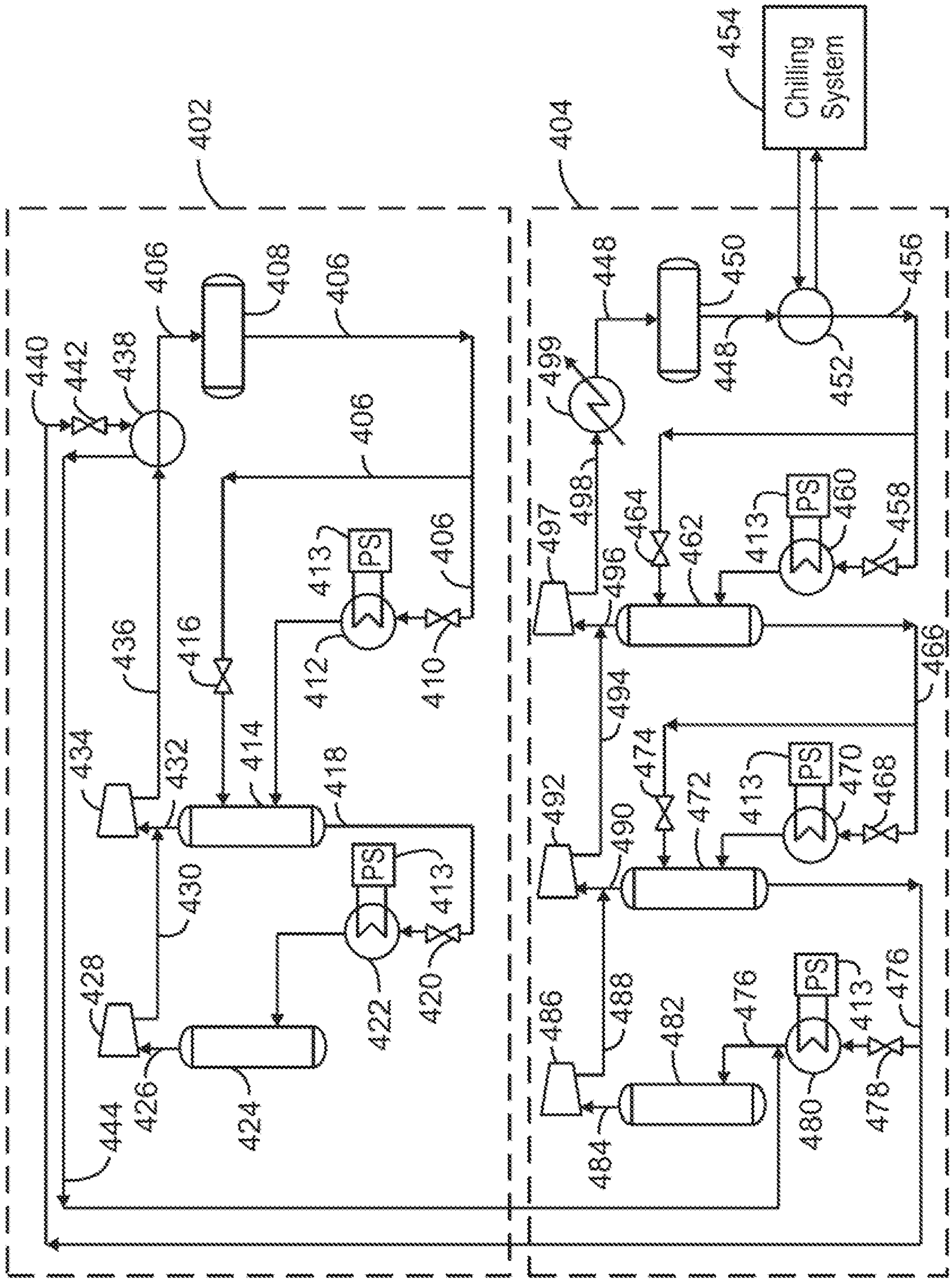
100
FIG. 1


Process Stream
116
104
118
210
118
208
212
208
108
120
110
112
102
204
202
206
214
216

