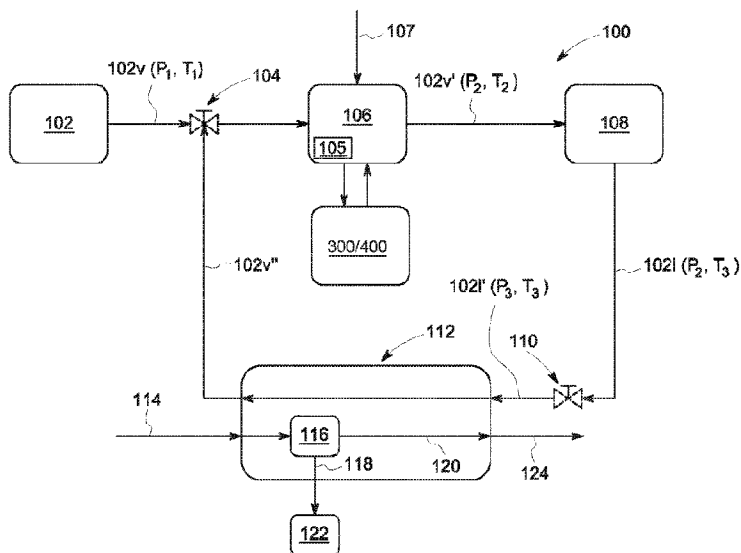




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(57) Abrégé/Abstract:

Systems, devices, and methods for recovering mixed refrigerant and/or nitrogen within liquefaction systems are provided. The systems, devices, and methods facilitate recovering mixed refrigerant (MR) and/or nitrogen vapor that can leak from a compressor, separating the MR from the nitrogen, and reusing the MR and/or the nitrogen within the liquefaction system. Recovering and reusing MR and/or nitrogen can minimize loss of MR and nitrogen which can lower the total operating cost of a liquefaction system. Additionally, recovering the MR, rather than burning it, can reduce environmental emissions by reducing the amount of MR that is burned.

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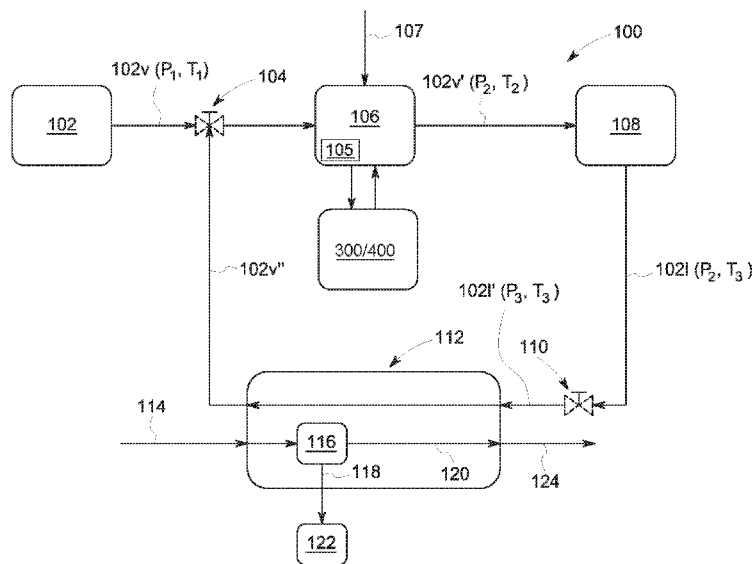


FIG. 1

(57) **Abstract:** Systems, devices, and methods for recovering mixed refrigerant and/or nitrogen within liquefaction systems are provided. The systems, devices, and methods facilitate recovering mixed refrigerant (MR) and/or nitrogen vapor that can leak from a compressor, separating the MR from the nitrogen, and reusing the MR and/or the nitrogen within the liquefaction system. Recovering and reusing MR and/or nitrogen can minimize loss of MR and nitrogen which can lower the total operating cost of a liquefaction system. Additionally, recovering the MR, rather than burning it, can reduce environmental emissions by reducing the amount of MR that is burned.

[Continued on next page]



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REFRIGERANT AND NITROGEN RECOVERY

[0001] [BLANK]

FIELD

[0002] Systems and methods are provided for reducing loss of refrigerant and/or nitrogen in liquefaction systems that liquefy gases, e.g., natural gas.

BACKGROUND

[0003] Liquefied natural gas (“LNG”) is natural gas which has been cooled to a temperature of approximately -162 degrees Celsius (~-260 degrees Fahrenheit) with a pressure of up to approximately 25 kPa (4 psig) and has thereby taken on a liquid state. Natural gas (NG) is primarily composed of methane, and can include ethane, propane, and heavy hydrocarbon components such as butanes, pentanes, hexanes, benzene, toluene, ethylbenzene, and xylenes. Many natural gas sources are located a significant distance away from the end-consumers. One cost-effective method of transporting NG over long distances is to liquefy the natural gas, converting it to liquefied natural gas (LNG), and to transport it in tanker ships, also known as LNG-tankers. The LNG is transformed back into gaseous natural gas at the destination.

[0004] In a typical NG liquefaction process, a compressor compresses a mixed refrigerant MR to an elevated pressure, forming a pressurized MR. The pressurized MR is delivered to a cold box, which in turn is used to cool an NG feedstock to form LNG. During normal operation, and in certain shutdown scenarios, MR and nitrogen can leak from the compressor. The nitrogen can employed as part of a dry gas seal employed for containment of MR within the compressor and mixes with the MR. Often, the leaked MR and nitrogen are captured and delivered to a flare to be burned. Over time this lost, flared MR and nitrogen must be replaced for the liquefaction process to continue, which is costly.

SUMMARY

[0005] Systems, devices, and methods are provided for reducing loss of refrigerant and nitrogen in liquefaction systems. In one aspect, a liquefaction system is provided that includes a first compressor and a recovery system in fluid communication with the first compressor. The recovery system can include a first heat exchanger configured to receive a first vapor from the first compressor. The first vapor can be, for example, a mixed refrigerant and nitrogen. The first heat exchanger can be configured to convert the first vapor to a mixture of nitrogen rich vapor and a hydrocarbon rich liquid. In certain embodiments, the first heat exchanger can have at least one cooling element configured to receive a cold fluid that provides refrigeration to the first vapor, and a separator configured to receive the mixture of hydrocarbon rich liquid and nitrogen rich vapor from the first heat exchanger, and to separate the hydrocarbon rich liquid and the nitrogen rich vapor.

[0006] In one embodiment, a method of operating a liquefaction system is provided. The method can include receiving a seal gas including hydrocarbons at a seal assembly of a first compressor. The method can also include receiving a nitrogen vapor at the seal assembly of the first compressor. The method can additionally include receiving, at a first heat exchanger, a first vapor including at least a portion of the seal gas and at least a portion of the nitrogen vapor. The method can also include transferring a cold fluid to a cooling element of the first heat exchanger. The method can further include transferring heat from the first vapor to the cold fluid, thereby creating a mixture of nitrogen rich vapor and a hydrocarbon rich liquid. The method can also include separating the hydrocarbon rich liquid from the nitrogen rich vapor at a separator positioned downstream of the first heat exchanger.

DESCRIPTION OF DRAWINGS

[0007] FIG. 1 is a diagram of one exemplary embodiment of a liquefaction system;

[0008] FIG. 2 shows a cross-sectional view of a sealing assembly of a compressor;

[0009] FIG. 3 is a schematic of one exemplary embodiment of a mixed refrigerant (MR) recovery system;

[0010] FIG. 4 is a schematic of one exemplary embodiment of a nitrogen recovery system; and

[0011] FIG. 5 is a flow diagram illustrating one exemplary embodiment of operating a liquefaction system.

