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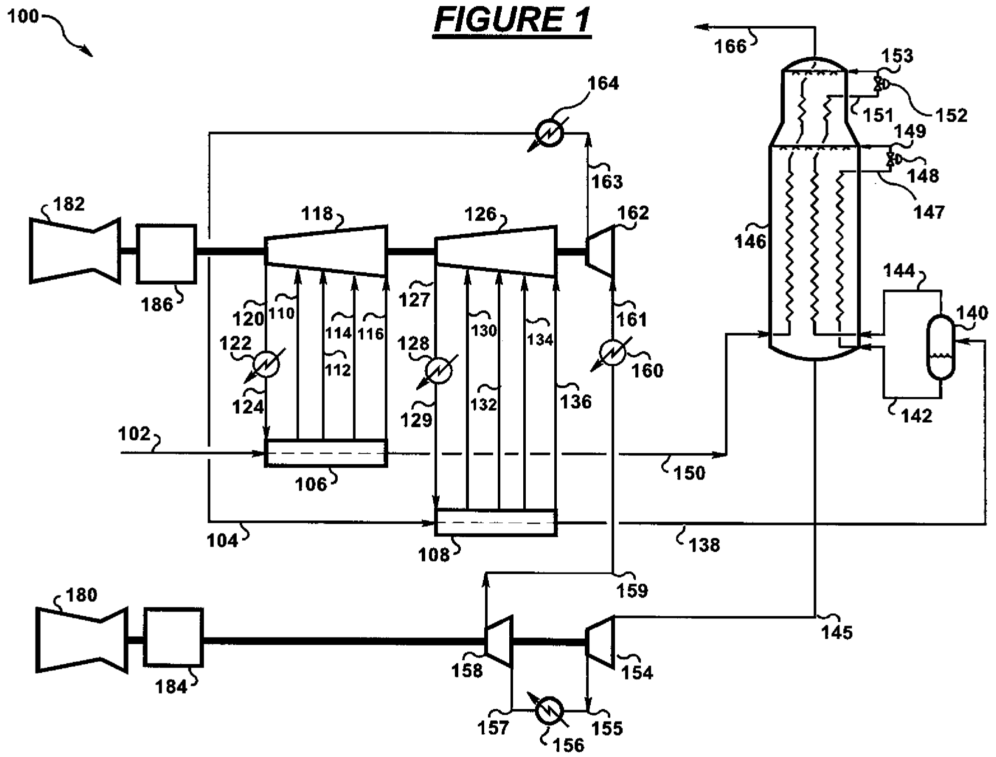
(54) **Alternative pre-cooling arrangement**

(57) A natural gas liquefaction system, the system comprising a first precooling refrigeration system (106) that accepts at least a natural gas feed stream (102), a second precooling refrigeration system (108) that accepts at least a first refrigerant stream (104); and a cryogenic heat exchanger (146) fluidly connected to the first precooling refrigeration system and the second precooling refrigeration system that accepts the natural gas feed stream (150) from the first precooling refrigeration system and the first refrigerant stream (138) from the second precooling refrigeration system to liquefy the natural gas feed stream (166), where the second precooling refrigeration system accepts only stream(s) having a composition different from the stream(s) accepted by the first precooling refrigeration system.

FIGURE 1



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Description

BACKGROUND

[0001] The present invention relates to a system and method for liquefaction of a gas stream, and more specifically, to a system and method for liquefaction of a natural gas stream in large capacity liquefaction plants.

[0002] Over the past few years, the liquid natural gas (LNG) industry has moved towards using large capacity liquefaction plants to achieve favorable economics associated with the large plants. Scale-up problems arise, however, when refrigerant mass and volume flow rates are increased. For example, the design of compression equipment, particularly the compression equipment associated with precooling, becomes problematic because the increased flow rates require larger compressor impellers with higher tip speeds, thicker and heavier casings, and higher inlet velocities to the impellers. As the equipment is scaled up, the design of the compressor becomes more problematic as fundamental aerodynamic limits are approached and, thus, the scale up may be limited by these considerations. In addition these precooling compressors are large and often contain multiple stages. Moreover, scale-up in many instances requires large, heavy equipment that can be difficult and costly to manufacture and/or install.

[0003] U.S. Patent No. 6,962,060 (Petrowski et al.) assigned to the assignee of the present invention, discloses one alternative system designed for liquefaction at large plants that includes a compressor system comprising a first compressor having a first stage and a second stage wherein the first stage of the first compressor is adapted to compress a first gas and the second stage of the first compressor is adapted to compress a combination of a fourth gas and an intermediate compressed gas from the first stage of the first compressor; and a second compressor having a first stage and a second stage wherein the first stage of the second compressor is adapted to compress a second gas and the second stage of the second compressor is adapted to compress a combination of a third gas and an intermediate compressed gas from the first stage of the second compressor.

[0004] There is a need for a method and system that provides stable operation at full rates and during turndown for larger capacity liquefaction plants.

BRIEF SUMMARY

[0005] Embodiments of the present invention satisfy this need in the art by providing a liquid natural gas liquefaction system and process that is stable and operational at full rates and during turndown for larger capacity liquefaction plants.

[0006] According to a first aspect, the present invention provides a natural gas liquefaction system, the system comprising: a first closed-loop precooling refrigeration system, for precooling at least a natural gas feed stream via indirect heat transfer with a precooling refrigerant circulating in said closed-loop of said first precooling refrigeration system; a second closed-loop precooling refrigeration system, for precooling at least a first refrigerant stream via indirect heat transfer with a precooling refrigerant circulating in said closed-loop of said second precooling refrigeration system; and a cryogenic heat exchanger in fluid connection with the first precooling refrigeration system and the second precooling refrigeration system so as to accept the precooled natural gas feed stream from the first precooling refrigeration system and the precooled first refrigerant stream from the second precooling refrigeration system in order to liquefy the natural gas feed stream; wherein the closed-loop of the second precooling refrigeration system is separate from the closed-loop of the first precooling refrigeration system, and wherein in operation no streams are precooled by both the second precooling refrigeration system and the first precooling refrigeration system.

[0007] In some embodiments, the first refrigerant stream is a mixed refrigerant stream. The first refrigerant stream may, for example, comprise nitrogen, methane, ethane, and propane.

[0008] In some embodiments, the natural gas liquefaction system further comprises a subcooler exchanger in fluid connection with the cryogenic heat exchanger, wherein the subcooler exchanger accepts a second refrigerant stream from the cryogenic heat exchanger to subcool the natural gas feed stream through indirect heat exchange.

[0009] In some embodiments, at least one of the first and second precooling refrigeration systems comprises at least one heat exchanger that accepts at least two load streams.

[0010] In some embodiments, the first precooling refrigeration system and the second precooling refrigeration system are CO_2 refrigeration systems.

[0011] In some embodiments, the first precooling refrigeration system and the second precooling refrigeration system each comprise: at least one device for reducing the pressure of or vaporizing at least a part of the precooling refrigerant; and a compressor in fluid connection with the at least one pressure reducing or vaporizing device and adapted to accept at least one precooling refrigerant stream.

[0012] In a preferred embodiment, where the precooling refrigerant is propane, the first precooling refrigeration system and the second precooling refrigeration system each comprise: at least one propane evaporator; and a propane compressor in fluid connection with the at least one propane evaporator and adapted to accept at least one propane vapor stream.

[0013] In a preferred embodiment, the natural gas liquefaction system further comprises a first driver and a second driver: wherein the first driver drives the compressor of the first precooling refrigeration system, the compressor of the second precooling refrigeration system, and a first high pressure refrigerant compressor; and wherein the second driver drives a first medium pressure refrigerant compressor and a first low pressure refrigerant compressor.

[0014] In another preferred embodiment, the natural gas liquefaction system further comprises a first driver and a second driver: wherein the first driver drives the compressor of the first precooling refrigeration system and one of either a first low pressure refrigerant compressor or a first high pressure refrigerant compressor; and wherein the second driver drives the compressor of the second precooling refrigeration system and the other of the first low pressure refrigerant compressor and the first high pressure refrigerant compressor not driven by the first driver.

[0015] In another preferred embodiment, the natural gas liquefaction system further comprises a first driver and a second driver: wherein the first driver drives the compressor of the first precooling refrigeration system and the compressor of the second precooling refrigeration system; and the second driver drives a first low pressure refrigerant compressor and a first high pressure refrigerant compressor. The system may further comprise a third driver, wherein the third driver drives a second low pressure refrigerant compressor and a second high pressure refrigerant compressor.

[0016] In the preferred embodiments described above, the first driver, the second driver and/or, if present, the third driver may, for example, be gas turbines.

[0017] In some embodiments, the cryogenic heat exchanger is a wound-coil heat exchanger.

[0018] According to a second aspect, the present invention provides a method for liquefying natural gas, the method comprising the steps of: precooling in a first closed-loop precooling refrigeration system, via indirect heat transfer with a precooling refrigerant circulating in said closed loop of said first precooling refrigeration system, at least a natural gas feed stream; precooling in a second closed-loop precooling refrigeration system, via indirect heat transfer with a precooling refrigerant circulating in said closed loop of said second precooling refrigeration system, at least a first refrigerant stream; and vaporizing the precooled first refrigerant stream in a cryogenic heat exchanger to cool the precooled natural gas feed stream through indirect heat exchange; wherein the closed-loop of the second precooling refrigeration system is separate from the closed-loop of the first precooling refrigeration system, and wherein the second precooling refrigeration system precools only stream(s) having a composition different from the stream(s) precooled by the first precooling refrigeration system.

[0019] In some embodiments, the natural gas feed stream and the first refrigerant stream are precooled to +60°F to -100°F (+16°C to -73°C).

[0020] In some embodiments, the method further comprises precooling a second refrigerant stream in either the first precooling refrigeration system or the second precooling refrigeration system, and vaporizing the second refrigerant stream to subcool the natural gas feed stream.

[0021] In some embodiments, the first refrigerant stream and/or, if present, the second refrigerant streams are mixed refrigerant streams.

[0022] In some embodiments, the precooling refrigerant is propane or CO_2.

[0023] In preferred embodiments, the method of the second aspect of the invention is carried out in a natural gas liquefaction system according to the first or third aspects.

