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(54) INTERMEDIATE PRESSURE LNG REFLUXED NGL RECOVERY PROCESS

(75) Inventor: Weldon L. Ransbarger, Houston, TX (US)

Correspondence Address:
ConocoPhilips Company - I.P. Legal
PO BOX 2443
BARTLESVILLE, OK 74005

(73) Assignee: CONOCOPHILLIPS COMPANY, Houston, TX (US)

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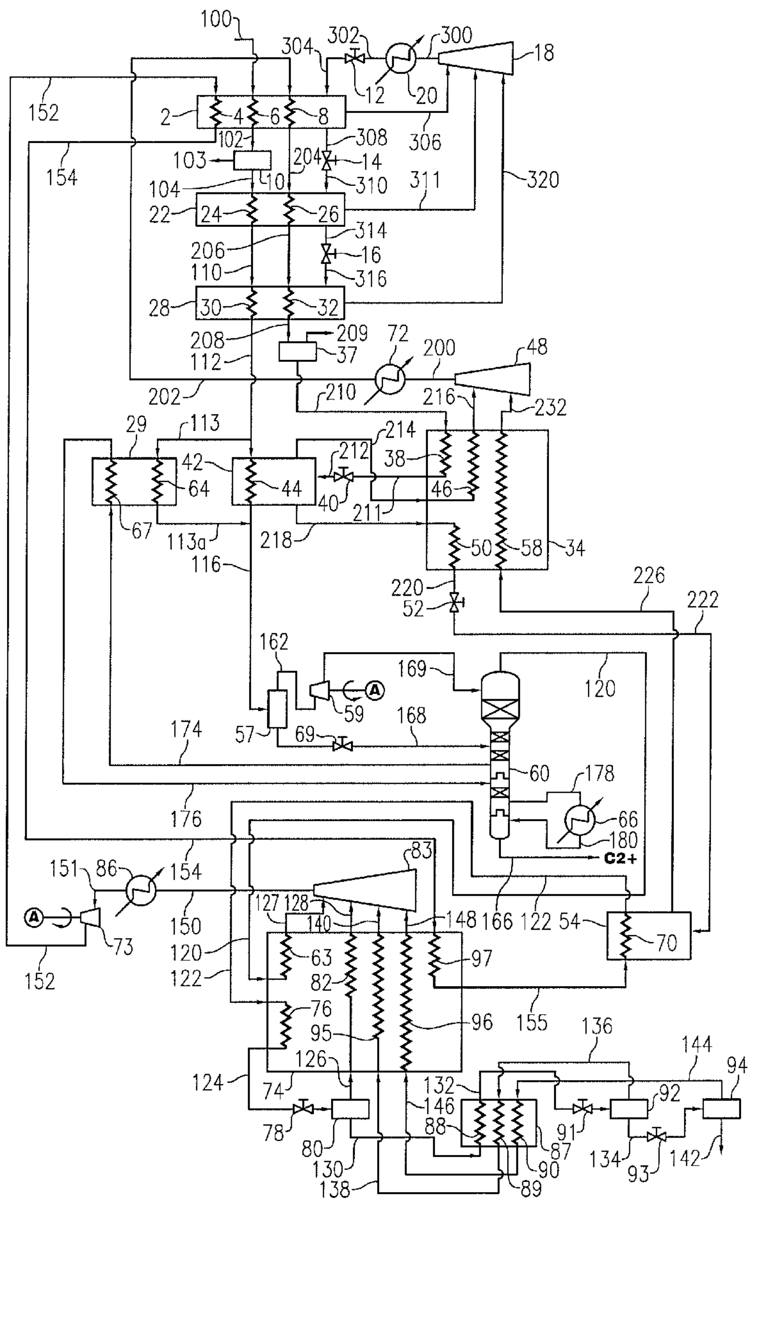
(57) ABSTRACT

Liquefied natural gas (LNG) facility employing an intermediate pressure distillation column for recovery of ethane and heavier components from the processed natural gas stream in a way that increases operational stability and minimizes capital and operating costs.