DETAILED DESCRIPTION

[0012] One method of addressing refrigerant leakage from a compressor of a compression system involves utilizing a recovery system that allows the refrigerant to be captured and injected directly back into the compressor or into circulation elsewhere within the refrigeration process, thereby eliminating, or mitigating, loss of refrigerant from the refrigeration system. However, for certain liquefaction systems that use a mixed refrigerant (MR), direct recovery and reintroduction of MR into the compressor, or into circulation within the refrigeration process, may not be feasible. As an example, the MR that leaks from the compressor does so through the seals of the compressor. Such compressor seal can include dry seals that employ nitrogen gas as a buffer gas and this nitrogen can contaminate the MR. As a result, a mixture of MR and nitrogen can leak from the compressor. Over time, direct reintroduction of the MR and nitrogen mixture into the compressor can result in performance degradation, since the composition of the MR within the liquefaction system will be altered, becoming enriched with nitrogen.

[0013] In order to address these issues, MR and nitrogen recovery systems can be employed to capture leaked mixtures of MR and nitrogen from a compressor of a liquefaction system. The MR and nitrogen recovery systems are each configured to separate the MR from the nitrogen (e.g., by condensing the MR hydrocarbons), allowing recovery of the MR and nitrogen. Recovered MR can safely be reintroduction back into the compressor, and/or into circulation within the refrigeration process. Recovered nitrogen can be used as a component of the buffer gas of the compressor seals, and/or for use elsewhere.

[0014] FIG. 1 illustrates one embodiment of a new LNG liquefaction system 100. The liquefaction system 100 includes a refrigerant supply system 102 containing a mixed refrigerant MR 102v in a vapor state, a compression system 106, one or more condensers 108, a heat exchanger 112, and a natural gas (NG) supply system 114 containing natural gas (NG) feedstock 114v in a vapor state. The refrigerant supply system 102 is in fluid communication with the compression system 106, and a valve 104 is interposed therebetween for regulating a flow rate of the supply MR 102v to the compression system 106. The condensers 108 are in fluid communication with, and downstream from, the compression

system 106. The heat exchanger 112 is in fluid communication with, and downstream from, the condensers 108. An expansion valve 110 is interposed between the condensers 108 and the heat exchanger 112. The heat exchanger 112 is in further configured to receive the NG feedstock 114v from the NG supply system 114. The heat exchanger 112 is also in fluid communication with the valve 104.

[0015] Operation of the liquefaction system 100 is discussed with further reference to FIG. 1. The valve 104 regulates a flow of mixed refrigerant, supply MR 102v in a vapor state at a first temperature T1 and a first pressure P1 from the refrigerant supply system 102 to the compression system 106. The compression system 106 can be, e.g., a multistage compression system including a compressor 105.

[0016] Embodiments of the compressors 105 can adopt a variety of forms. Examples of the compressor 105 can include a single-casing compressors, multi-stage compressors, and trains of multiple compressors, each with one or more compression stages. The compressors 105 are driven by a mover, which can be, e.g., a gas turbine, a steam turbine, an expander, or an electric motor that receives electric power 107 from an external power source (not shown).

[0017] The compression system 106 increases the temperature and pressure of the supply MR 102v from the first temperature T1 and the first pressure P1, yielding a high-temperature, high-pressure mixed refrigerant MR 102v' in the vapor state that possesses a second temperature T2 greater than the first temperature T1 and second pressure P2 greater than the first pressure P1.

[0018] The high-pressure, high-temperature MR 102v' can subsequently flow to one or more condensers 108 that are downstream of the compression system 106. The condensers 108 can be any device (e.g., condensers, intercoolers, air coolers, etc.) configured to facilitate a phase change of the high-temperature, high-pressure MR 102v' from vapor, or mostly vapor, to a predominantly liquid state, liquid MR 102l, by removing excess heat generated during the compression process. Thus, the liquid MR 102l can possess a third temperature T3 that is less than the first and second temperatures T1, T2. For clarity of discussion, it is assumed that the pressure of the liquid MR 102l remains constant at the second pressure P2. However, in alternative embodiments, the pressure of the liquid MR can be less than the second pressure P2.

[0019] FIG. 1 illustrates the condensers 108 as being downstream from the compression system 106. However, in alternative embodiments, the condensers can be located between stages of the compressors of the compression system 106. Condensers integrated with the compressors of the compression system can be provided in lieu of, or in addition to, condensers downstream from the compression system.

[0020] The liquid MR 102I output by the condensers 108 travels through the expansion valve 110. The expansion valve 110 creates a pressure drop that puts at least a portion of the liquid MR 102I in a low-pressure, low-temperature, liquid state, MR 102I'. The low-pressure, low-temperature liquid MR 102I' can possess a third pressure P3 that is lower than the first and second pressures P1, P2. It is assumed for clarity of discussion that the temperature of the low-temperature, low-pressure liquid MR 102I' remains constant at T3. However, in alternative embodiments, the temperature of this liquid MR can be less than the second temperature P2.

[0021] The low pressure, low-temperature, low-pressure liquid MR 102I' output from expansion valve 110 flows inside conduits (or channels) of heat exchange surface(s) of a heat exchanger 112. As shown, the heat exchanger 112 also receives the natural gas (NG) feedstock 114v and the low-temperature, low-pressure liquid MR 102I' cools the NG feedstock 114v that contacts the heat exchange surface(s). As the NG feedstock 114v and the low-temperature, low-pressure liquid MR 102I' travel through the heat exchanger 112, heat is transferred from the warmer NG feedstock 114v to the cooler low-temperature, low-pressure liquid MR 102I' such that the NG feedstock 114v cools and begins to condense, forming LNG 124.

[0022] The heat exchanger 112 can be any type of heat exchanger. Examples of the heat exchanger 112 can include core plate and fin, etched plate, diffusion bonded, wound coil, shell and tube, plate-and-frame, and the like.

[0023] The NG feedstock 114v can contain both NG vapor 120 and heavy hydrocarbon components (HHCs) such as butanes, pentanes, hexanes, benzene, toluene, ethylbenzene, and xylenes. It can be desirable to remove HHCs during production of the LNG 124 to prevent them from freezing. As illustrated in FIG. 1, the heat exchanger 112 can include a HHC separation system 116 configured to remove HHCs from the NG feedstock 114v. As the NG feedstock 114v is cooled within the heat exchanger 112, HHCs condense at higher

temperatures than lighter molecules, e.g., methane. Therefore, a liquid 118 containing primarily HHCs can be separated from NG feedstock 114v, yielding a purified NG vapor 120 by the HHC separation system 116. The purified NG vapor 120 flows through the heat exchanger 112 and condenses to form the LNG 124. The LNG 124 can be subsequently let down in pressure and stored in a storage vessel (not shown).

[0024] The liquid 118 can be handled in a variety of ways. In one embodiment, as shown, the liquid 118 exits the heat exchanger 112 and is stored in a HHC storage vessel 122. In alternative embodiments, not shown, the HHC liquid can be put through a multistage distillation process to separate it into its constituent components. The separated constituents can be stored in respective storage vessels.

[0025] The low-temperature, low-pressure liquid MR 102l' absorbs heat from the NG feedstock 114v, the purified NG vapor 120, and/or the LNG 124 within the heat exchanger 112. The absorbed heat is sufficient to result in vaporization of the low-temperature, low-pressure liquid MR 102l'. Thus, at least a portion of the MR that leaves the heat exchanger 112 undergoes a phase change to a vapor. This vapor can be recovered in the form of recycled MR 102v" that flows to the valve 104 to the compression system 106. In certain embodiments, the recycled MR 102v" can be conditioned to the first temperature T1 and the first pressure P1 prior to delivery at the valve 104 by one or more conditioning systems (not shown). By recovering and reusing the recycled MR 102v", rather than burning it, environmental emissions associated with burning can be avoided.