[0024] According to a third aspect, the present invention provides a natural gas liquefaction system for large capacity liquefaction plants, the system comprising: a first closed-loop precooling refrigeration system for precooling, via indirect heat transfer with a precooling refrigerant circulating in said closed-loop of said first precooling refrigeration system, one stream selected from the group consisting of a natural gas feed stream, and an at least one refrigerant stream; a second closed-loop precooling refrigeration system for precooling, via indirect heat transfer with a precooling refrigerant circulating in said closed-loop of said second precooling refrigeration system, any remaining stream(s) not precooled by the first precooling refrigeration system and from the group consisting of the natural gas feed stream, and the at least one refrigerant stream; and a cryogenic heat exchanger in fluid connection with the first precooling refrigeration system and the second precooling refrigeration system and adapted to accept the precooled natural gas feed stream and the precooled at least one refrigerant stream from the first precooling refrigeration system and the second precooling refrigeration system, wherein the at least one refrigerant stream is used to liquefy the natural gas feed stream; wherein the closed-loop of the second precooling refrigeration system is separate from the closed-loop of the first precooling refrigeration system, and wherein in operation no streams are precooled by both the second precooling refrigeration system and the first precooling refrigeration system.

[0025] In some embodiments, the at least one refrigerant stream is a mixed refrigerant stream.

[0026] In some embodiments, the at least one refrigerant stream comprises a first refrigerant stream and a second refrigerant stream.

[0027] According to a fourth aspect, the present invention provides a natural gas liquefaction system, the system comprising: a first precooling refrigeration system that accepts at least a natural gas feed stream; a second precooling refrigeration system that accepts at least a first refrigerant stream; and a cryogenic heat exchanger fluidly connected to the first precooling refrigeration system and the second precooling refrigeration system that accepts the natural gas feed stream from the first precooling refrigeration system and the first refrigerant stream from the second precooling refrigeration system to liquefy the natural gas feed stream, wherein the second precooling refrigeration system accepts only stream(s) having a composition different from the stream(s) accepted by the first precooling refrigeration system.

[0028] According to a fifth aspect, the present invention provides, a method for liquefying natural gas, the method comprising the steps of: providing a natural gas feed stream; providing a first refrigerant stream; precooling in a first precooling refrigeration system at least the natural gas feed stream; precooling in a second precooling refrigeration system at least the first refrigerant stream; and vaporizing the precooled first refrigerant stream in a cryogenic heat exchanger to cool the precooled natural gas feed stream through indirect heat exchange, wherein the second precooling refrigeration system precools only stream(s) having a composition different from the stream(s) precooled by the first precooling refrigeration system.

[0029] According to a sixth aspect, the present invention provides, a natural gas liquefaction system for large capacity liquefaction plants is disclosed, the system comprising: a first precooling refrigeration system that accepts one stream selected from the group consisting of: a natural gas feed stream, and an at least one refrigerant stream; a second precooling refrigeration system that accepts any remaining stream(s) not accepted by the first precooling refrigeration system and from the group consisting of: the natural gas feed stream, and the at least one refrigerant stream; and a cryogenic heat exchanger fluidly connected to the first precooling refrigeration system and the second precooling refrigeration system and adapted to accept the natural gas feed stream and the at least one refrigerant stream from the first precooling refrigeration system and the second precooling refrigeration system, wherein the at least one refrigerant stream is used to liquefy the natural gas feed stream, wherein the second precooling refrigeration system accepts only stream(s) having a composition different from the stream(s) accepted by the first precooling refrigeration system.

[0030] Some exemplary and preferred embodiments of the fourth, fifth and sixth aspects of the invention are as described above in relation to the first, second and third aspects.

BRIEF DESCRIPTION OF THE EXEMPLARY DRAWINGS

[0031] The foregoing brief summary, as well as the following detailed description of exemplary embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating embodiments of the invention, there is shown in the drawings exemplary embodiments of the invention; however, the invention is not limited to the specific methods and instrumentalities disclosed. In the drawings:

Figure 1 is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 2A is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 2B is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 3 is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 4 is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 5 is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 6 is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 7A is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 7B is a flow chart illustrating an exemplary system and method involving aspects of the present invention;

Figure 8A is a flow chart illustrating an exemplary system and method involving aspects of the present invention; and

Figure 8B is a flow chart illustrating an exemplary system and method involving aspects of the present invention.

DETAILED DESCRIPTION

[0032] Figure 1 illustrates an exemplary embodiment of the invention as applied to a pre-cooled refrigerant system and process. In this exemplary system 100, propane is used to precool both a natural gas feed stream 102 and a liquefaction refrigerant stream 104. The natural gas feed stream 102 may be pretreated, for example. The liquefaction refrigerant stream 104 may be a pure or a mixed refrigerant, for example. It should be noted that while the exemplary embodiments described below may refer to the liquefaction refrigerant stream as a mixed refrigerant stream, the liquefaction refrigerant stream described below may also be a pure refrigerant stream, for example. Depending on refrigerant availability in the local area and system requirements (*e.g.*, adjusting the composition of the mixed refrigerant to match the cooling curve for optimal cooling performance), the liquefaction refrigerant stream 104 may comprise one or more of the following: nitrogen, methane, ethylene, ethane, propylene, propane, iso-butane, n-butane, and iso-pentane, for example.

[0033] The compression of the propane vapor resulting from the cooling of the natural gas feed stream 102 may occur in one compressor 118 while the compression of the propane vapor generated from cooling of liquefaction refrigerant stream 104 may occur in a separate compressor 126.

[0034] Precooling of the natural gas feed stream 102 and the mixed refrigerant stream 104 may be accomplished by vaporizing a precooling refrigerant such as propane at four different pressure levels in closed-loop precooling refrigeration system(s). The natural gas feed stream 102 may be precooled because of equipment limitations and for efficiency purposes. It should be noted that while propane may be used as the precooling refrigerant for vaporizing at four different pressure levels (as illustrated in exemplary Figures 1-7A), carbon dioxide, methane, propane, butane, iso-butane, propylene, ethane, ethylene, R22, HFC refrigerants, including, but not limited to, R410A, R134A, R507, R23, or combinations thereof, may also be used, for example.

[0035] Cooling of the natural gas feed stream 102 is performed in unit 106. Unit 106 may comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2A. Natural gas feed stream 102 is cooled by indirect heat exchange against a precooling refrigerant in a series of propane evaporators 202, 204, 206, 208 that may operate at successively lower pressures (202 being the highest and 208 being the lowest, for example) producing cooled successive streams 203, 205, 207, and 150. The evaporation of propane at the four pressures results in four propane vapor streams 110, 112, 114, 116 that are then compressed in compressor 118. The resulting compressed stream 120 is then condensed in propane condenser 122, producing liquid stream 124 for reintroduction into the series of propane evaporators 202, 204, 206, 208. Propane condensers used in these types of methods and systems may include, for example, a propane de-superheater, a condenser, an accumulator, and a propane subcooler. It should be noted that while this exemplary embodiment illustrated in Figures 1, 2A, 2B, 3, 4, 5, 6, and 7A uses a four stage pre-cooling system, the pre-cooling system may comprise a single-stage, a two-stage, a three-stage, or systems with greater than four stages, for example, where the series of propane evaporators may operate at successively lower pressures.

[0036] Cooling of the mixed refrigerant stream 104 is performed in unit 108. Unit 108 may also comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2B. The mixed refrigerant stream 104 may also be cooled by indirect heat exchange against the precooling refrigerant in a series of propane evaporators 222, 224, 226, 228 that may operate at successively lower pressures (222 being the highest and 228 being the lowest, for example) producing cooled successive streams 223, 225, 227, and 138. The evaporation of propane at the four pressures results in four propane vapor streams 130, 132, 134, 136 that are then compressed in compressor 126. The resulting compressed stream 127 is then condensed in propane condenser 128, producing liquid stream 129 for reintroduction into the series of propane evaporators 222, 224, 226, 228.

[0037] Cooled mixed refrigerant stream 138 is separated in phase separator 140 into a liquid mixed refrigerant stream 142 and a vapor mixed refrigerant stream 144. Liquid mixed refrigerant stream 142 is sub-cooled in the cryogenic heat exchanger (MCHE) 146 producing stream 147. Stream 147 may then be reduced in pressure through isenthalpic valve 148 producing stream 149. Stream 149 may then be vaporized in the shell side of the MCHE 146 to provide cooling to tubeside streams 142, 144, 150.

[0038] Vapor mixed refrigerant steam 144 is condensed and sub-cooled in the MCHE 146 to produce stream 151. Stream 151 may then be reduced in pressure through isenthalpic valve 152 to produce stream 153. Stream 153 may then be vaporized in the shell side of the MCHE 146 to provide cooling to tubeside streams 142, 144, 150.

[0039] The cooled natural gas feed stream 150 may enter the MCHE 146 where it is further cooled producing product stream 166 that may be, for example, liquid natural gas (LNG).

[0040] Low pressure mixed refrigerant stream 145 exiting the MCHE 146 is compressed in the low pressure mixed refrigerant compressor 154 to produce stream 155. It should be noted that the refrigerant compressors of all of the exemplary embodiments may include one or more intercoolers and compressor casings. For example, mixed refrigerant compressor 154 may include one or more intercoolers and at least one compressor casing. Intercoolers and aftercoolers use an ambient heat sink (air or water) to reject compression heat to the environment.

[0041] Stream 155 is cooled in intercooler 156 to produce stream 157. Stream 157 is further compressed in the medium pressure mixed refrigerant compressor 158 to produce stream 159. Stream 159 is cooled in intercooler 160 to produce stream 161. Stream 161 is further compressed in high pressure mixed refrigerant compressor 162 to produce stream 163. Stream 163 is cooled in aftercooler 164 to be recycled back as original mixed refrigerant stream 104.

[0042] The exemplary embodiment illustrated in Figure 1 shows how the power supplied to the refrigeration compressors 118, 126, 154, 158, 162 are provided by two equal sized directly connected gas turbines 180, 182. For example, mixed refrigerant compressors 154, 158 are driven by gas turbine driver 180 while mixed refrigerant compressor 160 and the propane compressors 118, 126 are driven by gas turbine driver 182. In this exemplary embodiment, the design pressure level between the mixed refrigerant compressors 158 and 162 may be chosen such that the work required by the two gas turbine drivers 180, 182 is essentially equal. The gas turbine drivers in all exemplary embodiments may be single-shaft gas turbines or multi-shaft gas turbines, for example.

[0043] This exemplary embodiment is independent of the method used to power the refrigeration compressors 118, 126, 154, 158 and 162. The refrigeration compressors 118, 126, 154, 158 and 162, and the refrigeration compressors of the other exemplary embodiments may be driven by one or more gas turbines, electric motors, steam turbines, or a combination of different drivers. As illustrated in Figure 1, the gas turbines 180, 182 may include starter/helper electric motors 184, 186 respectively to assist in starting the gas turbines 180, 182 and optimally, to provide additional power to assist the gas turbines 180, 182, or to generate power for exportation into the power grid when excess power is available from the gas turbines. Moreover, for the exemplary embodiment illustrated in Figure 1, and all other exemplary embodiments disclosed, the order of the compressor bodies and the starter/helper electric motors coupled to each driver is not fixed and may be manipulated/altered pursuant to any system requirements, maintenance requirements, and/or plant design requirements. For example, starter/helper electric motor 186 in Figure 1 may be positioned away from and not adjacent to driver 182 (i.e., at the opposite end of the driver string). The positions of the compressor bodies 118, 126, 162 may also be exchanged.