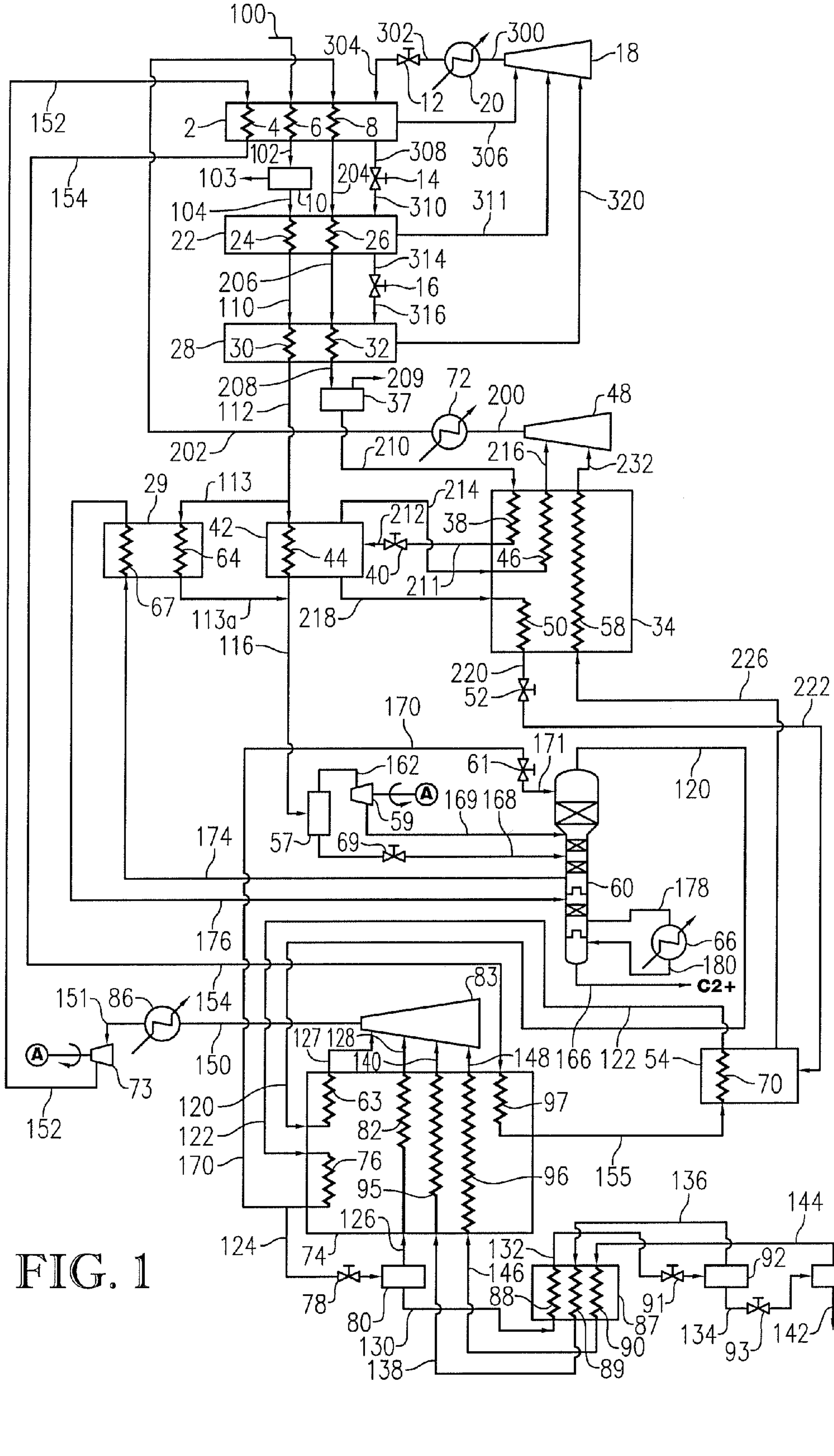

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FIG. 1