[0026] During normal operation of the liquefaction system 100, the compressors 105 can leak MR (e.g., supply MR 102v and/or high-temperature, high-pressure MR 102v') and nitrogen due to imperfect sealing at various locations. The liquefaction system 100 can also include at least one of an MR recovery system 300 and a nitrogen recovery system 400 in fluid communication with the compressor 105 of the compression system 106. As discussed in detail below, the MR recovery system 300 and the nitrogen recovery system 400 are each configured to separate the leaked MR from the nitrogen (e.g., by condensing the MR hydrocarbons), allowing recovery of the MR and nitrogen. The MR recovery system 300 is further configured to reintroduce recovered MR back into the compressor 105 of compression system 106, and/or into circulation within other portions of the liquefaction system 100 (e.g., between the condensers 108 and the expansion valve 110). The nitrogen recovery system 400

is further configured to reintroduce recovered MR as a component of the buffer gas of the compressor seals, and/or for use elsewhere.

[0027] Leakage of MR and nitrogen is discussed with reference to FIG. 2. FIG. 2 illustrates a cross-sectional view of a compressor 200 including a seal assembly 201 that can be used within a compression system, such as the compression system 106 shown in FIG. 1, to contain MR (e.g., supply MR 102v and/or high-temperature, high-pressure MR 102v'). The seal assembly 201 is positioned adjacent to an intake port and/or a discharge port of the compressor 200 to prevent leakage of fluids from the compressor. The seal assembly 201 includes a primary seal 202, a secondary seal 204, and a tertiary seal 206 positioned along a length of a shaft 203 of the compressor 200, between a compressor side 209 and a bearing side 211 of the compressor 200, to separate fluids that are within the compressor 200. The primary and secondary seals 202, 204 can be, e.g., dry gas seals, and the tertiary seal 206 can be, e.g., a type of carbon ring seal. The compression side 209 can include a compression chamber (not shown) used to compress MR (e.g., supply MR 102v), and the bearing side 211 can include one or more bearings (not shown) positioned about the shaft 203 of the compressor to allow the shaft 203 to rotate.

[0028] While the seal assembly 201 of FIG. 2 is illustrated in the form of a tandem type dry gas sealing system, other sealing systems can be used. Examples can include single dry gas seals, double dry gas seals, multi-arranged dry gas seals, labyrinth type seals, carbon ring type seals, any combination of the aforementioned seals, or any other type of seal known in the art.

[0029] A person skilled in the art will have a basic understanding of how compressors and sealing assemblies work. A brief description is provided below.

[0030] During normal operation, supply MR 102v, high-temperature, high-pressure MR 102v', and combinations thereof in the form of unfiltered MR 209, is present at a compressor side pressure. As discussed above, the supply MR 102v possesses the first temperature T1 and first pressure P1 and the high-temperature, high-pressure MR 102v' possess the second temperature T2 and the second pressure P2. Thus, the unfiltered MR 209 can possess a temperature ranging from approximately the first temperature T1 to the second temperature T2 and a pressure ranging from approximately the first pressure P1 and the second pressure P2. Solely for clarity, it is assumed in the discussion below that the unfiltered MR 209

possesses the second pressure P2.

[0031] The unfiltered MR 209 can leak through a sealing element 230 which can be, e.g., a labyrinth seal, and into the seal assembly 201, which can damage the primary, secondary, and tertiary seals 202, 204, 206. In order to prevent the unfiltered MR 209 from leaking through the sealing element 230, filtered, high-pressure MR 208, or another seal gas, can be delivered to a region 205 of the seal assembly 201 positioned adjacent the compressor side 209. The filtered, high-pressure MR 208 can pressurize a cavity 207 located adjacent the sealing element 230 to a fourth pressure P4 that is higher than that of the second pressure P2 on the compressor side 209, thereby preventing the unfiltered MR 209 from leaking into the seal assembly 201.

[0032] A portion of the filtered MR 208 can leak through the primary seal 202 and travel to a primary vent 212. To ensure that approximately all of the MR that leaks through the primary seal 202 (e.g., unfiltered MR 209, filtered MR 208) is directed toward the primary vent 212, a buffer gas such as, e.g., nitrogen 214 (e.g., nitrogen vapor), can be delivered to a primary buffer region 216 adjacent to the primary vent 212. The nitrogen 214 can be at a fifth pressure P5 that is high pressure than the fourth pressure P4 observed at the primary vent 212. A portion of the nitrogen 214 can leak through a sealing element 232 which can be, e.g., a labyrinth seal that prevents MR leakage, into the primary buffer region 216. The nitrogen 214 that leaks through the sealing element 232 can combine with the MR that leaks through the primary seal 202 (e.g., unfiltered MR 209, filtered MR 208) to create a mixture 218 of MR leakage and the nitrogen 214 at the primary vent 212. Another portion of the nitrogen 214 can leak through the secondary seal 204 and travel to a secondary vent 220. The mixture 218 of MR leakage and nitrogen 214 can be delivered from the primary vent 212 to a flare to be burned.

[0033] To prevent bearing oil mist from migrating from the bearing side of the tertiary seal 206, nitrogen 222 can also be injected into a secondary buffer region 224 between the secondary vent 220 and the bearing side 211 of the seal assembly 201. A portion of the nitrogen 222 that is delivered to the secondary buffer region 224 can leak beyond the tertiary seal 206 and travel to the secondary vent 220. Nitrogen 226 from the secondary vent 220 can be captured and reintroduced to the seal assembly 201 as buffer gas.

[0034] As discussed in detail below, rather than flaring the mixture 218 of leaked MR

and nitrogen 214 from the primary vent 212, as commonly done, embodiments of the present disclosure illustrate systems and corresponding methods that facilitate recovery of the MR (e.g., unfiltered MR 209, filtered MR 208) that leaks from a compressor of a liquefaction system (e.g., compressor 105 of liquefaction system 100) can be recovered and returned to circulation. This significantly reduces the need to stock, purchase and reintroduce “lost” MR into the liquefaction system 100.

[0035] FIG. 3 is a schematic diagram illustrating one exemplary embodiment of a new MR recovery system n for recovering all or a portion of either (or both) MR leakage (e.g., unfiltered MR 209, filtered MR 208) and/or nitrogen 214 that leaks from a compressor (e.g., compressor 105 of compression system 106).

[0036] The MR recovery system 300 includes a heat exchanger 302 and a two-phase separator 308. The heat exchanger 302 is configured to receive a cold fluid 304 and a nitrogen rich vapor 305 having MR components and nitrogen (e.g., mixture 218) from a compressor of a compression system, such as compressor 105 of the compression system 106 shown in FIG. 1. The heat exchanger 302 can include at least one cooling element configured to receive the cold fluid 304 carried from a second conduit portion 340 of conduit 342 that branches from a first conduit portion 344 at first conduit location 346, and provide refrigeration to the nitrogen rich vapor 305. The two-phase separator 308 is configured to separate an input fluid into two or more different phases.

[0037] The cold fluid 304 can be a liquefied product created by the liquefaction system 100. For example, the cold fluid 304 can be LNG, such as the LNG 124 that exits the heat exchanger 112 shown in FIG. 1. Accordingly, the cold fluid 304' that leaves the heat exchanger 302 is delivered to a storage vessel 320, via the second conduit portion 340 and valve 311, so as to rejoin the first conduit portion 344 at a second conduit location 348, whereby the cold fluid 304' is able to be stored and/or distributed as desired. Alternatively, the cold fluid 304 can be a refrigerant from another refrigeration system configured for the described purpose. Therefore, the cold fluid 404' that leaves the heat exchanger 302 can continue within a refrigeration cycle to provide refrigeration to the nitrogen rich vapor 305.