[0044] Figure 3 illustrates another exemplary embodiment 300 where the propane compressors 318, 326 are powered by different drivers 380, 382 respectively. In this exemplary embodiment, the power demand from the equivalent gas turbine drivers 380, 382 may be balanced by adjustment of the discharge pressure of low pressure mixed refrigerant compressor 354.

[0045] As illustrated in the exemplary embodiment 300 in Figure 3, cooling of the natural gas feed stream 302 is performed in unit 306. Like unit 106 of Figure 1, unit 306 may comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2A. Natural gas feed stream 302 is cooled by indirect heat exchange to ultimately produce cooled stream 350. The evaporation of propane at the four pressures results in four propane vapor streams 310, 312, 314, 316 that may then be compressed in compressor 318. The resulting compressed stream 320 may then be condensed in propane condenser 322, producing liquid stream 324 for reintroduction into the series of propane evaporators as shown in Figure 2A.

[0046] Cooling of the mixed refrigerant stream 304 is performed in unit 308. Unit 308 may also comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2B. The mixed refrigerant stream 304 may also be cooled by indirect heat exchange to ultimately produce cooled stream 338. The evaporation of propane at the four pressures results in four propane vapor streams 330, 332, 334, 336 that may then be compressed in compressor 326. The resulting compressed stream 327 may then be condensed in propane condenser 328, producing liquid stream 329 for reintroduction into the series of propane evaporators as shown in Figure 2B.

[0047] Again cooled mixed refrigerant stream 338 is separated in phase separator 340 into a liquid mixed refrigerant stream 342 and a vapor mixed refrigerant stream 344. Liquid mixed refrigerant stream 342 is sub-cooled in the cryogenic heat exchanger (MCHE) 346 producing stream 347. Stream 347 may then be reduced in pressure through isenthalpic valve 348 producing stream 349. Stream 349 may then be vaporized in the shell side of the MCHE 346 to provide cooling to tubeside streams 342, 344, 350.

[0048] Vapor mixed refrigerant steam 344 is condensed and sub-cooled in the MCHE 346 to produce stream 351. Stream 351 may then be reduced in pressure through isenthalpic valve 352 to produce stream 353. Stream 353 may then be vaporized in the shell side of the MCHE 346 to provide cooling to tubeside streams 342, 344, 350.

[0049] The cooled natural gas feed stream 350 may enter the MCHE 346 where it is further cooled producing product stream 366 that may be, for example, liquid natural gas (LNG).

[0050] Low pressure mixed refrigerant stream 345 exiting the MCHE 346 is compressed in the low pressure refrigerant compressor 354 to produce stream 355. Stream 355 is cooled in intercooler 356 to produce stream 357. Stream 357 is further compressed in the high pressure refrigerant compressor 362 to produce stream 363. Stream 363 is cooled in aftercooler 364 to be recycled back as original mixed refrigerant stream 304.

[0051] Power is supplied to the refrigeration compressors 318, 326, 354, 362 by two equal sized directly connected gas turbines 380, 382. As illustrated in Figure 3, the gas turbines 380, 382 may include starter/helper electric motors 384, 386 respectively to assist in starting the gas turbines 380, 382 and optimally, to provide additional power to assist the gas turbines 380, 382, or for exportation into the power grid when excess power is available from the gas turbines.

[0052] Figure 4 illustrates another exemplary embodiment 400 where the position of compressors 418, 426 of Figure 3 may be swapped such that one of the drivers provides power to the propane compressor 418 and the high pressure refrigerant compressor 462, while the other driver provides power to the propane compressor 426 and the low pressure refrigerant compressor 454.

[0053] As illustrated in the exemplary embodiment 400 in Figure 4, cooling of the natural gas feed stream 402 is performed in unit 406. Like unit 106 of Figure 1, unit 406 may comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2A. Natural gas feed stream 402 is cooled by indirect heat exchange to ultimately produce cooled stream 450. The evaporation of propane at the four pressures results in four propane vapor streams 410, 412, 414, 416 that may then be compressed in compressor 418. The resulting compressed stream 420 may then be condensed in propane condenser 422, producing liquid stream 424 for reintroduction into the series of propane evaporators as shown in Figure 2A.

[0054] Cooling of the mixed refrigerant stream 404 is performed in unit 408. Unit 408 may also comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2B. The mixed refrigerant stream 404 may also be cooled by indirect heat exchange to ultimately produce cooled stream 438. The evaporation of propane at the four pressures results in four propane vapor streams 430, 432, 434, 436 that may then be compressed in compressor 426. The resulting compressed stream 427 may then be condensed in propane condenser 428, producing liquid stream 429 for reintroduction into the series of propane evaporators as shown in Figure 2B.

[0055] Again cooled mixed refrigerant stream 438 is separated in phase separator 440 into a liquid mixed refrigerant stream 442 and a vapor mixed refrigerant stream 444. Liquid mixed refrigerant stream 442 is sub-cooled in the cryogenic heat exchanger (MCHE) 446 producing stream 447. Stream 447 may then be reduced in pressure through isenthalpic valve 448 producing stream 449. Stream 449 may then be vaporized in the shell side of the MCHE 446 to provide cooling to tubeside streams 442, 444, 450.

[0056] Vapor mixed refrigerant steam 444 is condensed and sub-cooled in the MCHE 446 to produce stream 451. Stream 451 may then be reduced in pressure through isenthalpic valve 452 to produce stream 453. Stream 453 may then be vaporized in the shell side of the MCHE 446 to provide cooling to tubeside streams 442, 444, 450.

[0057] The cooled natural gas feed stream 450 may enter the MCHE 446 where it is further cooled producing product stream 466 that may be, for example, liquid natural gas (LNG).

[0058] Low pressure mixed refrigerant stream 445 exiting the MCHE 446 is compressed in the low pressure refrigerant compressor 454 to produce stream 455. Stream 455 is cooled in intercooler 456 to produce stream 457. Stream 457 is further compressed in high pressure refrigerant compressor 462 to produce stream 463. Stream 463 is cooled in after-cooler 464 to be recycled back as original mixed refrigerant stream 404.

[0059] Power is supplied to the refrigeration compressors 418, 426, 454, 462 by two equal sized directly connected gas turbines 480, 482. As illustrated in Figure 4, the gas turbines 480, 482 may include starter/helper electric motors 484, 486 respectively to assist in starting the gas turbines 480, 482 and optimally, to provide additional power to assist the gas turbines 480, 482, or for exportation into the power grid when excess power is available from the gas turbines.

[0060] Figure 5 illustrates yet another exemplary embodiment 500 as applied to a three loop refrigeration system. In this exemplary embodiment 500, unit 506 precools a third refrigerant stream 503 in addition to the natural gas feed stream 502. Like unit 106 of Figure 1, unit 506 may comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2A. Natural gas feed stream 502 is cooled by indirect heat exchange to ultimately produce cooled stream 550. The evaporation of propane at the four pressures results in four propane vapor streams 510, 512, 514, 516 that may then be compressed in compressor 518. The resulting compressed stream 520 may then be condensed in propane condenser 522, producing liquid stream 524 for reintroduction into the series of propane evaporators as shown in Figure 2A.

[0061] Cooling of the mixed refrigerant stream 504 is performed in unit 508. Unit 508 may also comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2B. The mixed refrigerant stream 504 may also be cooled by indirect heat exchange to ultimately produce cooled stream 538. The evaporation of propane at the four pressures results in four propane vapor streams 530, 532, 534, 536 that may then be compressed in compressor 526. The resulting compressed stream 527 may then be condensed in propane condenser 528, producing liquid stream 529 for reintroduction into the series of propane evaporators as shown in Figure 2B.

[0062] Cooled mixed refrigerant stream 538 is subcooled in the cryogenic heat exchanger (MCHE) 546 producing stream 547. Stream 547 may then be reduced in pressure through isenthalpic valve 548 producing stream 549. Stream 549 may then be vaporized in the shell side of the MCHE 546 to provide cooling to tubeside streams 505, 538, and 550.

[0063] Cooled mixed refrigerant stream 505 may also be subcooled and liquefied in MCHE 546 producing stream 569 then subcooled in exchanger 568 producing stream 551. Exchanger 568 may be a wound coil type exchanger, for example. The resulting stream 551 may then be reduced in pressure through isenthalpic valve 552 to produce stream 553. Stream 553 may then be vaporized in exchanger 568 to provide refrigeration for subcooling both the feed gas stream (entering as stream 567 and exiting as 566) and the third refrigerant stream 569. After vaporization and warming, third refrigerant stream 553 exits exchanger 568 as stream 593 and is then compressed by compressor 594 to produce stream 595. Stream 595 is then cooled in the mixed refrigerant intercooler 596 to produce stream 597. Stream 597 is compressed in compressor 598 to produce stream 599. Stream 599 is then cooled in mixed refrigerant aftercooler 501 to be recycled back as original stream 503.

[0064] The cooled natural gas feed stream 550 may enter the MCHE 546 where it is further cooled producing stream 567. Stream 567 may then be subcooled in exchanger 568 to produce product stream 566 that may be, for example, liquid natural gas (LNG).

[0065] Low pressure mixed refrigerant stream 545 exiting the MCHE 546 is compressed in the low pressure refrigerant compressor 554 to produce stream 555. Stream 555 is cooled in intercooler 556 to produce stream 557. Stream 557 is further compressed in high pressure refrigerant compressor 558 to produce stream 559. Stream 559 is cooled in after-cooler 564 to be recycled back as original mixed refrigerant stream 504.

[0066] Power is supplied to the refrigeration compressors 518, 526, 554, 558, 594, 598 by three equal sized directly connected gas turbines 580, 582, 592. As illustrated in Figures 1, 3, and 4, the gas turbines may include starter/helper electric motors (not shown in this embodiment) to assist in starting the gas turbines and optimally, to provide additional power to assist the gas turbines, or for exportation into the power grid when excess power is available from the gas turbines.

[0067] Figure 6 illustrates yet another exemplary embodiment 600 as applied to another three loop refrigeration system. In this exemplary embodiment 600, unit 606 precools the natural gas feed stream 602 only. Like unit 106 of Figure 1, unit 606 may comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2A. Natural gas feed stream 602 is cooled by indirect heat exchange to ultimately produce cooled stream 650. The evaporation of propane at the four pressures results in four propane vapor streams 610, 612, 614, 616 that may then be compressed in compressor 618. The resulting compressed stream 620 may then be condensed in propane condenser 622, producing liquid stream 624 for reintroduction into the series of propane evaporators as shown in Figure 2A.