200
FIG. 2

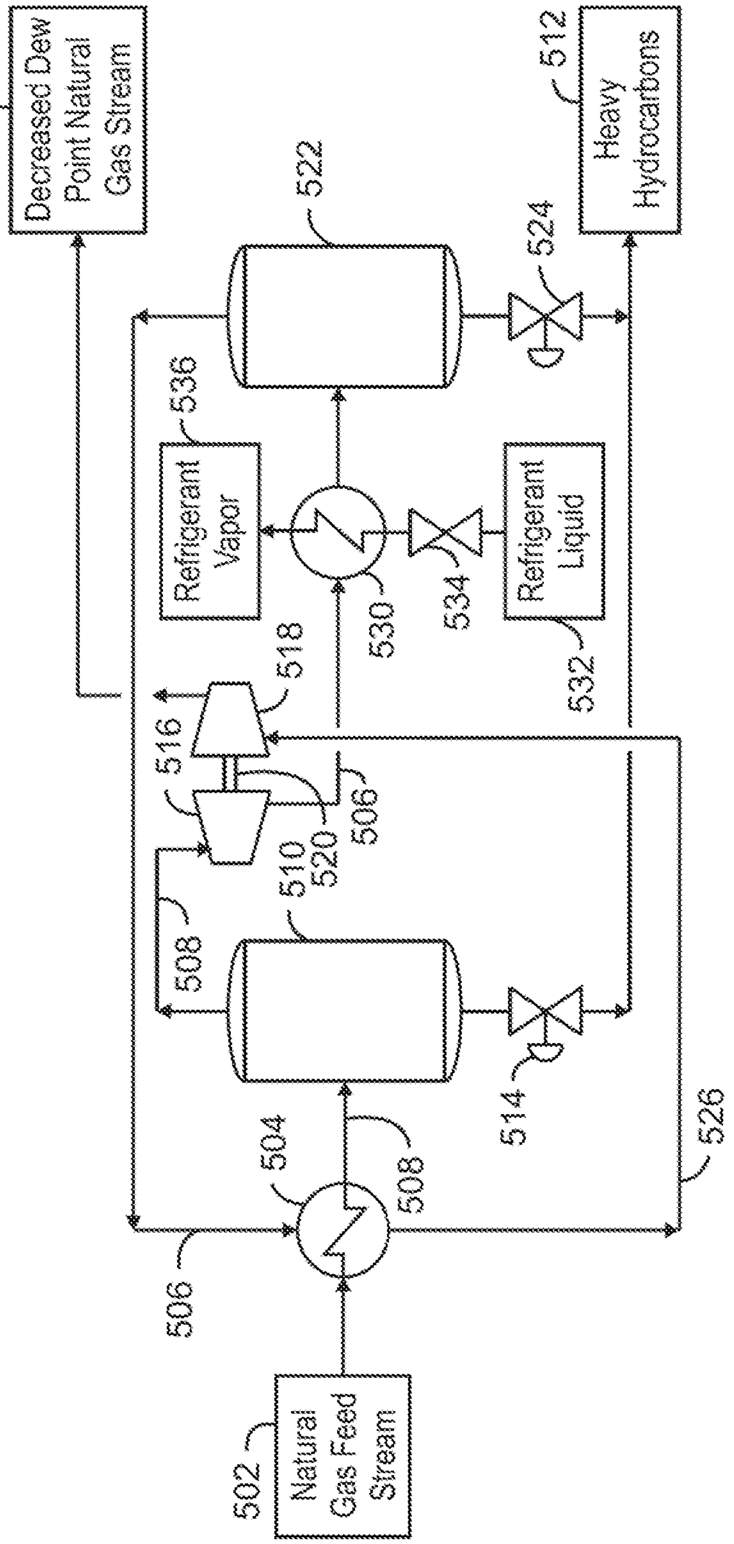

118
108
110
106
304
120
112
302
118
102
114
104
116
Process
Stream

300
FIG. 3

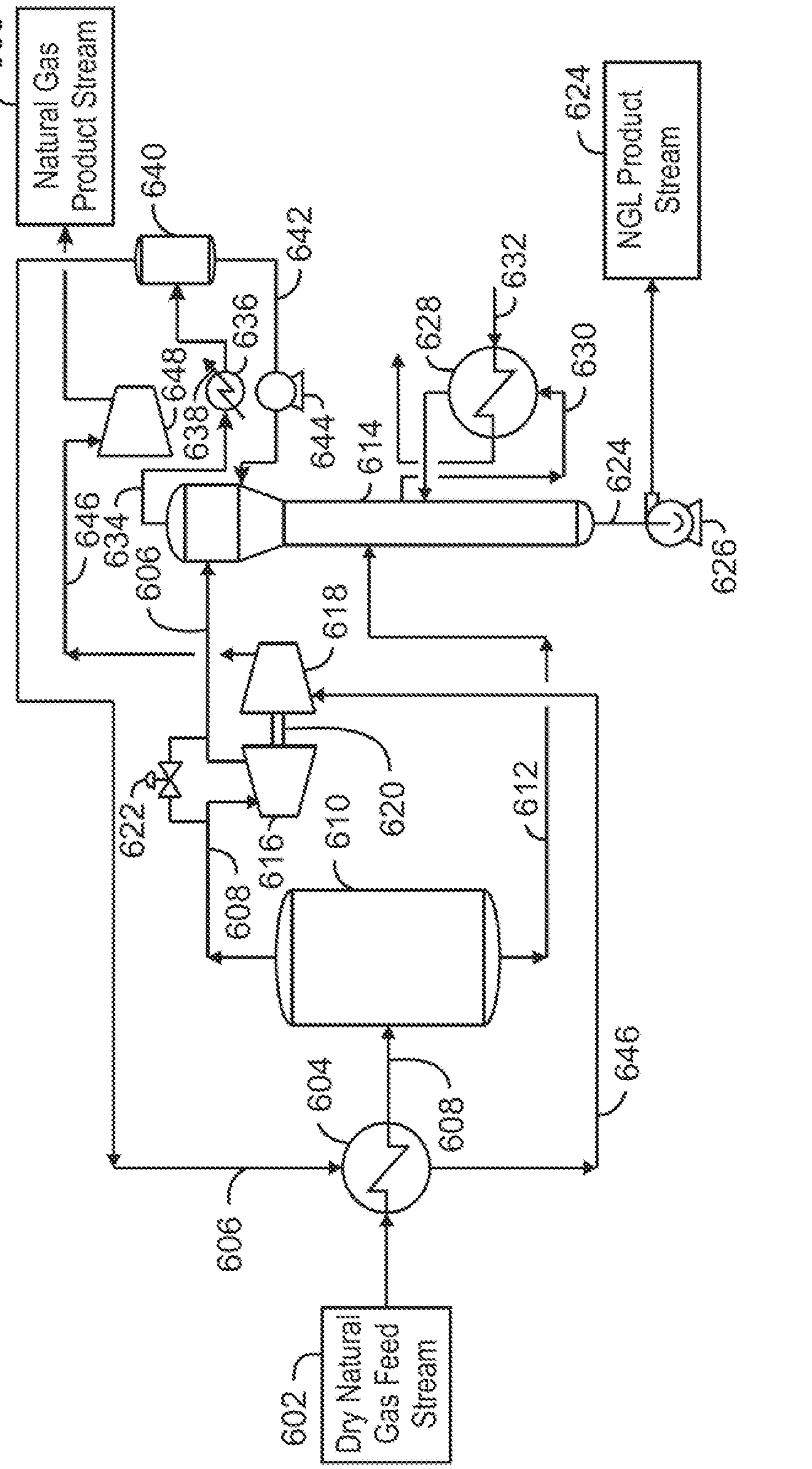

Chilling System
454
402
404
406
408
410
412
413
PS
414
416
418
420
422
424
426
428
430
432
434
436
438
440
442
444
448
450
452
456
458
460
462
464
466
468
470
472
474
476
478
480
482
484
486
488
490
492
494
496
497
498
499