[0038] The heat exchanger 302 can take a variety of forms. In certain embodiments, the heat exchanger 302 can be, e.g., a shell and tube heat exchanger, or it can be a condensing coil heat exchanger. Alternatively, other heat exchangers such as core, core plate-and-fin, etched plate, diffusion bonded, wound coil, shell and tube, plate-and-frame, etc. can be used. As shown, valves 309, 311 are positioned on either side of the heat exchanger 302 control a

flow rate of the cold fluid 304 through the heat exchanger 302.

[0039] In some embodiments, prior to being delivered to the heat exchanger 302, the nitrogen rich vapor 305 is delivered to a nitrogen removal assembly 303 positioned upstream of the heat exchanger 302. As discussed above, the nitrogen rich vapor 305 can be the mixture 218 of leaked MR and nitrogen. The nitrogen removal assembly 303 is configured to remove a portion of the nitrogen from the nitrogen rich vapor 305 and outputs a nitrogen poor vapor 307 that contains less nitrogen than the nitrogen rich vapor 305. As an example, the nitrogen removal assembly 303 can be an absorption bed. The nitrogen poor vapor 307 exiting the nitrogen removal assembly 303 is delivered to the heat exchanger 302.

[0040] As the nitrogen poor vapor 307 and the cold fluid 304 travel through the heat exchanger 302, heat is transferred from the nitrogen poor vapor 307 to the cold fluid 304 such that the nitrogen poor vapor 307 begins to cool and condense. While the nitrogen poor vapor 307 is cooled within the heat exchanger 302, hydrocarbon components that make up MR condense at higher temperatures than lighter components such as nitrogen. Therefore, a mixture 306 of a nitrogen rich vapor 310, and a hydrocarbon rich liquid 312 can be formed. The mixture 306 can be cooled sufficiently to achieve the nitrogen rich vapor 310 with high purity due to preferential condensation of hydrocarbon components. In some cases, the mixture 306 is cooled sufficiently to produce the nitrogen rich vapor 310 with approximately 95% purity. As an example temperature of the mixture 306 that exits the heat exchanger 302 can be at a temperature in the range of approximately -51 to -160 degrees Celsius (-60 to -257 degrees Fahrenheit).

[0041] The mixture 306 exiting the heat exchanger 302 flows to the two-phase separator 308. The two-phase separator 308 is configured to receive the mixture 306 of the nitrogen rich vapor 310 and hydrocarbon rich liquid 312 from the heat exchanger 302 and to separate the nitrogen rich vapor 310 and the hydrocarbon rich liquid 312. As shown, the hydrocarbon rich liquid 312 is delivered to a pump 316 that pumps the hydrocarbon rich liquid 312 to a refrigerant supply system, such as refrigerant supply system 102 shown in FIG. 1, and the nitrogen rich vapor 310 is delivered to a flare 322.

[0042] However, in alternative embodiments, the hydrocarbon rich liquid 312 and/or the nitrogen rich vapor 330 output from the two-phase separator 308 can be handled differently than discussed above.

[0043] In one aspect, the hydrocarbon rich liquid can be directly reintroduced to circulation within the liquefaction system (e.g., between the condenser and the expansion valve), or it can be vaporized and reintroduced within the compressor as the filtered MR 208 described above with regard to FIG. 2. In some cases, the hydrocarbon rich liquid is heated before reintroduction into circulation within the liquefaction system, and/or prior to reintroduction within the compressor of the compression system, to prevent low-temperature embrittlement of components of the liquefaction system and/or the compressor.

[0044] In a further aspect, the hydrocarbon rich liquid can be distilled to separate various hydrocarbon components such as, e.g., methane, ethylene, and propane, and pentanes such that they can be stored separately within the refrigerant supply system.

[0045] In alternative embodiments the nitrogen rich vapor output from the two-phase separator can be handled differently than flaring. In one aspect, the nitrogen rich vapor can be distilled to further purify the nitrogen. The purified nitrogen vapor can be delivered back to the compressor as a buffer gas of a dry seal of the compressor, it can be stored in a storage vessel, or it can be delivered to other components within a liquefaction system.

[0046] In alternative embodiments, not shown, a distillation system can be used to separate components of the nitrogen poor vapor into nitrogen rich vapor and hydrocarbon rich liquid, rather than the heat exchanger and two-phase separator. In either case, each of the components of the nitrogen poor vapor 307 can be separated, reintroduced to the liquefaction system 100, stored, and/or distributed as desired.

[0047] As described above, nitrogen and MR that leak from a compressor of a compressor system are recovered, separated, stored, and/or reintroduced back into a liquefaction system. FIG. 4 shows one example of a nitrogen recovery system 400 for recovering nitrogen and MR that leaks from a compressor 429 of a compressor system 430. In certain embodiments, the compressor system 430 can be compression system 106 of liquefaction system 100. Nitrogen buffer gas that leaks from the compressor (e.g., compressor 105, compressor 200), without mixing with MR, can also be recovered and reintroduced to the compressor as a buffer gas (e.g., nitrogen 214 of seal assembly 201).

[0048] As shown, the nitrogen recovery system 400 includes a heat exchanger 402 and a two-phase separator 408. The heat exchanger 402 is configured to receive a cold fluid 404

and a vapor 405 having MR components and nitrogen from a compressor (e.g., compressor 105, compressor 200) of a compression system, such as the compression system 106 shown in FIG. 1. The heat exchanger 402 can generally be similar to heat exchanger 302. Valves 409, 411 are positioned on either side of the heat exchanger 402 for control a flow rate of the cold fluid 404 through the heat exchanger 402. The two-phase separator 408 can be generally similar to the two-phase separator 308 and is configured to separate an input fluid into two or more different phases.

[0049] In some embodiments, the cold fluid 404 is a liquefied product created by the liquefaction system 100. For example, the cold fluid 404 can be LNG, such as the LNG 124 that exits the heat exchanger 112 shown in FIG. 1. Alternatively, the cold fluid 404 can be, e.g. propane, R-134A, propylene, etc. As another example, the cold fluid 404 can be liquid nitrogen or ethylene stored at the liquefaction system 100. Accordingly, the cold fluid 404' that leaves the heat exchanger 402, via valve 411, is delivered to a storage vessel 420 to be stored, and/or distributed as desired. Alternatively, the cold fluid 404 can be a refrigerant from another refrigeration system configured for the described purpose. Therefore, the cold fluid 404' that leaves the heat exchanger 402 can continue within a refrigeration cycle to provide refrigeration to the vapor 405.

[0050] As the vapor 405 and the cold fluid 404 travel through the heat exchanger 402, heat is transferred from the vapor 405 to the cold fluid 404 such that the vapor 405 begins to cool and condense. As the vapor 405 is cooled within the heat exchanger 402, hydrocarbon components that make up MR condense at higher temperatures than lighter components such as nitrogen. Therefore, a mixture 406 of a nitrogen rich vapor 410 and a hydrocarbon rich liquid 412 can exit the heat exchanger 402. The mixture 406 can be cooled sufficiently such that the nitrogen rich vapor 410 is of high purity due to preferential condensation of hydrocarbon components. In some cases, the mixture 406 is cooled sufficiently to produce the nitrogen rich vapor 410 with approximately 95% purity. For example, the mixture 406 can exit the heat exchanger 402 at a temperature in a range of approximately -118 to -160 degrees Celsius (-180 to -257 degrees Fahrenheit).