[0068] In this exemplary embodiment, both mixed refrigerant streams 603, 604 are cooled in unit 608. Unit 608 may also comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2B. The mixed refrigerant streams 603, 604 may also be cooled by indirect heat exchange to ultimately produce cooled streams 605, 638. The evaporation of propane at the four pressures results in four propane vapor streams 630, 632, 634, 636 that may then be compressed in compressor 626. The resulting compressed stream 627 may then be condensed in propane condenser 628, producing liquid stream 629 for reintroduction into the series of propane evaporators as shown in Figure 2B.

[0069] Cooled mixed refrigerant stream 638 is subcooled in the cryogenic heat exchanger (MCHE) 646 producing stream 647. Stream 647 may then be reduced in pressure through isenthalpic valve 648 producing stream 649. Stream 649 may then be vaporized in the shell side of the MCHE 646 to provide cooling to tubeside streams 605, 638, and 650.

[0070] Cooled mixed refrigerant stream 605 may also be subcooled and liquefied in MCHE 646 producing stream 669 then subcooled in exchanger 668 producing stream 651. Exchanger 668 may be a wound coil type exchanger, for example. The resulting stream 651 may then be reduced in pressure through isenthalpic valve 652 to produce stream 653. Stream 653 may then be vaporized in exchanger 668 to provide refrigeration for subcooling both the feed gas stream (entering as stream 667 and exiting as 666) and the third refrigerant stream 669. After vaporization and warming, third refrigerant stream 653 exits exchanger 668 as stream 693 and is then compressed by compressor 694 to produce stream 695. Stream 695 is then cooled in the mixed refrigerant intercooler 696 to produce stream 697. Stream 697 is compressed in compressor 698 to produce stream 699. Stream 699 is then cooled in mixed refrigerant aftercooler 601 to be recycled back as original stream 603.

[0071] The cooled natural gas feed stream 650 may enter the MCHE 646 where it is further cooled producing stream 667. Stream 667 may then be subcooled in exchanger 668 to produce product stream 666 that may be, for example, liquid natural gas (LNG).

[0072] Low pressure mixed refrigerant stream 645 exiting the MCHE 646 is compressed in the low pressure refrigerant compressor 654 to produce stream 655. Stream 655 is cooled in intercooler 656 to produce stream 657. Stream 657 is further compressed in the high pressure refrigerant compressor 658 to produce stream 659. Stream 659 is cooled in aftercooler 664 to be recycled back as original mixed refrigerant stream 604.

[0073] Power is supplied to the refrigeration compressors 618, 626, 654, 658, 694, 698 by three equal sized directly connected gas turbines 680, 682, 692. As illustrated in Figures 1, 3, and 4, the gas turbines may include starter/helper electric motors (not shown in this embodiment) to assist in starting the gas turbines and optimally, to provide additional power to assist the gas turbines, or for exportation into the power grid when excess power is available from the gas turbines.

[0074] Figure 7A illustrates another exemplary embodiment 700A as applied to yet another three loop refrigeration system. In this exemplary embodiment 700A, unit 706 precools the natural gas feed stream 702 and the mixed refrigerant stream 704. Like unit 106 of Figure 1, unit 706 may comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2A. Natural gas feed stream 702 and mixed refrigerant stream 704 is cooled by indirect heat exchange to ultimately produce cooled streams 750, 738. The evaporation of propane at the four pressures results in four propane vapor streams 710, 712, 714, 716 that may then be compressed in compressor 718. The resulting compressed stream 720 may then be condensed in propane condenser 722, producing liquid stream 724 for reintroduction into the series of propane evaporators as shown in Figure 2A.

[0075] In this exemplary embodiment, only mixed refrigerant stream 703 is cooled in unit 708. Unit 708 may also comprise a series of heat exchangers, valves, and separators as illustrated in Figure 2B. The mixed refrigerant stream 703 is cooled by indirect heat exchange to ultimately produce cooled streams 705. The evaporation of propane at the four pressures results in four propane vapor streams 730, 732, 734, 736 that may then be compressed in compressor 726. The resulting compressed stream 727 may then be condensed in propane condenser 728, producing liquid stream 729 for reintroduction into the series of propane evaporators as shown in Figure 2B.

[0076] Cooled mixed refrigerant stream 738 is subcooled in the cryogenic heat exchanger (MCHE) 746 producing stream 747. Stream 747 may then be reduced in pressure through isenthalpic valve 748 producing stream 749. Stream 749 may then be vaporized in the shell side of the MCHE 746 to provide cooling to tubeside streams 705, 738, and 750.

[0077] Cooled mixed refrigerant stream 705 may also be subcooled and liquefied in MCHE 746 producing stream 769 then subcooled in exchanger 768 producing stream 751. Exchanger 768 may be a wound coil type exchanger, for example. The resulting stream 751 may then be reduced in pressure through isenthalpic valve 752 to produce stream 753. Stream 753 may then be vaporized in exchanger 768 to provide refrigeration for subcooling both the feed gas stream (entering as stream 767 and exiting as 766) and the third refrigerant stream 769. After vaporization and warming, third refrigerant stream 753 exits exchanger 768 as stream 793 and is then compressed by compressor 794 to produce stream 795. Stream 795 is then cooled in the mixed refrigerant intercooler 796 to produce stream 797. Stream 797 is compressed in compressor 798 to produce stream 799. Stream 799 is then cooled in mixed refrigerant aftercooler 701 to be recycled back as original stream 703.

[0078] The cooled natural gas feed stream 750 may enter the MCHE 746 where it is further cooled producing stream 767. Stream 767 may then be subcooled in exchanger 768 to produce product stream 766 that may be, for example, liquid natural gas (LNG).

[0079] Low pressure mixed refrigerant stream 745 exiting the MCHE 746 is compressed in the low pressure refrigerant compressor 754 to produce stream 755. Stream 755 is cooled in intercooler 756 to produce stream 757. Stream 757 is further compressed in the high pressure refrigerant compressor 758 to produce stream 759. Stream 759 is cooled in aftercooler 764 to be recycled back as original mixed refrigerant stream 704.

[0080] Power is supplied to the refrigeration compressors 718, 726, 754, 758, 794, 798 by three equal sized directly connected gas turbines 780, 782, 792. As illustrated in Figures 1, 3, and 4, the gas turbines may include starter/helper electric motors (not shown in this embodiment) to assist in starting the gas turbines and optimally, to provide additional power to assist the gas turbines, or for exportation into the power grid when excess power is available from the gas turbines.

[0081] Figure 7B illustrates yet another exemplary embodiment 700B similar to 700A, however, in this exemplary embodiment 700B, unit 706 precools the natural gas feed stream 702 and the mixed refrigerant stream 704 through indirect heat exchange with a mixed refrigerant stream in a two-stage mixed refrigerant precooling system. While Figure 7B discloses use of a two-stage mixed refrigerant precooling system, the precooling may be performed using a single-stage mixed refrigerant precooling system, or mixed refrigerant precooling systems with greater than two stages, for example. Additionally, a mixed refrigerant precooling system may be interchanged with the propane precooling systems disclosed in any of the exemplary embodiments.

[0082] Figures 8A and 8B illustrate exemplary units 706 and 708 shown in Figure 7B. Unit 706 may comprise two heat exchangers 810, 812 where streams 702, 704, and at least a portion of stream 724 are cooled through indirect heat exchange against stream 713 in heat exchanger 810. Stream 724 enters heat exchanger 810 and is cooled producing stream 830. Stream 830 is split into two streams 831, 832 where stream 831 is further cooled in heat exchanger 812 while stream 832 is let down in pressure across isenthalpic valve 814 to produce stream 833. Stream 833 then enters heat exchanger 810 to provide cooling to streams 702, 704, 724 and exits the heat exchanger 810 as stream 713.

[0083] After stream 831 is cooled in heat exchanger 812 to produce stream 834 and let down in pressure across isenthalpic valve 816, the resulting stream 835 is introduced into heat exchanger 812 to provide further cooling for resultant streams 738, 750, 834.

[0084] Unit 708 may comprise two heat exchangers 818, 820 where streams 703, 729 are cooled through indirect heat exchange against stream 733 in heat exchanger 818. Stream 729 enters heat exchanger 818 and is cooled producing stream 840. Stream 840 is split into two streams 841, 842 where stream 841 is further cooled in heat exchanger 820 while stream 842 is let down in pressure across isenthalpic valve 822 to produce stream 843. Stream 843 then enters heat exchanger 818 to provide cooling to streams 703, 729 and exits the heat exchanger 818 as stream 733.

[0085] After stream 841 is cooled in heat exchanger 820 to produce stream 844 and let down in pressure across isenthalpic valve 824, the resulting stream 845 is introduced into heat exchanger 820 to provide further cooling for resultant streams 705, 844.

[0086] Heat exchangers 810, 812, 818, 820 may be wound-coil heat exchangers, plate-and-fin brazed aluminum (core) type heat exchangers, or shell and tube heat exchangers, for example. Heat exchangers 810, 812 may be combined into a single heat exchanger, for example. Heat exchangers 818, 820 may also be combined into a single heat exchanger, for example. Finally, heat exchangers 810, 812, 818, 820 may be combined into a single heat exchanger, for example. Heat exchangers 810, 812, 818, 820 may accept two or more load streams, for example.

[0087] Pre-cooling in units 106, 108 may provide, for example, enough cooling to feed stream 102 and liquefaction refrigerant stream 104 such that the temperatures of streams 150 and 138 may reach +60°F (+16°C) to as low as -100°F (-73°C) before further cooling in the MCHE 146. The same cooling ranges may be achieved in Figures 3-7B. In one embodiment, for example, propane may be used as the pre-cooling refrigerant to reach the temperature range of +20°F to -40°F (-7°C to -40°C).

[0088] The isenthalpic valves 148, 152 (and the corresponding isenthalpic valves in Figures 3-7B) may optionally be replaced by work extracting liquid turbines, for example, to improve efficiency. Additionally, propane condensers 122, 128 (and the corresponding propane condensers in Figures 3-7A) may be ambient heat sink coolers used to condense, desuperheat, and/or optimally subcool precooling refrigerant, for example.

EXAMPLE

[0089] The following example is based on a computer simulation of Figures 1, 2A, and 2B as applied to a propane precooled mixed refrigerant process. As in Figure 1, the natural gas feed stream 102 entered unit 106 after pretreatment, including the removal of moisture (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), mercury, and other heavy components, including, but not limited to, benzene, ethylbenzene, and toluene, if they exist in the natural gas feed stream 102 in concentrations that would lead to freezing in the MCHE 146. The pretreated natural gas feed stream 102 was at 35°C and 40 bar absolute and had a flow rate of 12,260 kg-mole/hr. Natural gas feed stream 102 was cooled by indirect heat exchange in a series of propane evaporators 202, 204, 206, 208 (illustrated in Figure 2A) that operate at successively lower pressures of 7.16 bar, 4.25 bar, 2.54 bar and 1.47 bar, where propane evaporator 202 is at the highest pressure and propane evaporator 208 is at the lowest pressure. The evaporation of propane at the four pressures resulted in four propane vapor streams 110, 112, 114, 116 that were then compressed in compressor 118. Resulting stream 120 (at 16.2 bar, and 10,930 kgmole/hr) was then condensed in propane condenser 122 using an ambient heat sink (air or water), producing liquid stream 124.