400

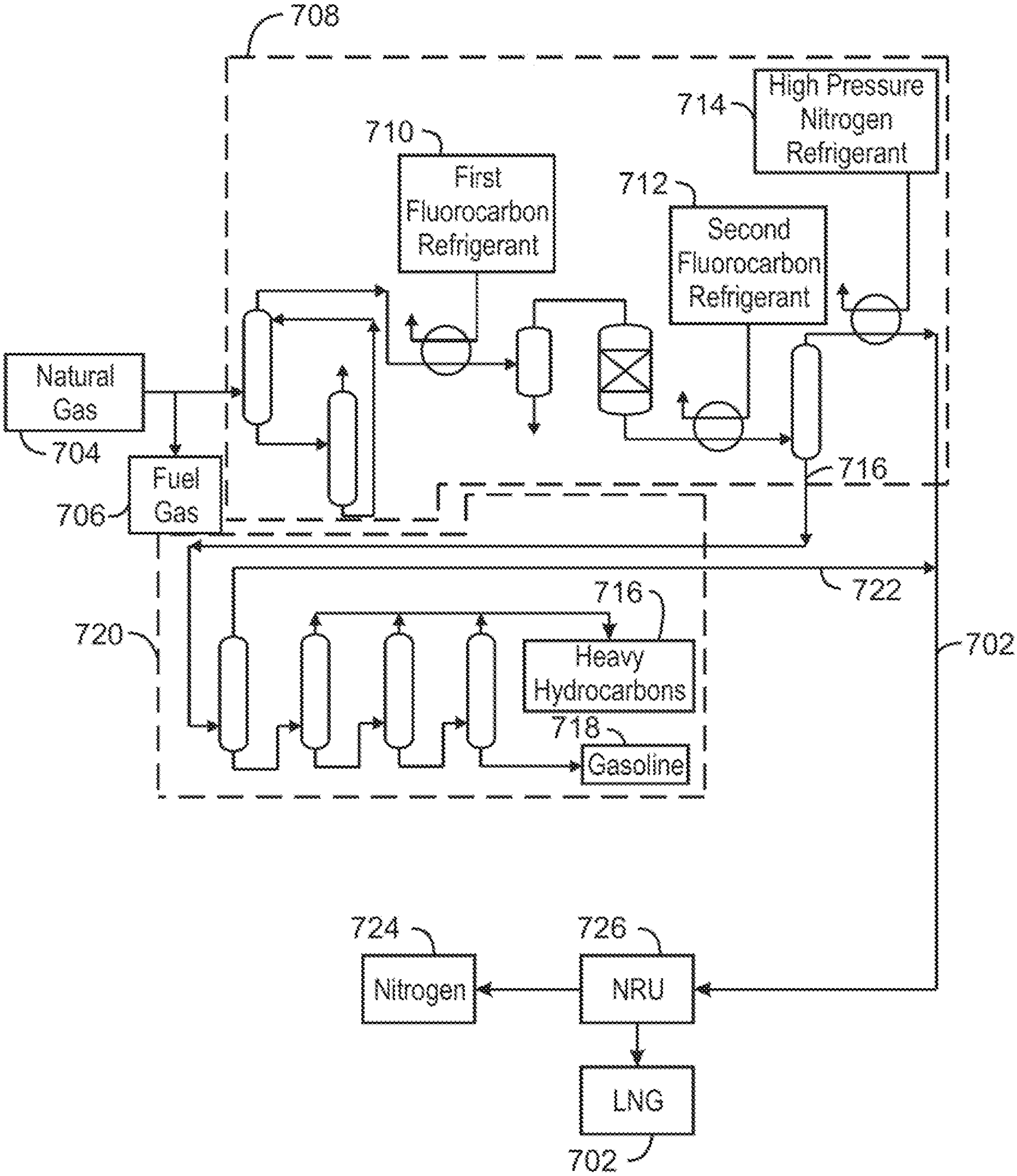
FIG. 4


Natural Gas Feed Stream
502
506
504
508
510
508
514
526
516
520
506
518
530
534
532
Refrigerant Vapor
536
Refrigerant Liquid
522
524
Heavy Hydrocarbons
512
Decreased Dew Point Natural Gas Stream
528

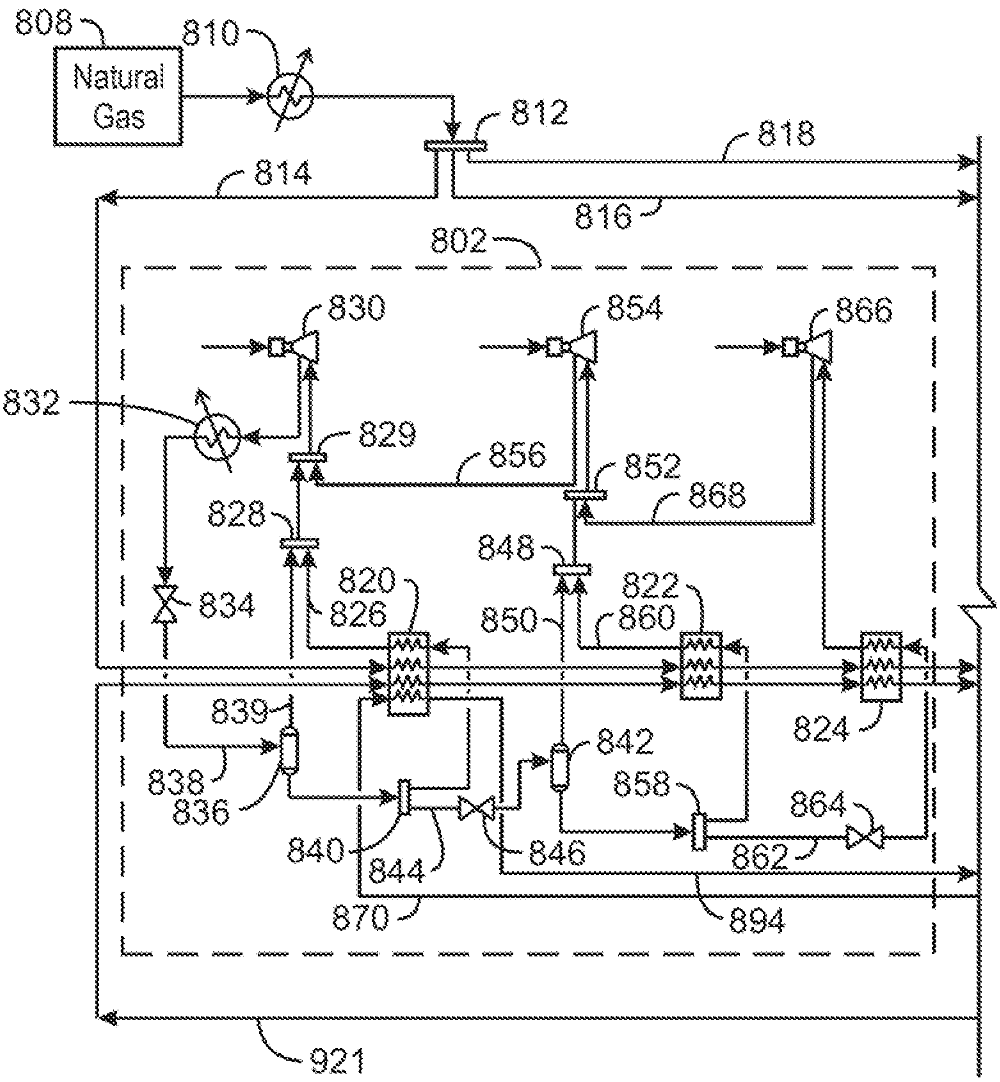
500
FIG. 5


Natural Gas Product Stream
650
NGL Product Stream
624
Dry Natural Gas Feed Stream
602
604
606
608
610
612
614
616
618
620
622
624
626
628
630
632
634
636
638
640
642
644
646
648