[0051] The mixture 406 exiting the heat exchanger 402 is flow to the two-phase separator 408 and is separated into the nitrogen rich vapor 410 and the hydrocarbon rich liquid 412. The nitrogen rich vapor 410 is combined with nitrogen vapor 431 from the compressor 429 of

the compressor system 430 (e.g., a first compressor), and is delivered to a second compressor 425. The nitrogen vapor 431 can be nitrogen that leaks from a compressor, such as nitrogen 226 described above with regard to FIG. 2.

[0052] Nitrogen vapor 424 exiting the second compressor 425 is urged into combination with nitrogen vapor 426 from a nitrogen source 428 such that it is delivered back to the compressor 429 of the compressor system 430 to be used as a buffer gas (e.g., nitrogen 214 of seal assembly 201), as described above with regard to FIG. 2. In some cases, the nitrogen vapor 424 can be heated prior to being combined with the nitrogen vapor 426 from the nitrogen source 428, and/or prior to reintroduction into the compressor system 430, to prevent low temperature embrittlement of components of the compressor system 430.

[0053] In some embodiments, prior to combination with the nitrogen vapor 431 from the compressor of the compressor system 430 and input to the second compressor 425, the nitrogen rich vapor 410 is delivered to a nitrogen removal system 417. The nitrogen removal system 417 is positioned downstream from the two-phase separator 408 and configured to remove at least a portion of nitrogen within the nitrogen rich vapor 410. As an example, the nitrogen removal system 417 can be an adsorption bed that removes a portion of adsorbed nitrogen. The adsorbed nitrogen is released as a result of a desorption process, and the released nitrogen is delivered to the second compressor 425, and combined with the nitrogen vapor 426, as described above.

[0054] In alternative embodiments, the nitrogen vapor 424 output by the second compressor 425 can be handled differently than being combined with the nitrogen vapor 426. In one aspect, rather than delivering the nitrogen vapor back to the compressor system, the nitrogen vapor can be compressed, condensed, and stored in a storage vessel (not shown). In another aspect, the nitrogen vapor can be stored as a vapor, or delivered to another component of a liquefaction system for use elsewhere.

[0055] As shown, in FIG. 4, the hydrocarbon rich liquid 412 that exits the two-phase separator 408 is delivered to a pump 416 that pumps the hydrocarbon rich liquid 412 to a flare 422. However, in alternative embodiments, the hydrocarbon rich liquid 412 can be handled differently. In one aspect, rather than flaring the hydrocarbon rich liquid 412, a portion of the hydrocarbon rich liquid 412 can be distilled to remove excess nitrogen. The distillation process separates the hydrocarbon rich liquid 412 into various hydrocarbon

components such as methane, ethylene, and propane, and pentanes such that they can be stored separately within a refrigerant supply system. As another example, rather than using the heat exchanger 402 and two-phase separator 408, a distillation system can be used to separate components of the vapor 405. Accordingly, each of the components of the vapor can be separated, reintroduced to a liquefaction system, stored, and/or distributed as desired.

[0056] FIG. 5 is a flow diagram illustrating one exemplary embodiment of a method 500 for operating a liquefaction system. Embodiments of the method include operations 502-512. It can be understood that, in alternative embodiments, the method can include greater or fewer operations and the operations can be performed in an order different than illustrated in FIG. 5.

[0057] In operation 502, a seal gas is received at a seal assembly of a first compressor (e.g., compressor 105). In certain embodiments, the seal gas is a mixed refrigerant (MR), such as supply MR 102v, high-temperature, high-pressure MR 102v', and combinations thereof.

[0058] In operation 504, a nitrogen vapor is received at the seal assembly of the first compressor. In certain embodiments, the nitrogen vapor is the nitrogen 214 employed as a buffer gas in the seal assembly 201.

[0059] In operation 506, a first vapor is received at the first heat exchanger. In certain embodiments, the first vapor includes at least a portion of the sea gas and at least a portion of the nitrogen vapor.

[0060] In operation 508, a cold fluid is transmitted to a cooling element of the first heat exchanger. As an example, the cold fluid can be cold fluid 304. Examples of the cold fluid 304 include a liquefied product created by the liquefaction system 100 (e.g., LNG 124 that exits the heat exchanger 112), a refrigerant from another refrigeration system, different from the liquefaction system 100, and combinations thereof.

[0061] In operation 510, heat is transferred from the first vapor to the cold fluid, thereby creating a mixture of nitrogen rich vapor and a hydrocarbon rich liquid. In certain embodiments, the nitrogen rich vapor is possesses approximately 95% purity or greater. The heat transfer can be performed by a heat exchanger (e.g., 302, 402).

[0062] In operation 512, the hydrocarbon rich liquid is separated from the nitrogen rich

vapor at a separator (e.g., 308, 408) positioned downstream of the first heat exchanger.

[0063] Embodiments of the method 900 can optionally include one or more of the following operations.

[0064] In another embodiment, the method 500 can include receiving the nitrogen rich vapor (e.g., 410) at a second compressor. As an example, the second compressor can be second compressor 425 and the nitrogen rich vapor 410 can be received from the heat exchanger 402. Following receipt by the second compressor 425, the nitrogen rich vapor 410 is compressed by the second compressor 425. At least a portion of the nitrogen rich vapor 410 output by the second compressor 425 is delivered to the seal assembly of the first compressor (e.g., 201). Optionally, the nitrogen rich vapor 410 is combined with the nitrogen 214 prior to delivery to the seal assembly 201.

[0065] In another embodiment, the method 500 can include receiving a methane-containing vapor at a second heat exchanger and removing heat from the methane-containing vapor within the second heat exchanger to thereby create the cold fluid. In certain embodiments, the methane-containing vapor can be a natural gas (NG). In further embodiment, the second heat exchanger can be heat exchanger 302.

[0066] In another embodiment, the method 500 can include receiving a second vapor at a nitrogen removal assembly positioned upstream of the first heat exchanger. The second vapor includes at least a portion of the seal gas and at least a portion of the nitrogen vapor. In certain embodiments, the second vapor is nitrogen rich vapor 305 and the nitrogen removal assembly is nitrogen removal assembly 303. Following receipt of the second vapor, the nitrogen removal assembly removes a portion of the nitrogen vapor from the second vapor, thereby generating the first vapor (e.g., nitrogen poor vapor 307).

[0067] In another embodiment, the method 500 can include receiving the nitrogen rich vapor at a nitrogen removal assembly positioned downstream of the separator; and removing a portion of the nitrogen from the nitrogen rich vapor. As an example, the separator is two-phase separator 408, the nitrogen removal assembly positioned downstream of the two-phase separator 408 is nitrogen removal system 417, and the nitrogen rich vapor is nitrogen rich vapor 410.

[0068] In another embodiment, the method 500 can include receiving the hydrocarbon rich liquid at a pump (e.g., 316, 416) and pumping the hydrocarbon rich liquid (e.g., 312, 412) to a storage vessel (e.g., 322, 422).

[0069] A person skilled in the art will appreciate that the methods, systems, and devices described herein can be applied within liquefaction facilities that can produce liquefied products other than LNG. For example, embodiments of the MR recovery system 300, and/or the nitrogen recovery system 400, can be implemented in liquefaction system that produces liquefied petroleum gas (LPG), ethane, propane, helium, ethylene etc.