[0090] The natural gas feed stream 102 was precooled by the propane to -22.5 °C. Resulting cooled stream 150 was then cooled and liquefied in MCHE 146 by vaporizing mixed refrigerant producing liquid natural gas (LNG) stream 166 at -163.3°C.

[0091] The mixed refrigerant stream 104 had a molar composition as follows:

Table I

Component	Mole Composition (%)
Nitrogen	12
Methane	38
Ethane	42
Propane	8

[0092] The mixed refrigerant stream 104 was at 35 °C and 62 bar absolute and had a flow rate of 50,250 kg-mole/hr. The mixed refrigerant stream 104 was cooled by indirect heat exchange in a series of propane evaporators 222, 224, 226, 228 (illustrated in Figure 2B) that operate at successively lower pressures of 7.16 bar absolute, 4.25 bar, 2.54 bar and 1.47 bar where propane evaporator 203 is the highest and propane evaporator 209 is the lowest. The evaporation of propane at the four pressures results in four propane vapor streams 130, 132, 134, 138 which are then compressed in compressor 126. Resulting stream 127 (at 16.2 bar absolute and 31,600 kgmole/hr) is condensed in propane condenser 128 using an ambient heat sink (air or water), producing liquid stream 129.

[0093] The precooled mixed refrigerant stream 138 is then separated into liquid stream 142 and vapor stream 144 in phase separator 140. Liquid stream 142 is then subcooled to -125°C, flashed isenthalpically through valve 148, and then vaporized in the shell side of exchanger 146 to provide cooling to the tubeside streams 142, 144, 150. Vapor stream 144 is liquefied, subcooled to a temperature of -163°C, flashed isenthalpically through valve 152, and then vaporized and warmed in the shell side of exchanger 146 to provide cooling to the tubeside streams 142, 144, 150. After vaporization and warming, the combined mixed refrigerant stream 145 exits the MCHE 146 at a temperature of - 32.7°C and a pressure of 4.14 bar absolute. The combined mixed refrigerant stream 154 is then compressed in three stages of compressors 156, 158, 160 back to a pressure of 62 bar absolute, completing the loop.

<u>Comparison with U.S. Patent No. 6,962,060</u>

[0094] Computer simulations of the exemplary embodiment illustrated in Figure 1 were performed on the same basis as the simulation of a propane precooled mixed refrigerant process utilizing the precooling arrangement of U.S. Patent No. 6,962,060.

[0095] Results for the simulations are listed in Table II below. For both simulations, the same propane low pressure suction pressure was assumed and two compressor casings were required. For both simulations, preliminary sizing calculations for the compressors were performed. In the case of the exemplary embodiment illustrated in Figure 1, the compressor casings 118 and 126 were smaller in diameter and had lower volumetric flow rates translating into lower cost. In addition, depending on the vendor and the scale of the plant, construction of large diameter impellers and casings may not have been feasible, thus, the solution utilizing the prior art may have been more limited in scale-up potential.

[0096] As illustrated in Table II, the exemplary embodiment of Figure 1 allows more optimal and feasible compressor designs than the system disclosed in U.S. Patent No. 6,962,061 using the same number of compressor casings and providing the same pre-cooling service. This is achieved by segregating the heat loads requiring pre-cooling refrigeration into two independent systems.

Table II

		U.S. Patent No. 6,962,060	**Exemplary Embodiment in Figure 1**
	Precooling Temperature (°C)	-30.2	-30.2
	Liquid Natural Gas Production (kg/h)	490,000	490,000
Compressor 1	Identifier	Compressor 43	Compressor 126
	Maximum Impeller Diameter (inches)	55	50
	Maximum Volume Flow Rate (m^3/hr)	149,000	119,000
Compressor 2	Identifier	Compressor 49	Compressor 118
	Maximum Impeller Diameter (inches)	52	51
	Maximum Volume Flow Rate (m^3/hr)	78,000	57,000

Claims

1. A natural gas liquefaction system, the system comprising:

a first closed-loop precooling refrigeration system, for precooling at least a natural gas feed stream via indirect heat transfer with a precooling refrigerant circulating in said closed-loop of said first precooling refrigeration system;

a second closed-loop precooling refrigeration system, for precooling at least a first refrigerant stream via indirect heat transfer with a precooling refrigerant circulating in said closed-loop of said second precooling refrigeration system; and

a cryogenic heat exchanger in fluid connection with the first precooling refrigeration system and the second precooling refrigeration system so as to accept the precooled natural gas feed stream from the first precooling refrigeration system and the precooled first refrigerant stream from the second precooling refrigeration system in order to liquefy the natural gas feed stream;

wherein the closed-loop of the second precooling refrigeration system is separate from the closed-loop of the first precooling refrigeration system, and wherein in operation no streams are precooled by both the second precooling refrigeration system and the first precooling refrigeration system.

2. The system of claim 1, further comprising a subcooler exchanger in fluid connection with the cryogenic heat exchanger, wherein the subcooler exchanger accepts a second refrigerant stream from the cryogenic heat exchanger to subcool the natural gas feed stream through indirect heat exchange.

3. The system of any preceding claim, wherein at least one of the first and second precooling refrigeration systems comprises at least one heat exchanger that accepts at least two load streams.

4. The system of any preceding claim, wherein the first precooling refrigeration system and the second precooling refrigeration system each comprise:

at least one device for reducing the pressure of or vaporizing at least a part of the precooling refrigerant; and
a compressor in fluid connection with the at least one pressure reducing or vaporizing device and adapted to accept at least one precooling refrigerant stream.

5. The system of claim 4, further comprising a first driver and a second driver:
wherein the first driver drives the compressor of the first precooling refrigeration system, the compressor of the second precooling refrigeration system, and a first high pressure refrigerant compressor; and wherein the second driver drives a first medium pressure refrigerant compressor and a first low pressure refrigerant compressor.

6. The system of claim 4, further comprising a first driver and a second driver:
wherein the first driver drives the compressor of the first precooling refrigeration system and one of either a first low pressure refrigerant compressor or a first high pressure refrigerant compressor; and wherein the second driver drives the compressor of the second precooling refrigeration system and the other of the first low pressure refrigerant compressor and the first high pressure refrigerant compressor not driven by the first driver.

7. The system of claim 4, further comprising a first driver and a second driver:
wherein the first driver drives the compressor of the first precooling refrigeration system and the compressor of the second precooling refrigeration system; and the second driver drives a first low pressure refrigerant compressor and a first high pressure refrigerant compressor.

8. The system of claim 7, further comprising a third driver, wherein the third driver drives a second low pressure refrigerant compressor and a second high pressure refrigerant compressor.

9. The system of any one of claims 5 to 8, wherein the first driver, the second driver and/or, if present, the third driver are gas turbines.

10. The system of any preceding claim, wherein the cryogenic heat exchanger is a wound-coil heat exchanger.

11. A method for liquefying natural gas, the method comprising the steps of:

precooling in a first closed-loop precooling refrigeration system, via indirect heat transfer with a precooling refrigerant circulating in said closed loop of said first precooling refrigeration system, at least a natural gas feed stream;
precooling in a second closed-loop precooling refrigeration system, via indirect heat transfer with a precooling refrigerant circulating in said closed loop of said second precooling refrigeration system, at least a first refrigerant stream; and
vaporizing the precooled first refrigerant stream in a cryogenic heat exchanger to cool the precooled natural gas feed stream through indirect heat exchange;

wherein the closed-loop of the second precooling refrigeration system is separate from the closed-loop of the first precooling refrigeration system, and wherein the second precooling refrigeration system precools only stream(s) having a composition different from the stream(s) precooled by the first precooling refrigeration system.

12. The method of claim 11, wherein the natural gas feed stream and the first refrigerant stream are precooled to +16°C to -73°C (+60°F to -100°F).

13. The method of claim 11 or 12, the method further comprising precooling a second refrigerant stream in either the first precooling refrigeration system or the second precooling refrigeration system, and vaporizing the second refrigerant stream to subcool the natural gas feed stream.

14. The method of any one of claims 11 to 13, wherein the first refrigerant stream and/or, if present, the second refrigerant streams are mixed refrigerant streams.

15. The method of any one of claims 11 to 14, wherein the precooling refrigerant is propane or CO_2.

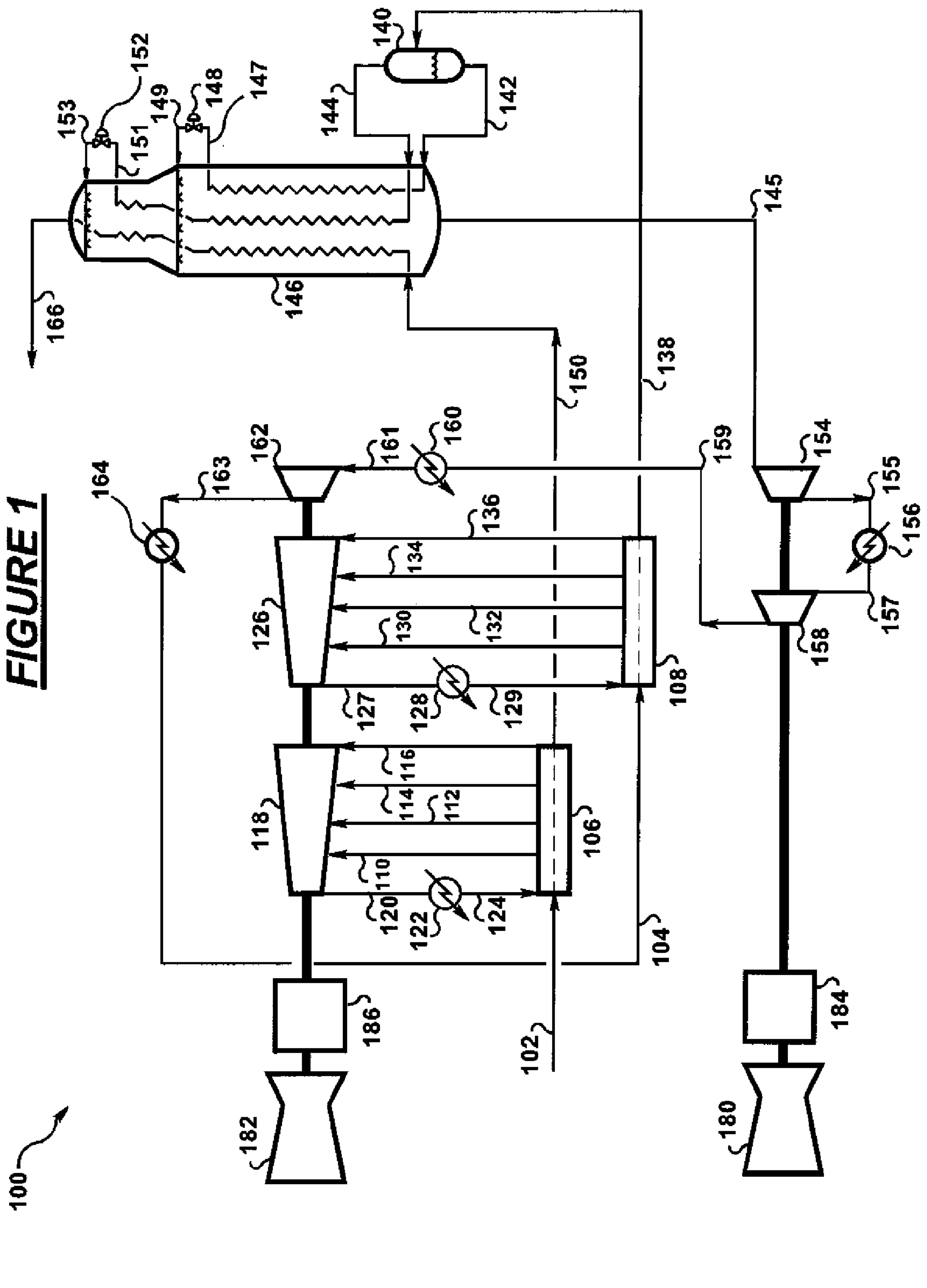
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FIGURE 1