600
FIG. 6

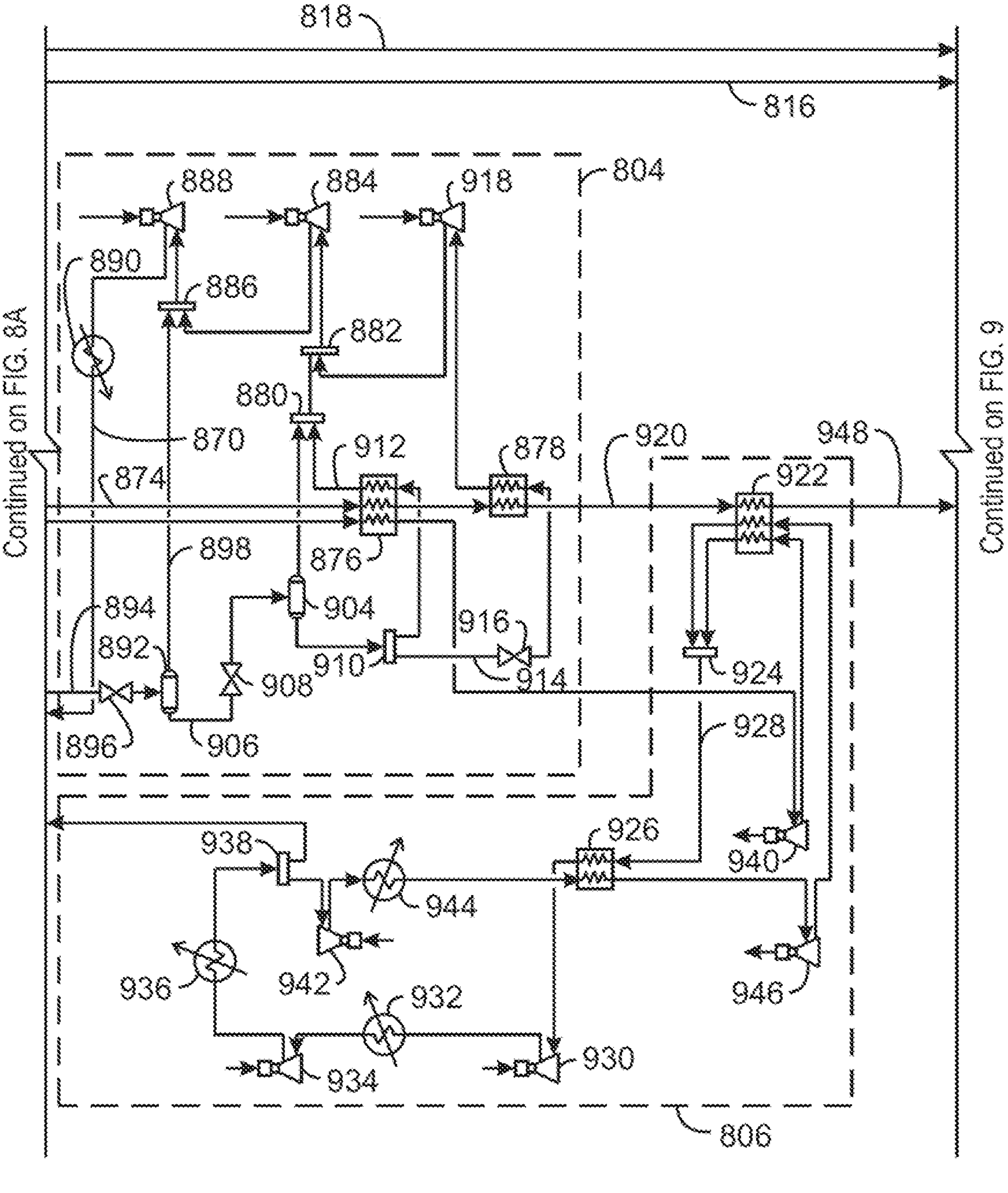

708
710
First Fluorocarbon Refrigerant
714
High Pressure Nitrogen Refrigerant
712
Second Fluorocarbon Refrigerant
Natural Gas
704
Fuel Gas
706
716
720
716
Heavy Hydrocarbons
718
Gasoline
722
702
724
Nitrogen
726
NRU
LNG
702

700
FIG. 7



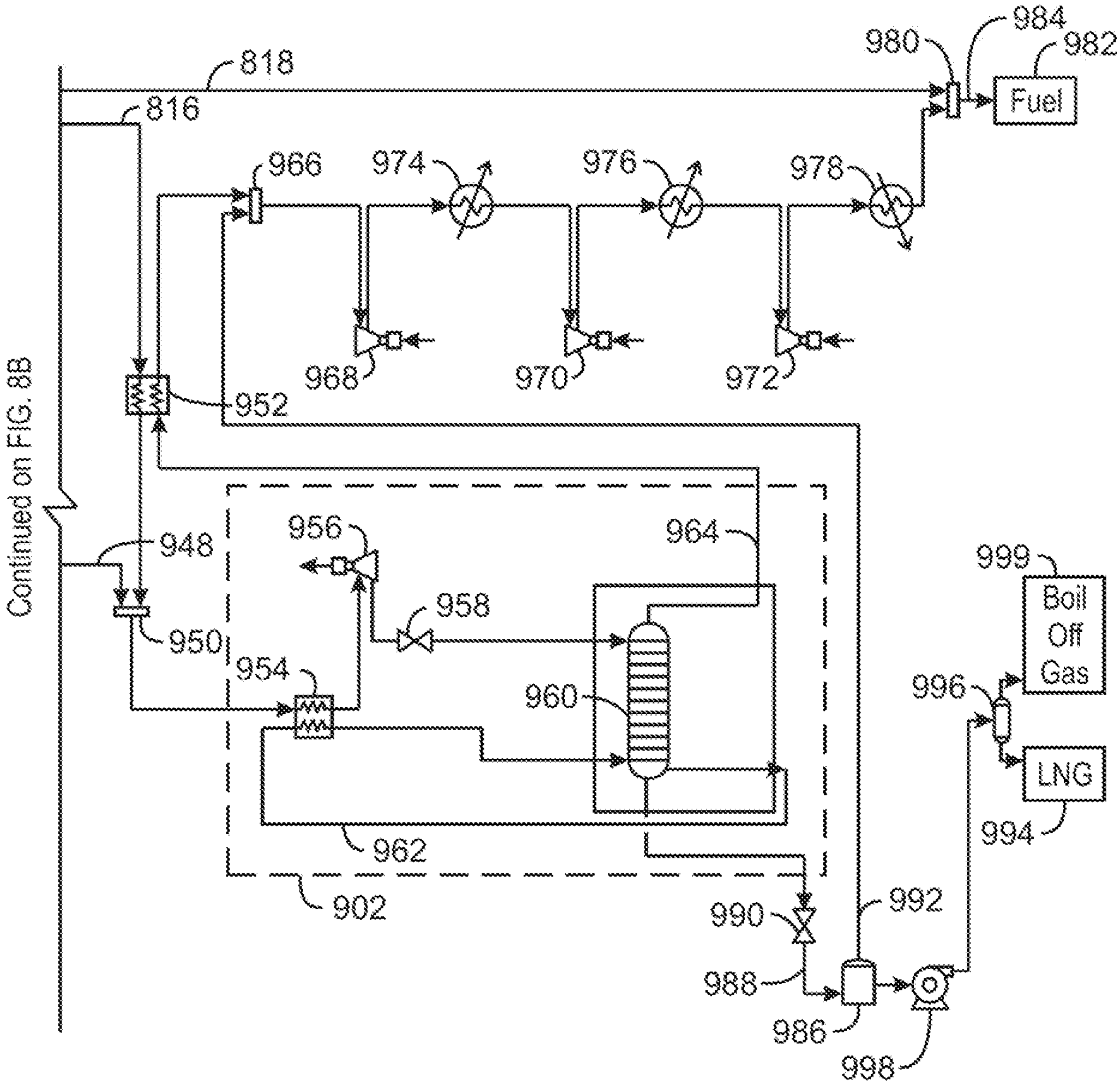
Continued on FIG. 8B

800
FIG. 8A


818
816
804
888
884
918
890
886
882
880
870
874
912
878
920
948
922
876
898
904
916
894
892
908
910
914
924
896
906
928
926
938
940
944
942
936
932
946
934
930
806
Continued on FIG. 8A
Continued on FIG. 9