[0070] Exemplary technical effects of the methods, systems, and devices described herein include, by way of non-limiting example, the ability to recover, and separate, and store MR components and/or nitrogen that leak from a compressor. Other technical effects of the methods, systems, and devices described herein include the ability to reintroduce the MR components into circulation within a liquefaction system, and/or to reuse recovered nitrogen as a buffer gas within a compressor. Recovering and reusing MR and nitrogen can minimize loss of MR and nitrogen which can lower the total operating cost of a liquefaction system. Additionally, recovering the MR, rather than burning it, can reduce environmental emissions by reducing the amount of MR that is burned.

[0071] Certain exemplary embodiments are described to provide an overall understanding of the principles of the structure, function, manufacture, and use of the systems, devices, and methods disclosed herein. One or more examples of these embodiments are illustrated in the accompanying drawings. Those skilled in the art will understand that the systems, devices, and methods specifically described herein and illustrated in the accompanying drawings are non-limiting exemplary embodiments and that the scope of the invention is defined solely by the claims. The features illustrated or described in connection with one exemplary embodiment may be combined with the features of other embodiments. Such modifications and variations are intended to be included within the scope of the present invention. Further, in the present disclosure, like-named components of the embodiments generally have similar features, and thus within a particular embodiment each feature of each like-named component is not necessarily fully elaborated upon.

[0072] In the descriptions above and in the claims, phrases such as “at least one of” or “one or more of” may occur followed by a conjunctive list of elements or features. The term

“and/or” may also occur in a list of two or more elements or features. Unless otherwise implicitly or explicitly contradicted by the context in which it is used, such a phrase is intended to mean any of the listed elements or features individually or any of the recited elements or features in combination with any of the other recited elements or features.

[0073] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about” and “substantially,” are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Here and throughout the specification and claims, range limitations may be combined and/or interchanged, such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise.

WHAT IS CLAIMED IS:

1. A liquefaction system, the system comprising:
 - a first compressor;
 - a recovery system in fluid communication with the first compressor, the recovery system comprising,
 - a first heat exchanger configured to receive a first vapor comprising nitrogen and a mixed refrigerant including hydrocarbons from the first compressor and a cold fluid that provides refrigeration to the first vapor, and to convert the first vapor to a mixture of nitrogen rich vapor and a hydrocarbon rich liquid,
 - a separator configured to receive the mixture of hydrocarbon rich liquid and nitrogen rich vapor from the first heat exchanger, and to separate the hydrocarbon rich liquid and the nitrogen rich vapor; and
 - a conduit carrying the cold fluid, the conduit including a first portion terminating at a storage vessel and a second portion branching from the first portion at a first conduit location and rejoining the first portion at a second conduit location, wherein the second portion is in fluid communication with the first heat exchanger.
2. The liquefaction system of claim 1, further comprising a nitrogen removal assembly positioned upstream of the first heat exchanger, the nitrogen removal assembly being configured to produce the first vapor from a second vapor comprising mixed refrigerant and nitrogen, wherein the first vapor possesses less nitrogen than the second vapor.
3. The liquefaction system of claim 2, wherein the nitrogen removal assembly includes an adsorption bed.
4. The liquefaction system of claim 1, further comprising a nitrogen removal assembly positioned downstream of the separator, the nitrogen removal assembly being configured to receive the nitrogen rich vapor from the separator and to remove a portion of the nitrogen from the nitrogen rich vapor.

5. The liquefaction system of claim 1, wherein the first compressor includes a seal assembly comprising at least one dry seal that is configured to receive at least a portion of the nitrogen rich vapor from the separator.

6. The liquefaction system of claim 5, further comprising a second compressor in fluid communication with the separator, the second compressor being configured to receive the at least a portion of the nitrogen rich vapor from the separator and to urge the at least a portion of the nitrogen rich vapor to the seal assembly.

7. The liquefaction system of claim 1, further comprising a second heat exchanger in fluid communication with the compressor, the second heat exchanger being configured to receive a methane-containing vapor and to convert the methane-containing vapor to a methane-containing liquid.

8. The liquefaction system of claim 7, wherein the cold fluid comprises at least a portion of the methane-containing liquid.

9. The liquefaction system of claim 1, further comprising a pump configured to receive the hydrocarbon rich liquid from the separator and to pump the hydrocarbon rich liquid to a storage vessel.

10. The liquefaction system of claim 1, further comprising a first valve positioned between the first and second conduit locations and a second valve positioned between the first heat exchanger and the second conduit location.

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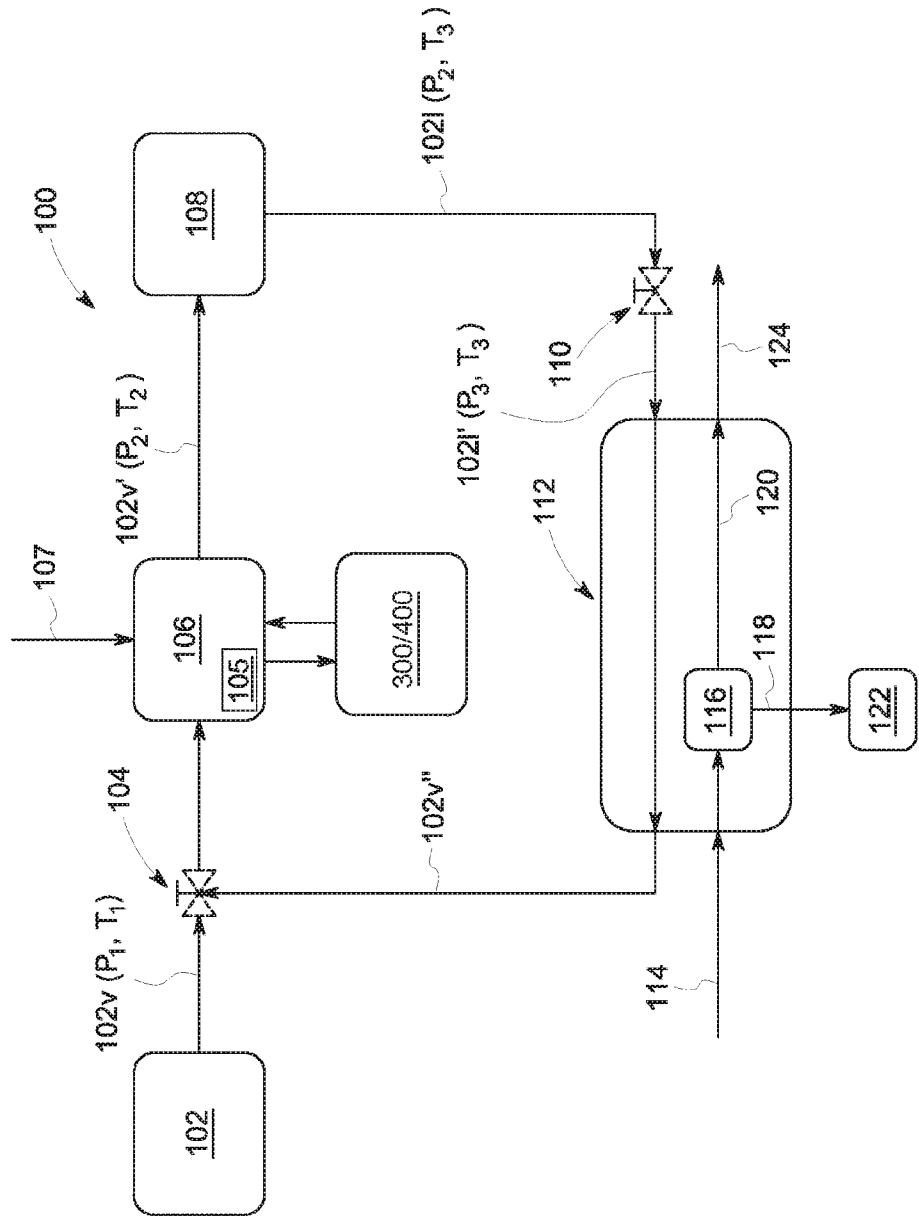