FIGURE 2A

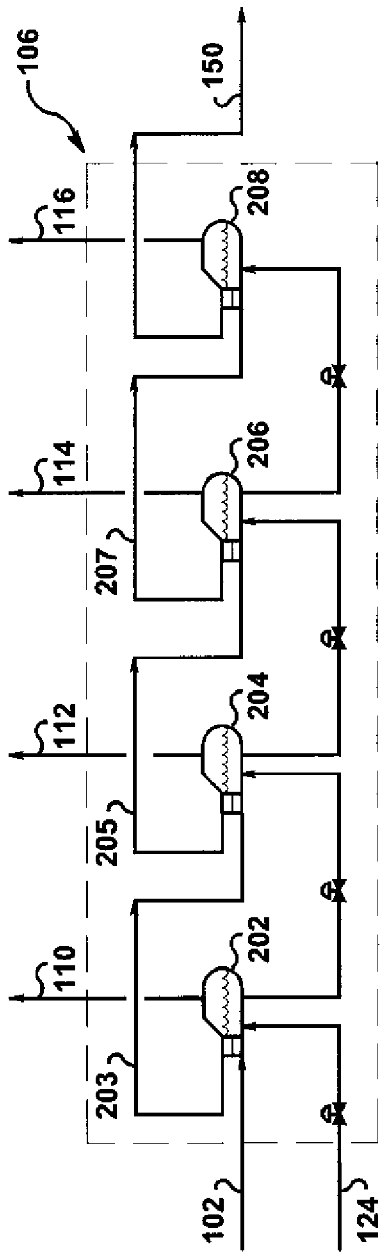
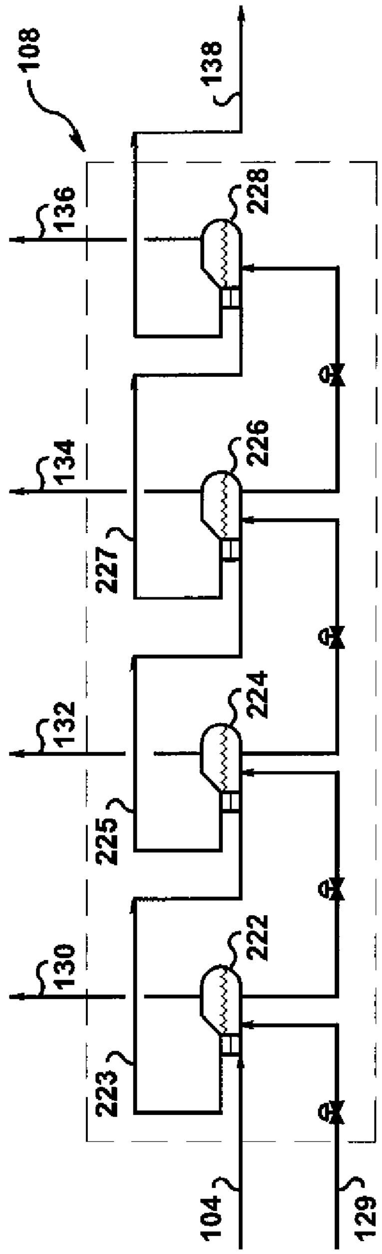