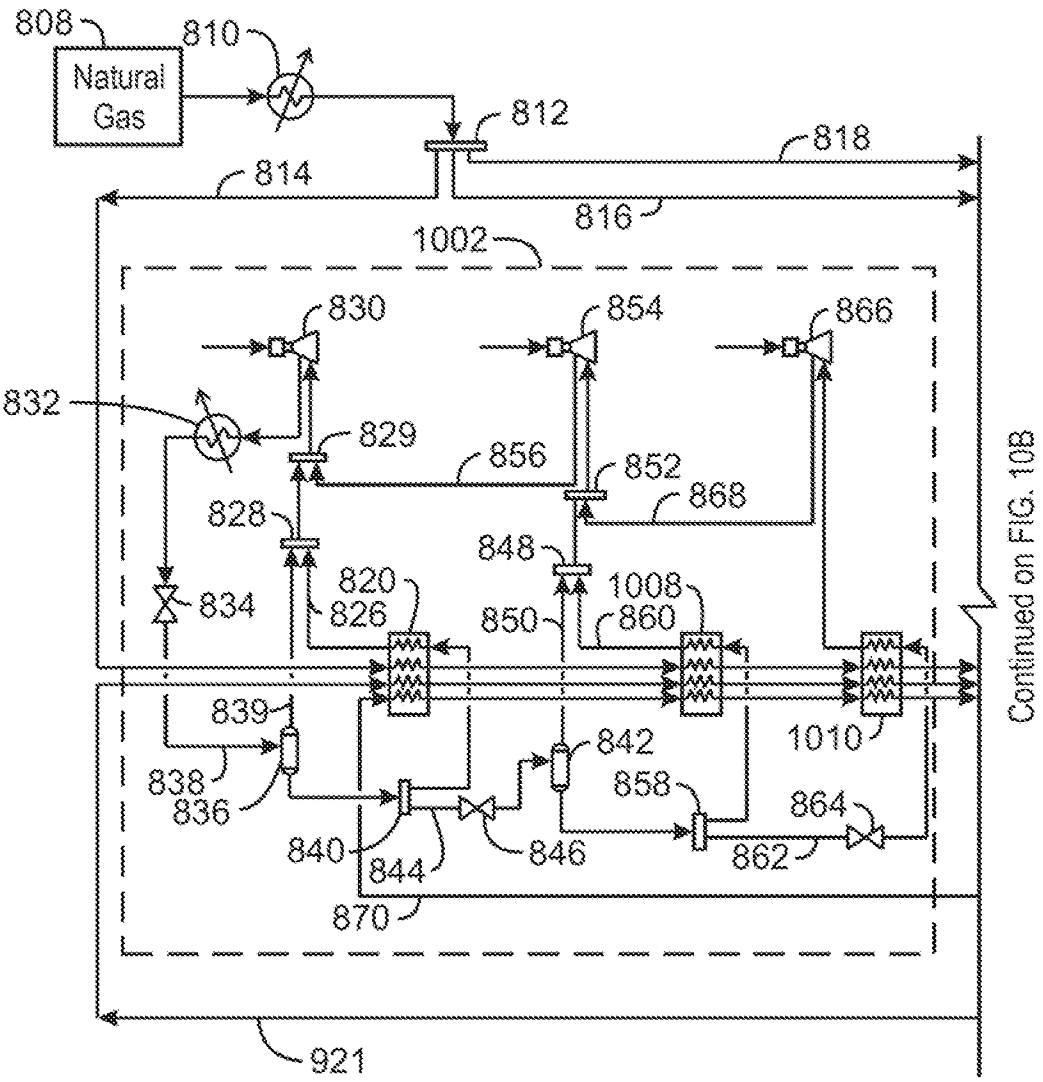
800

FIG. 8B


818
816
980
984
982
Fuel
966
974
976
978
968
970
972
952
Continued on FIG. 8B
948
950
956
964
958
954
960
962
902
999
Boil Off Gas
996
LNG
994
990
992
988
986
998