FIG. 1

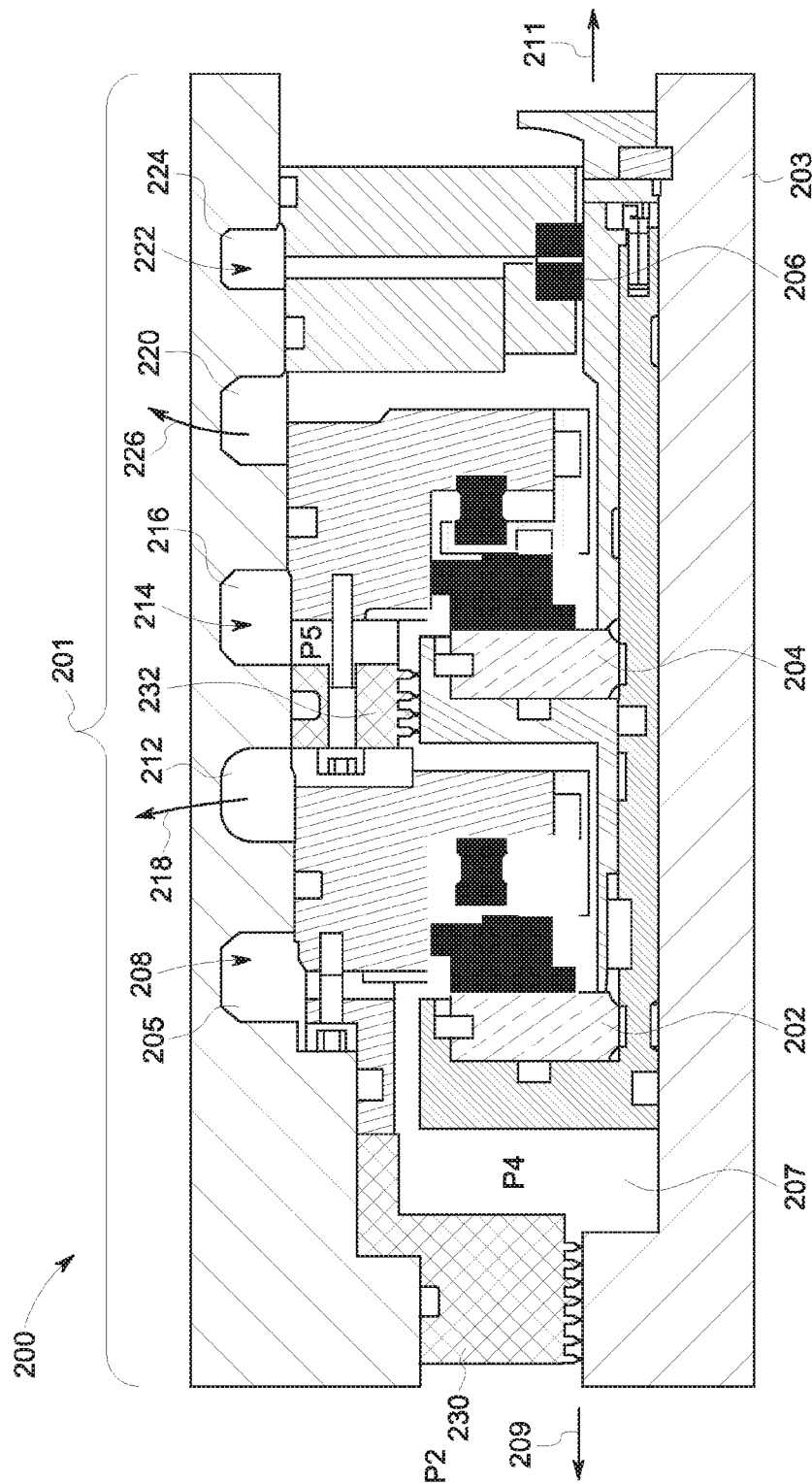


FIG. 2

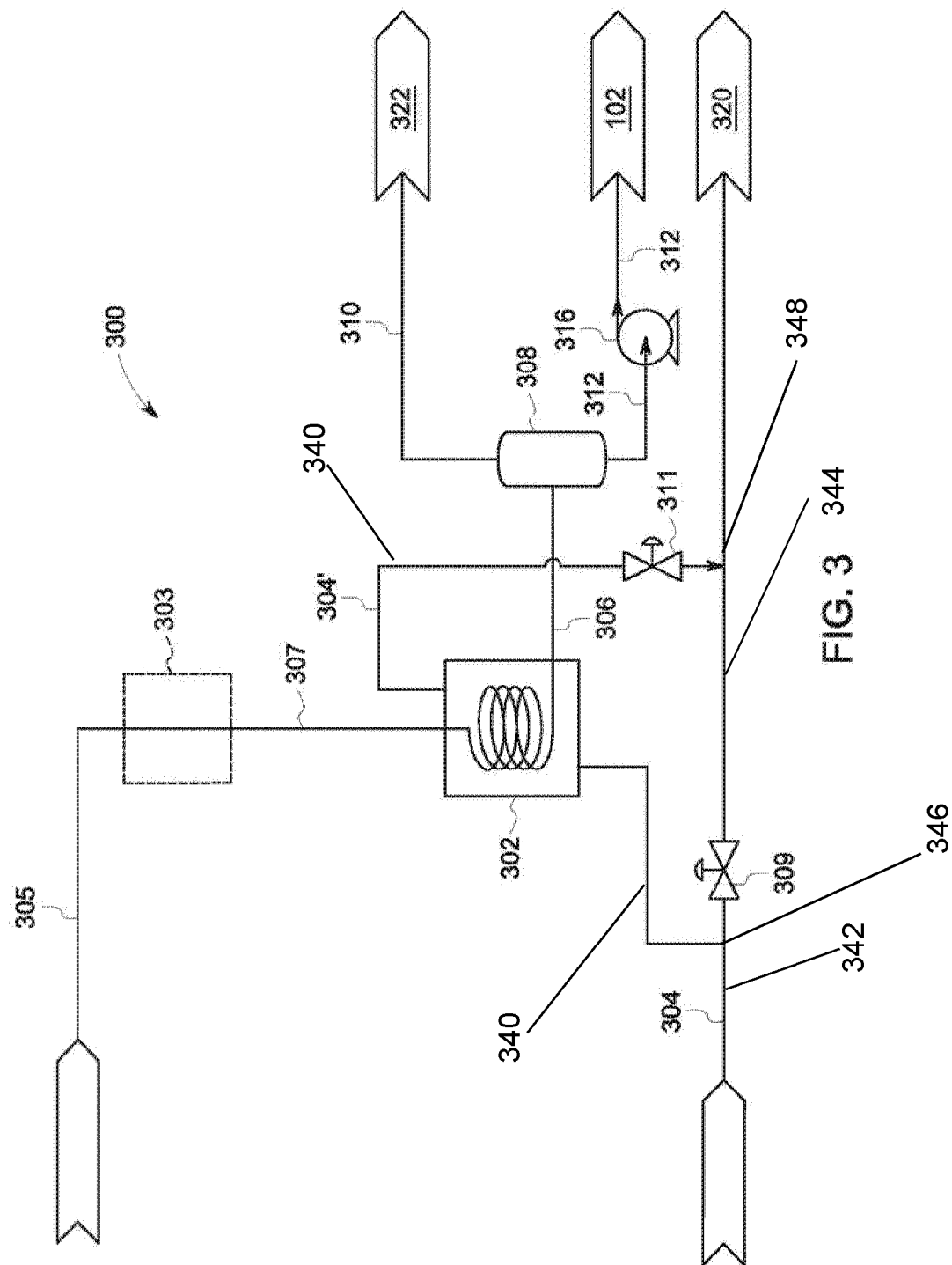
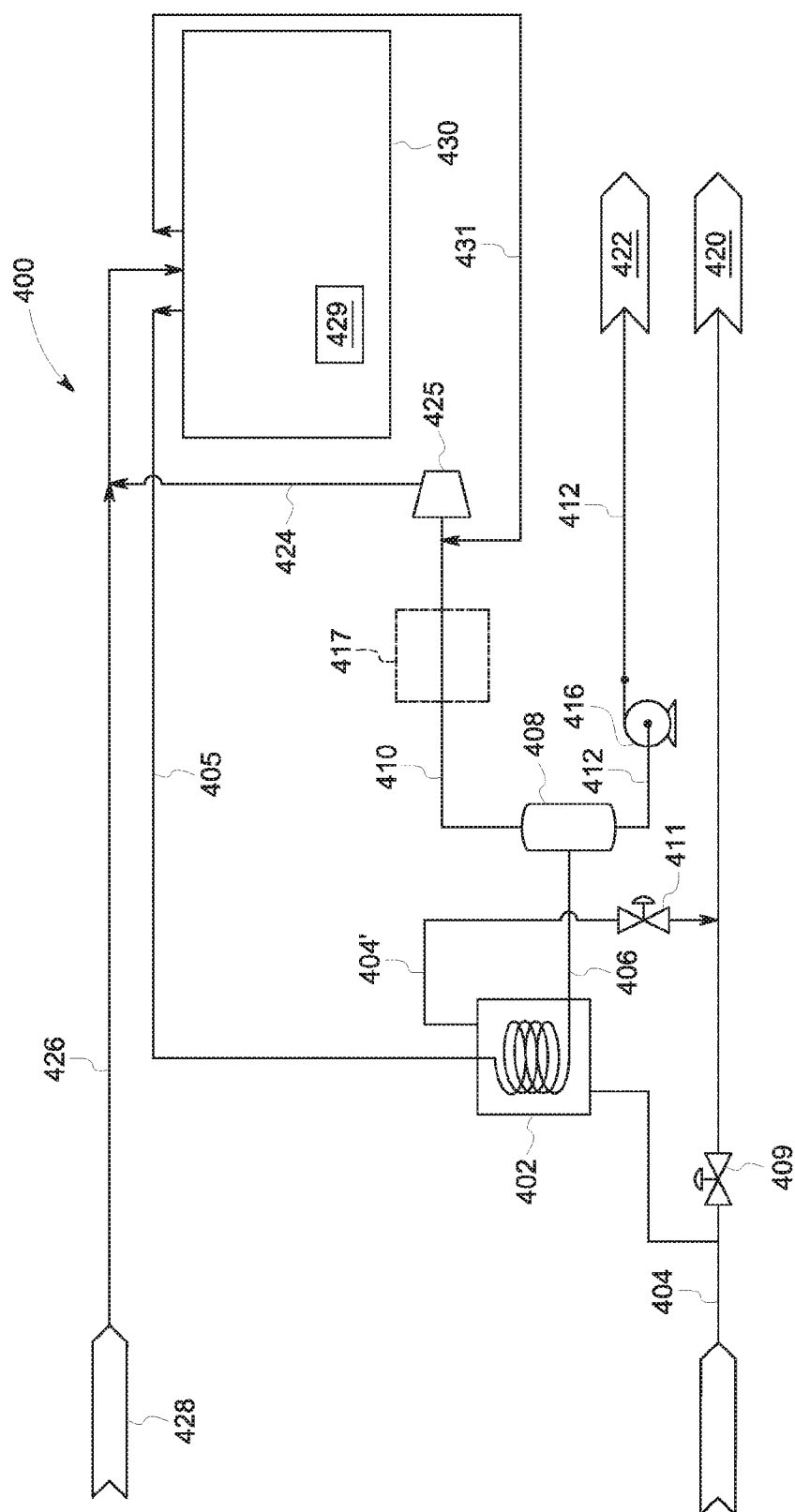