FIGURE 2B



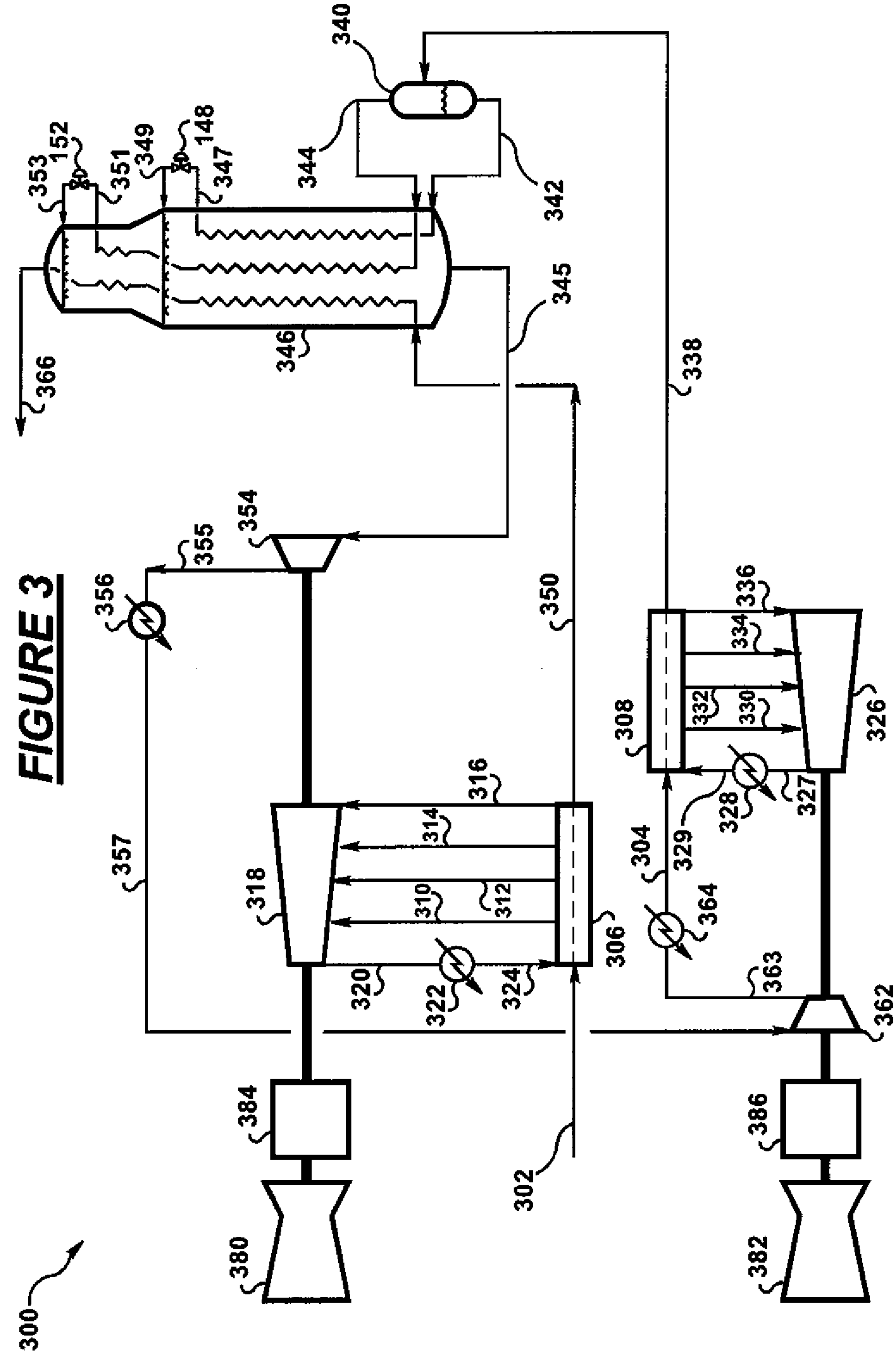

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FIGURE 3

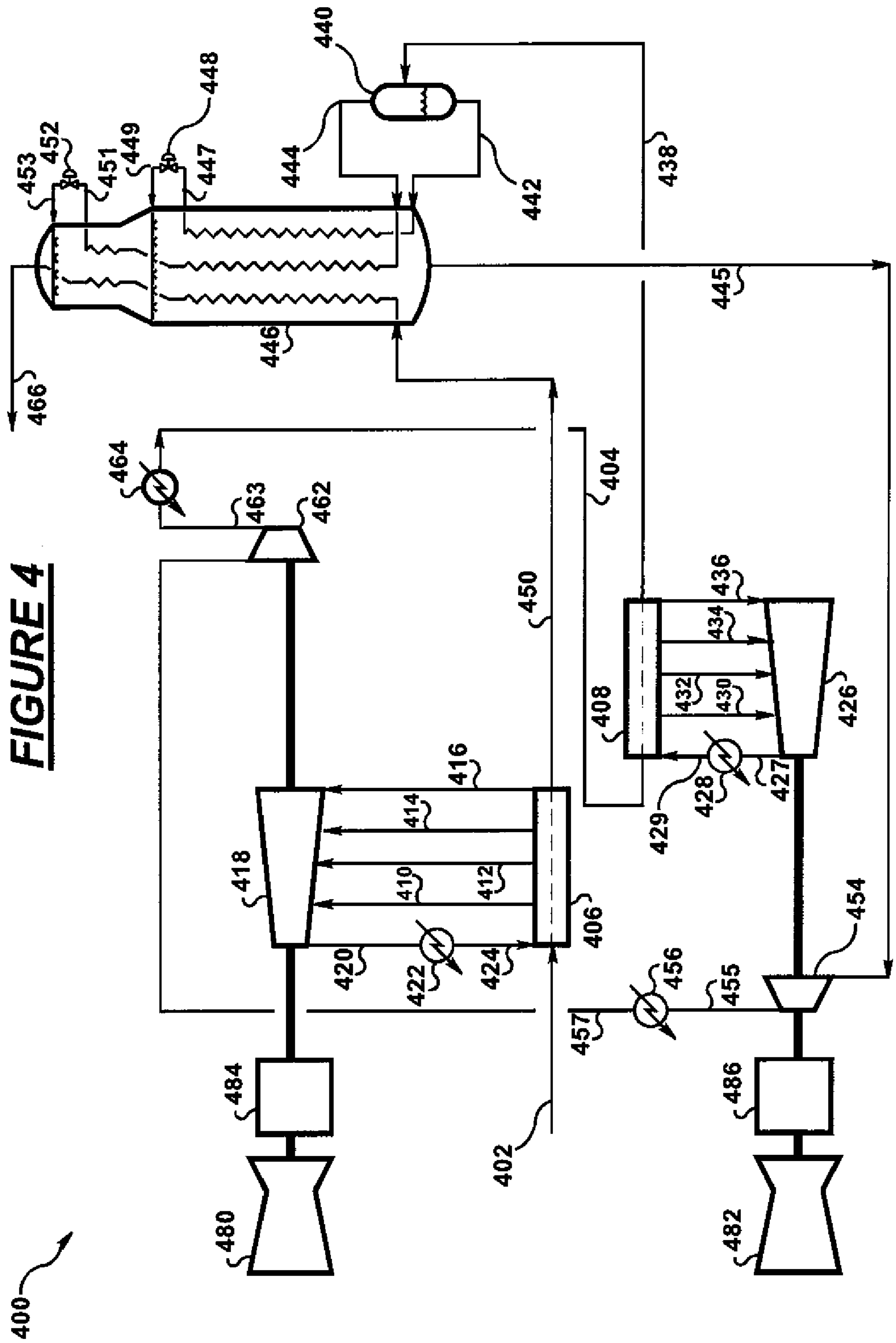
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FIGURE 4

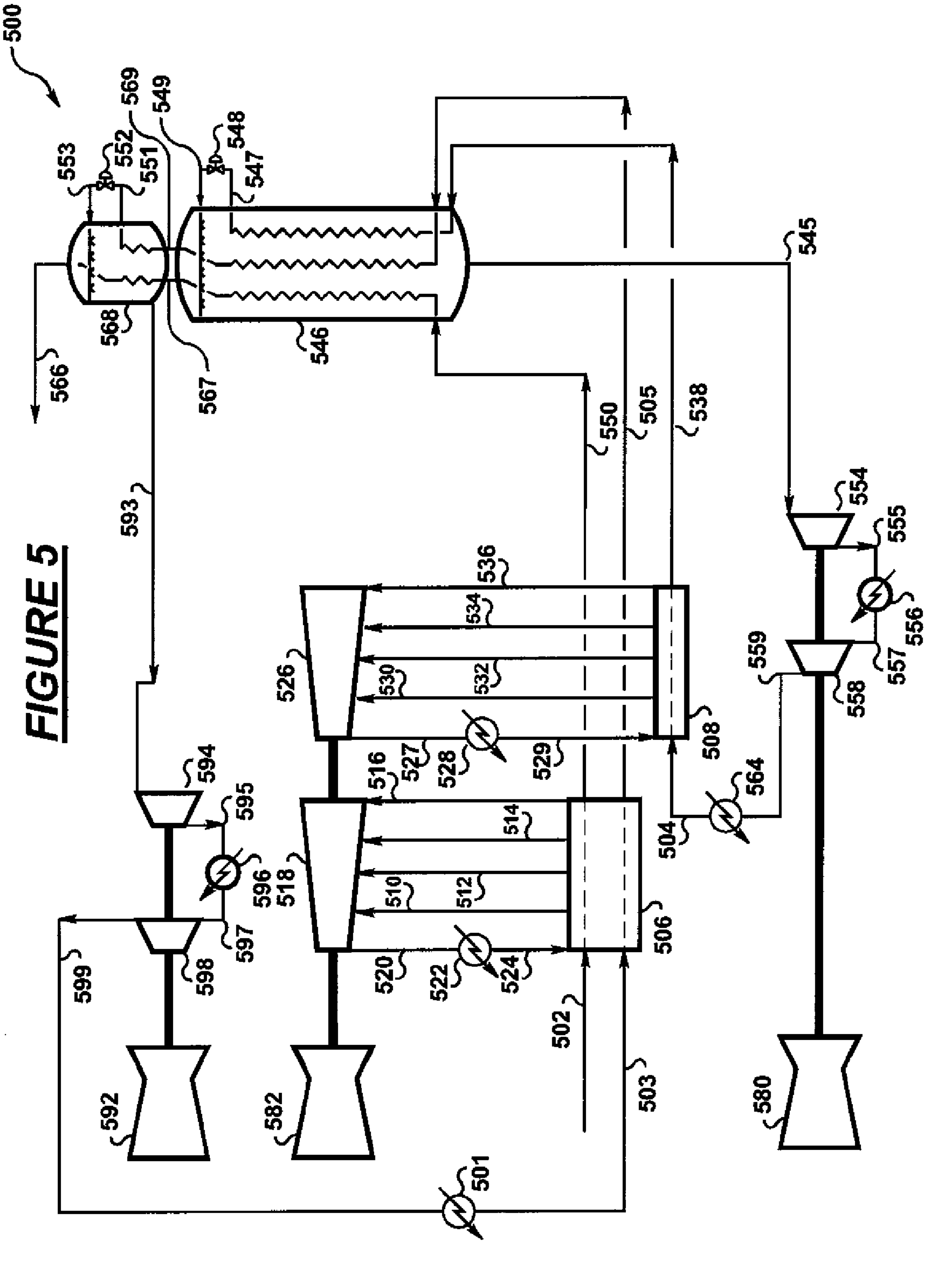
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FIGURE 5

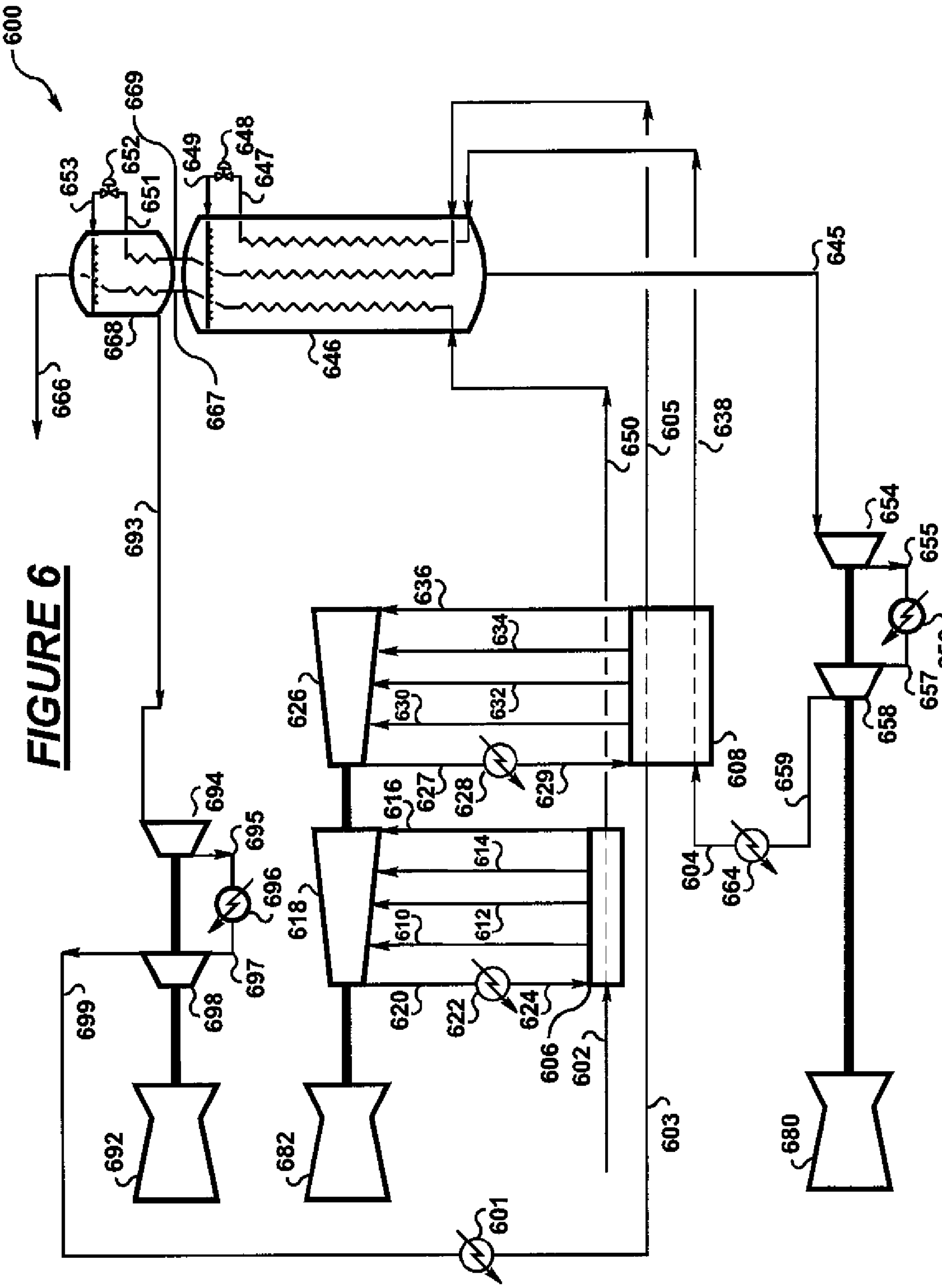
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FIGURE 6