900

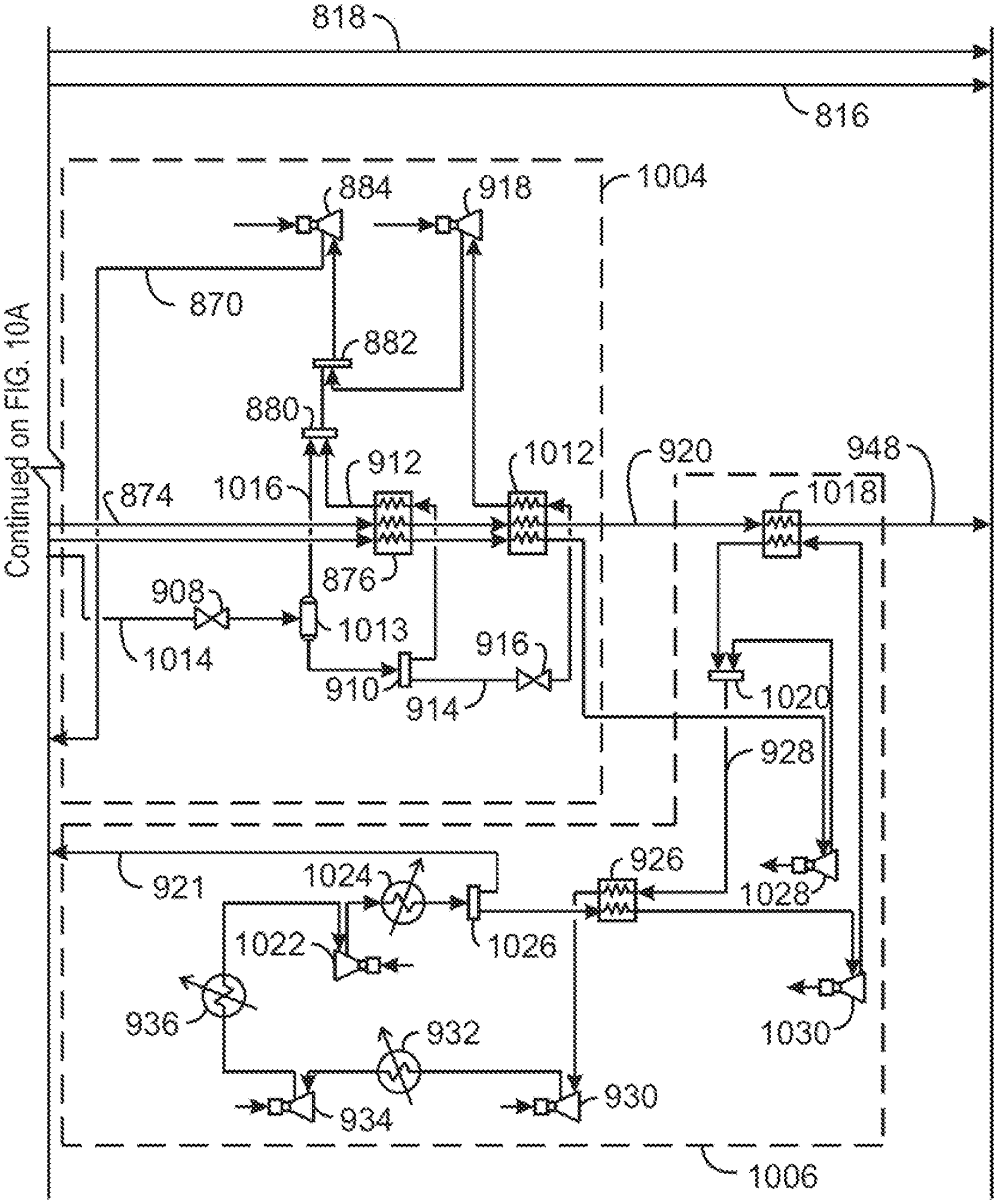
FIG. 9



808
Natural Gas
810
812
818
814
816
1002
830
854
866
832
829
856
852
868
828
848
820
1008
834
826
850
860
839
842
1010
838
836
858
864
840
844
846
862
870
921
Continued on FIG. 10B

1000

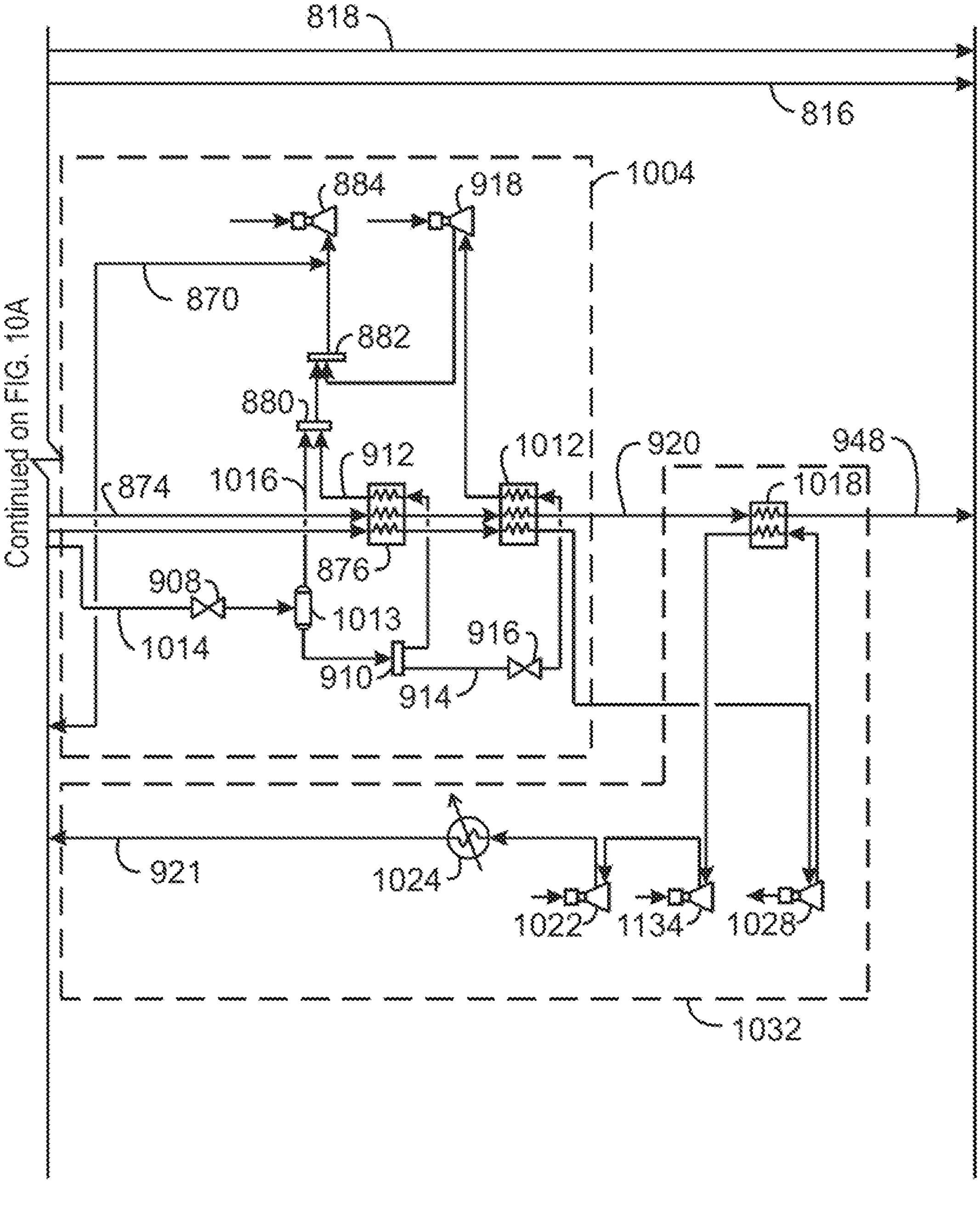
FIG. 10A



818
816
1004
884
918
870
882
880
Continued on FIG. 10A
874
1016
912
1012
920
948
1018
876
908
1013
1014
916
910
914
1020
928
921
1024
926
1028
1022
1026
1030
936
932
934
930
1006