FIG. 3



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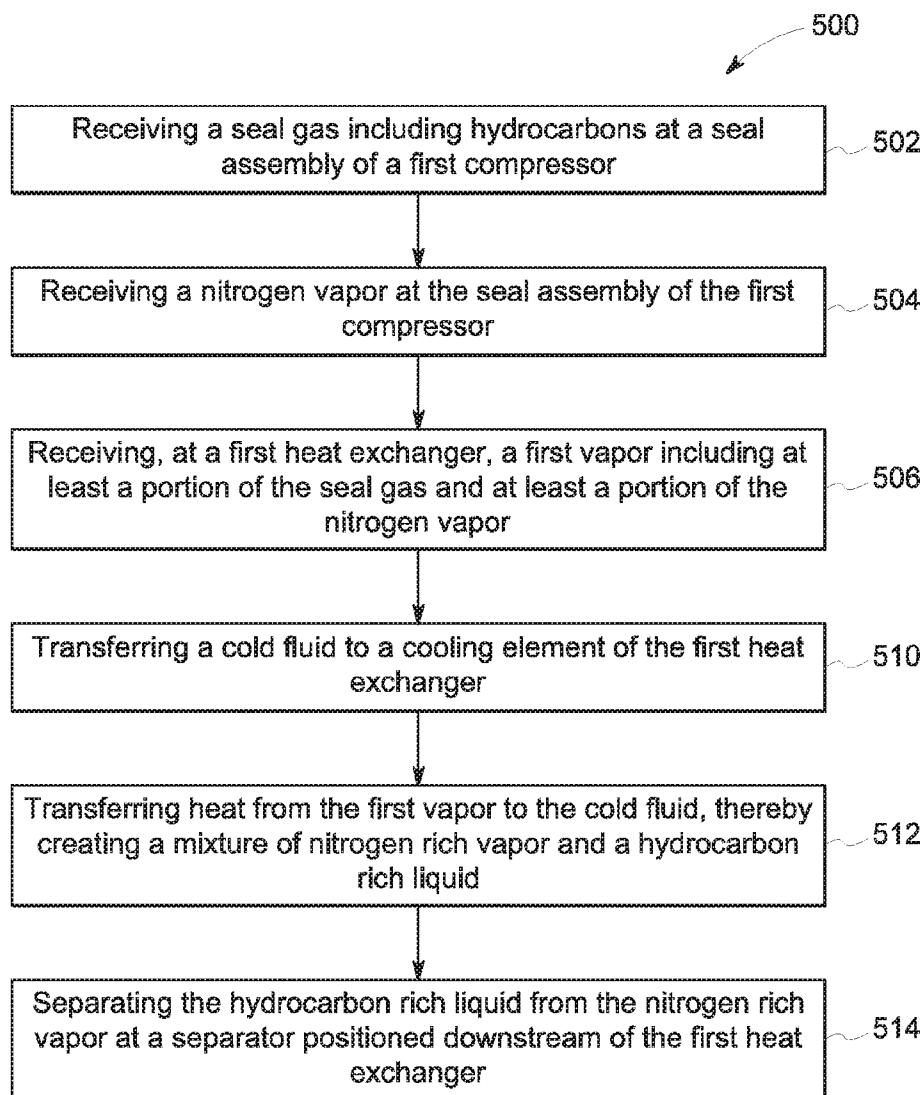


FIG. 5