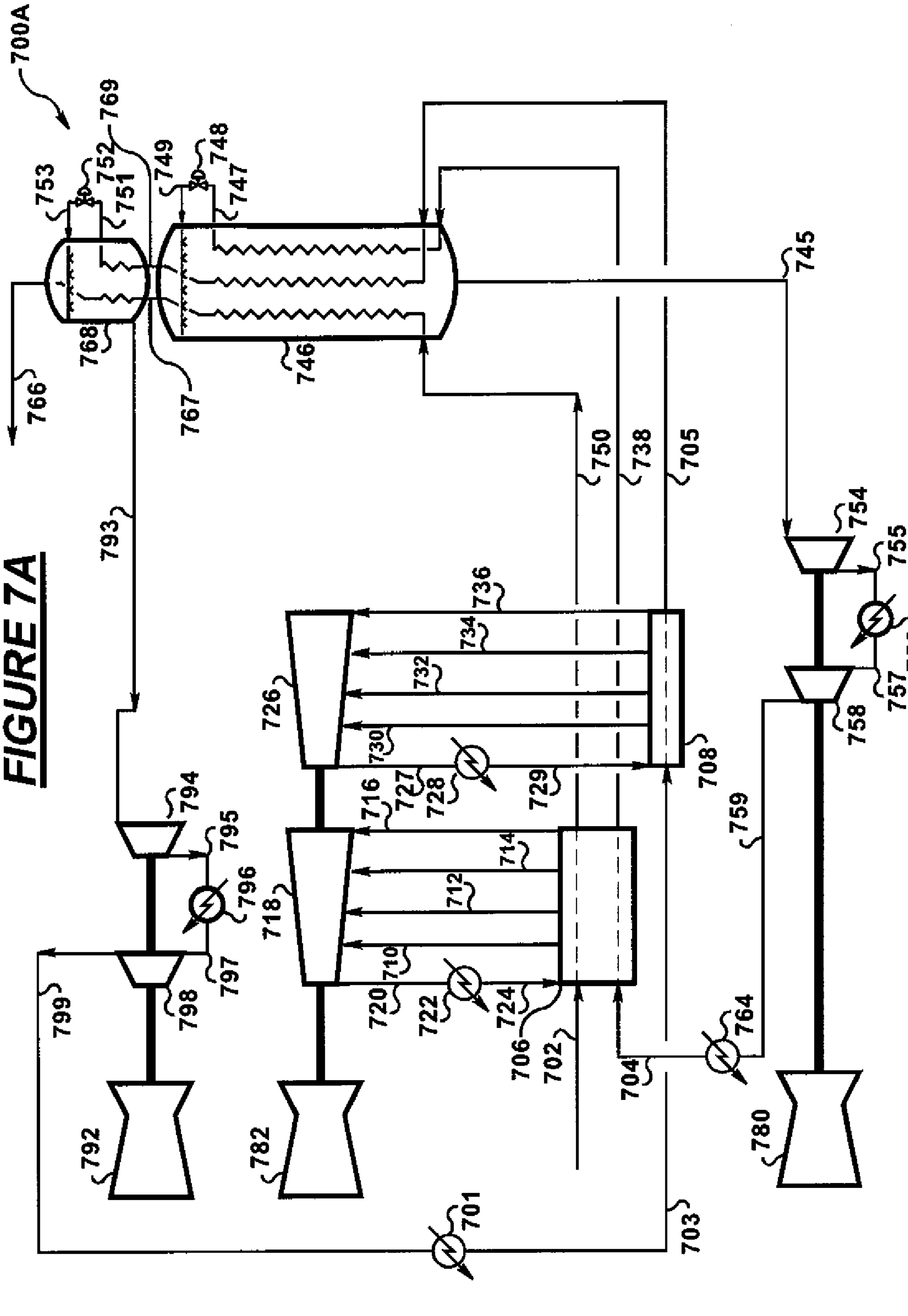
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FIGURE 7A

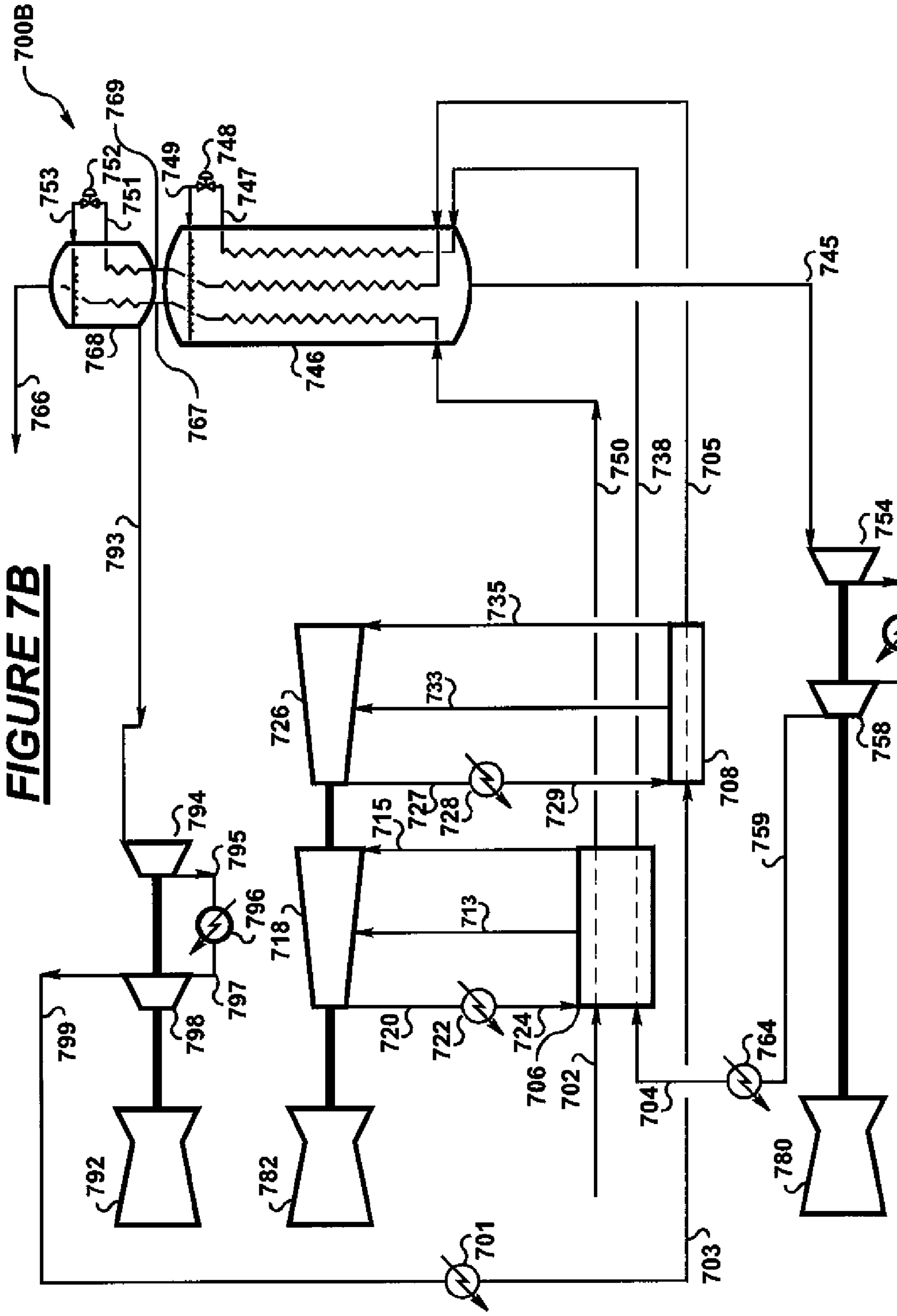
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FIGURE 7B

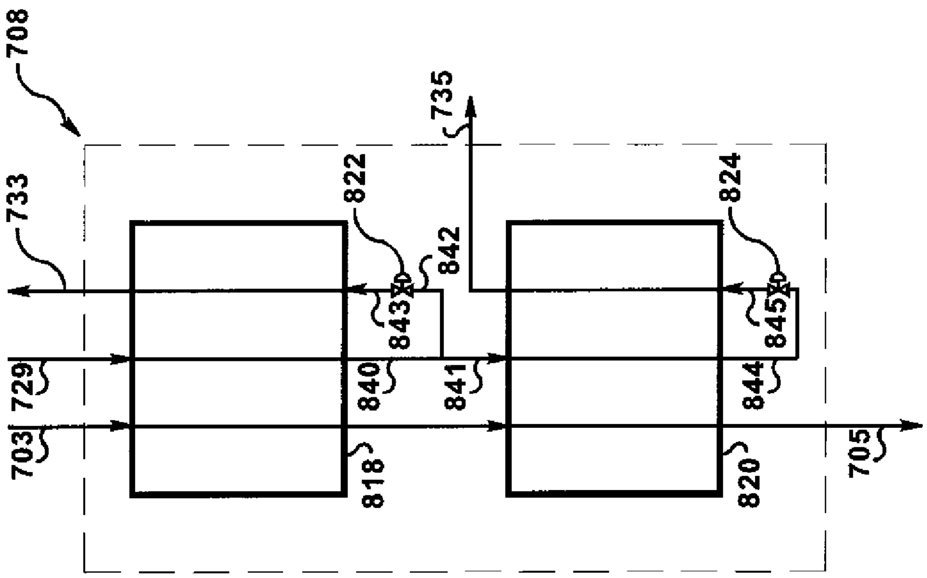

FIGURE 8B

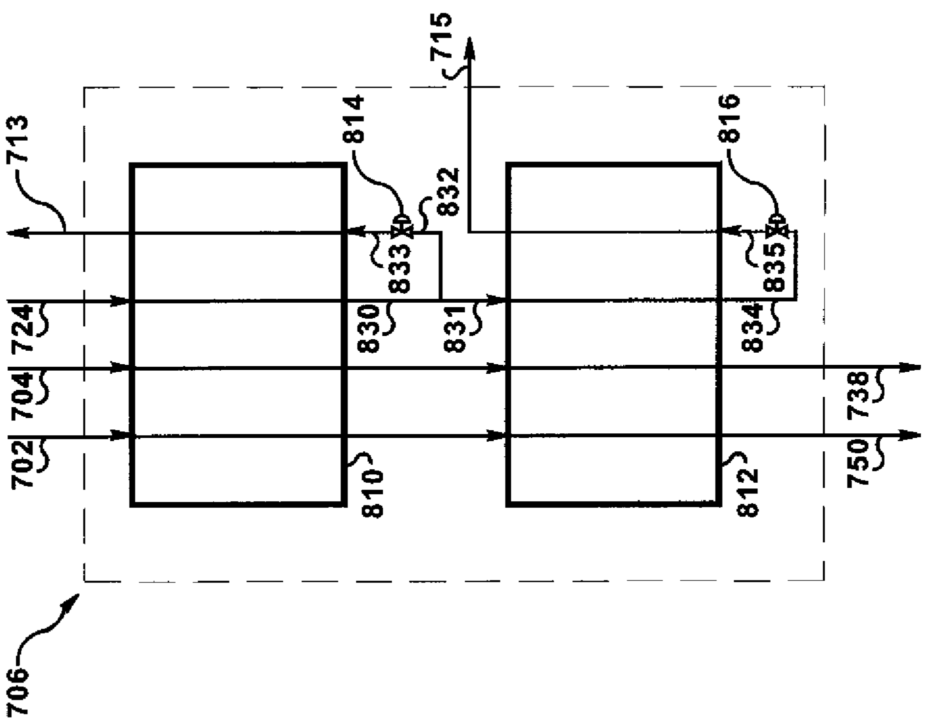

FIGURE 8A

REFERENCES CITED IN THE DESCRIPTION

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- US 6962061 B **[0096]**