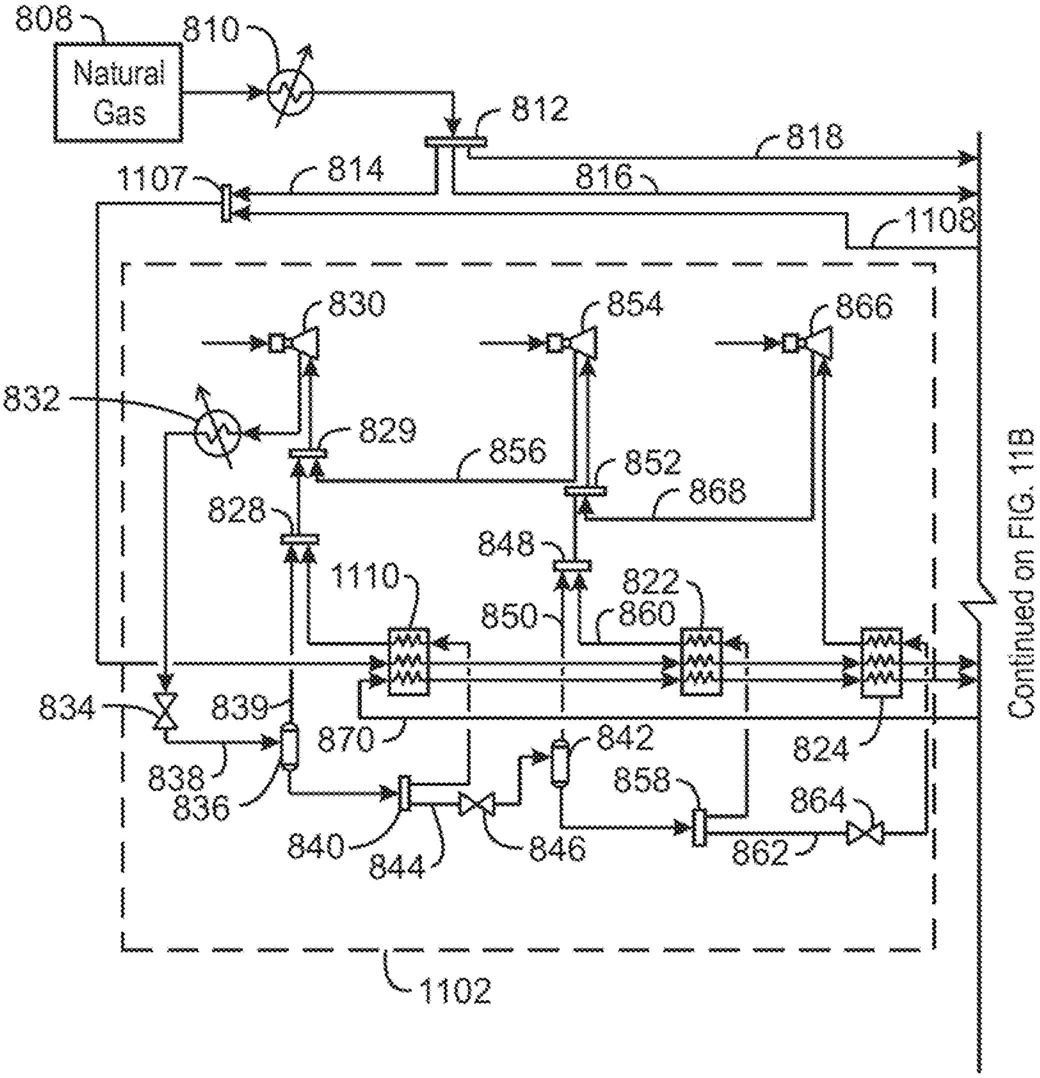
1000

FIG. 10B


818
816
1004
884
918
870
882
880
Continued on FIG. 10A
874
1016
912
1012
920
948
1018
876
908
1013
1014
916
910
914
921
1024
1022
1134
1028
1032

1000

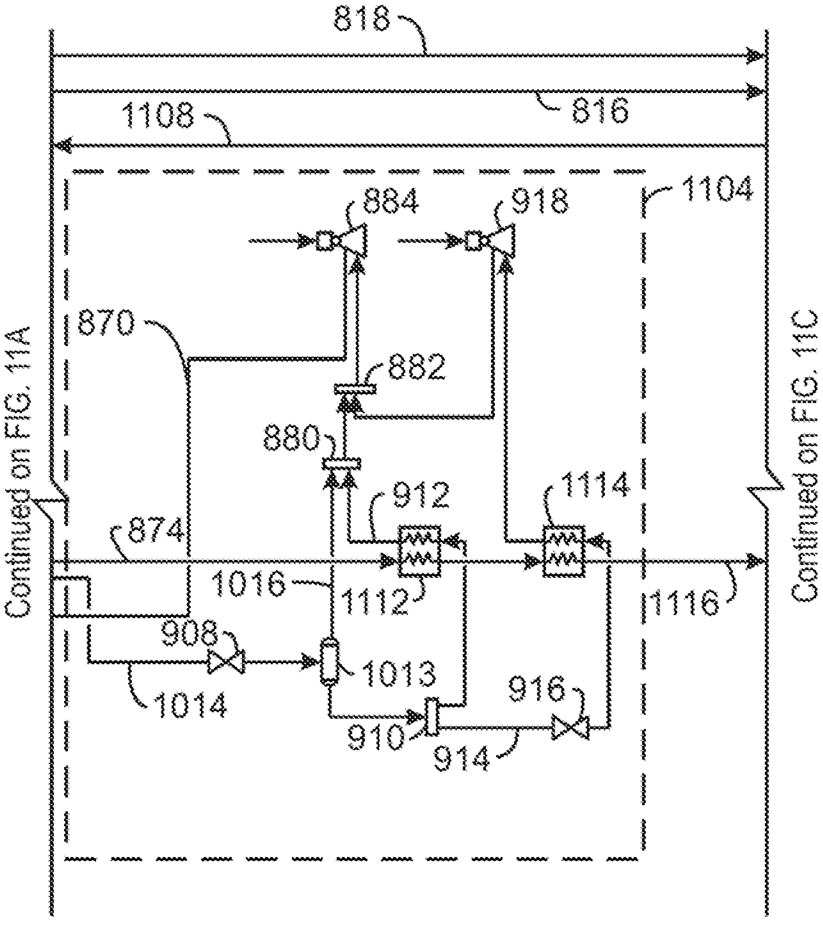
FIG. 10C



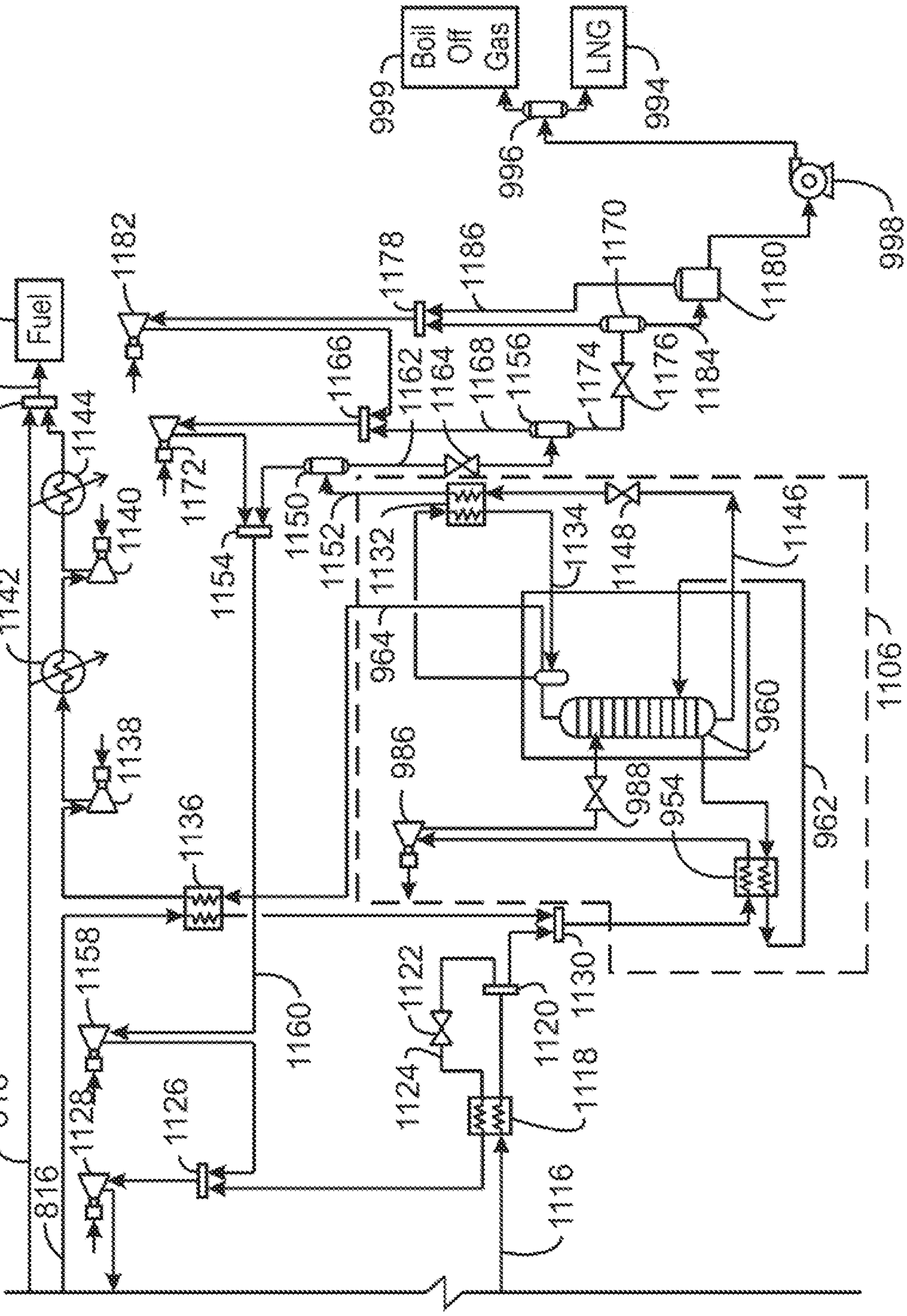
808
Natural Gas
810
812
818
814
816
1107
1108
830
854
866
832
829
856
852
868
828
848
1110
822
860
850
834
839
870
842
824
838
836
858
864
840
844
846
862
1102
Continued on FIG. 11B

1100

FIG. 11A


818
816
1108
1104
884
918
870
882
880
912
1114
874
1016
1112
1116
908
1013
1014
916
910
914
Continued on FIG. 11A
Continued on FIG. 11C

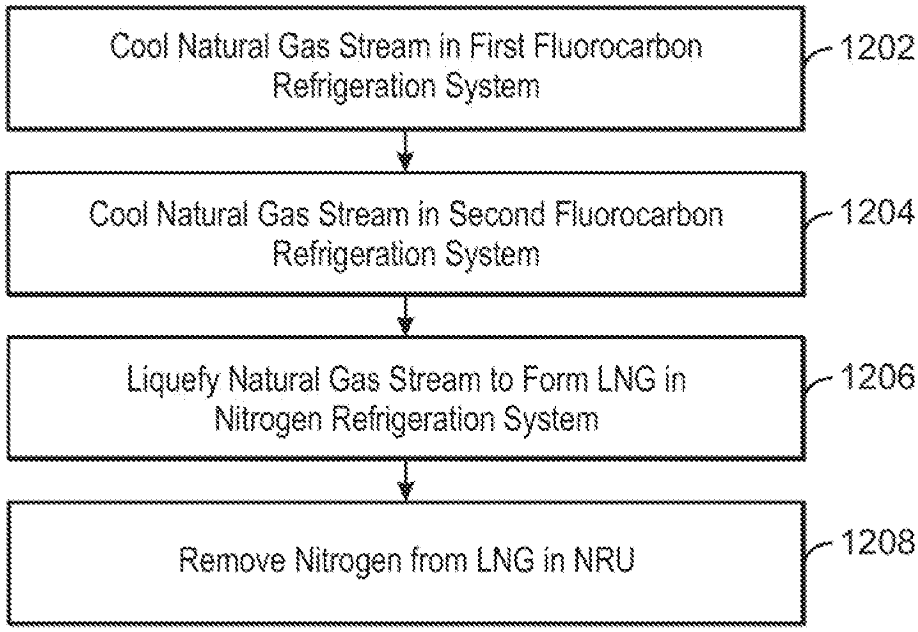
1100
FIG. 11B



Continued on FIG. 11B

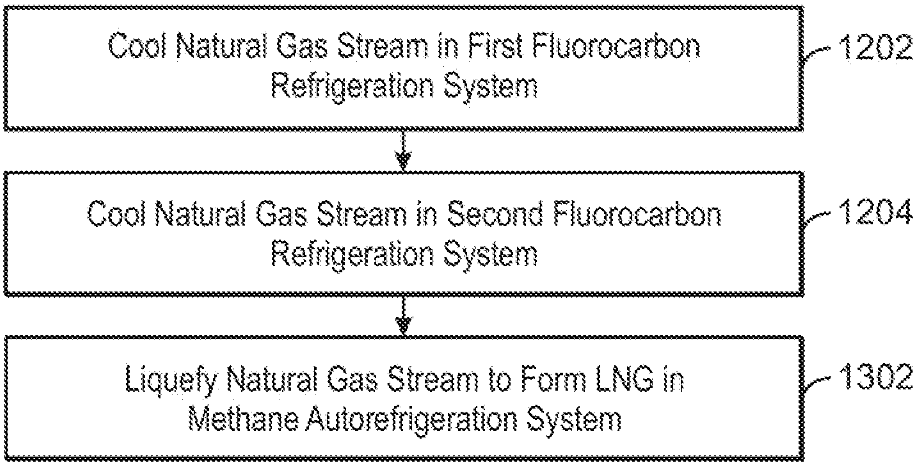
1105

FIG. 11C


Cool Natural Gas Stream in First Fluorocarbon Refrigeration System
1202
Cool Natural Gas Stream in Second Fluorocarbon Refrigeration System
1204
Liquefy Natural Gas Stream to Form LNG in Nitrogen Refrigeration System
1206
Remove Nitrogen from LNG in NRU
1208

1200

FIG. 12


Cool Natural Gas Stream in First Fluorocarbon Refrigeration System
1202
Cool Natural Gas Stream in Second Fluorocarbon Refrigeration System
1204
Liquefy Natural Gas Stream to Form LNG in Methane Autorefrigeration System
1302

1300

FIG. 13