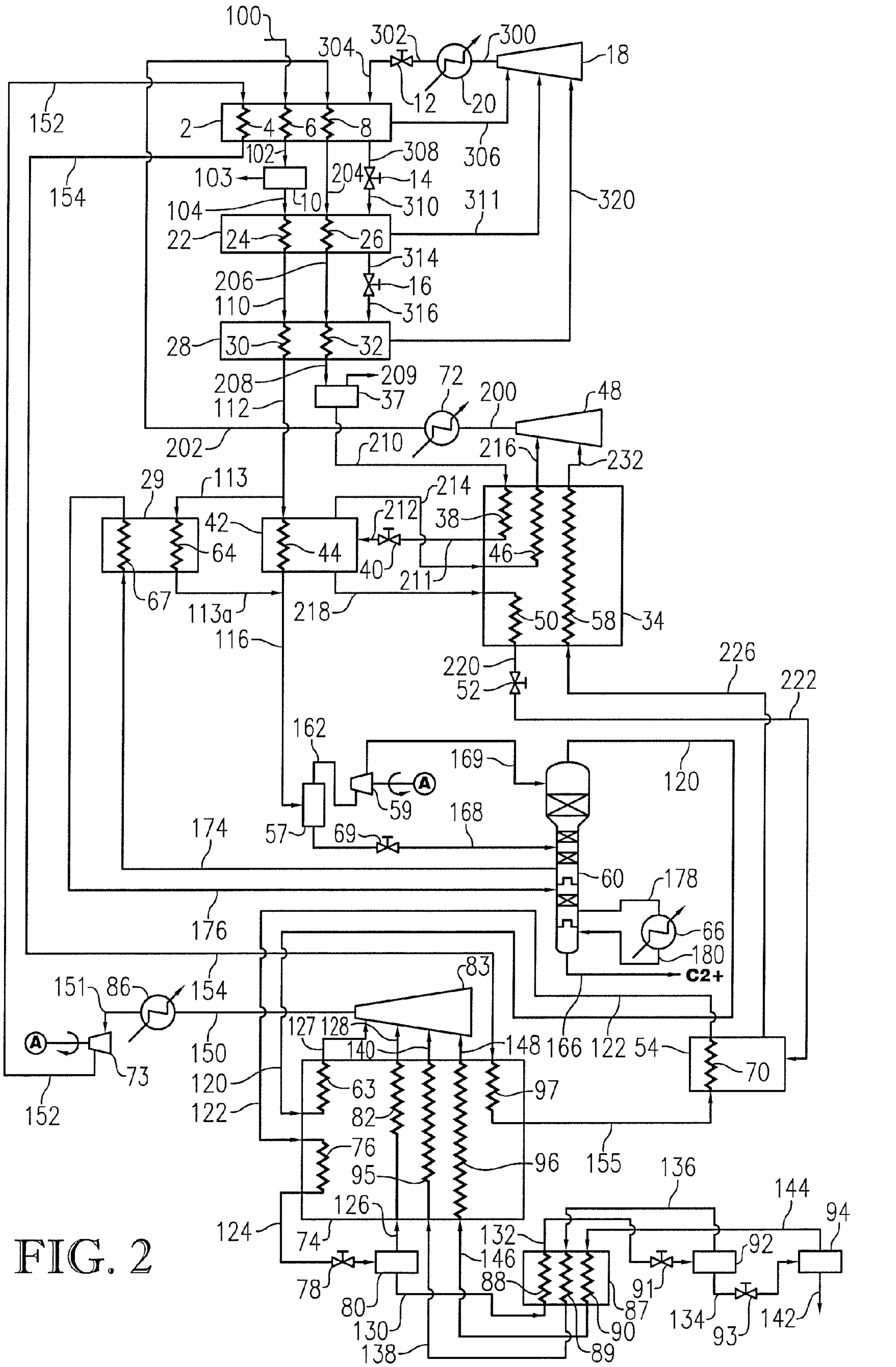
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FIG. 2

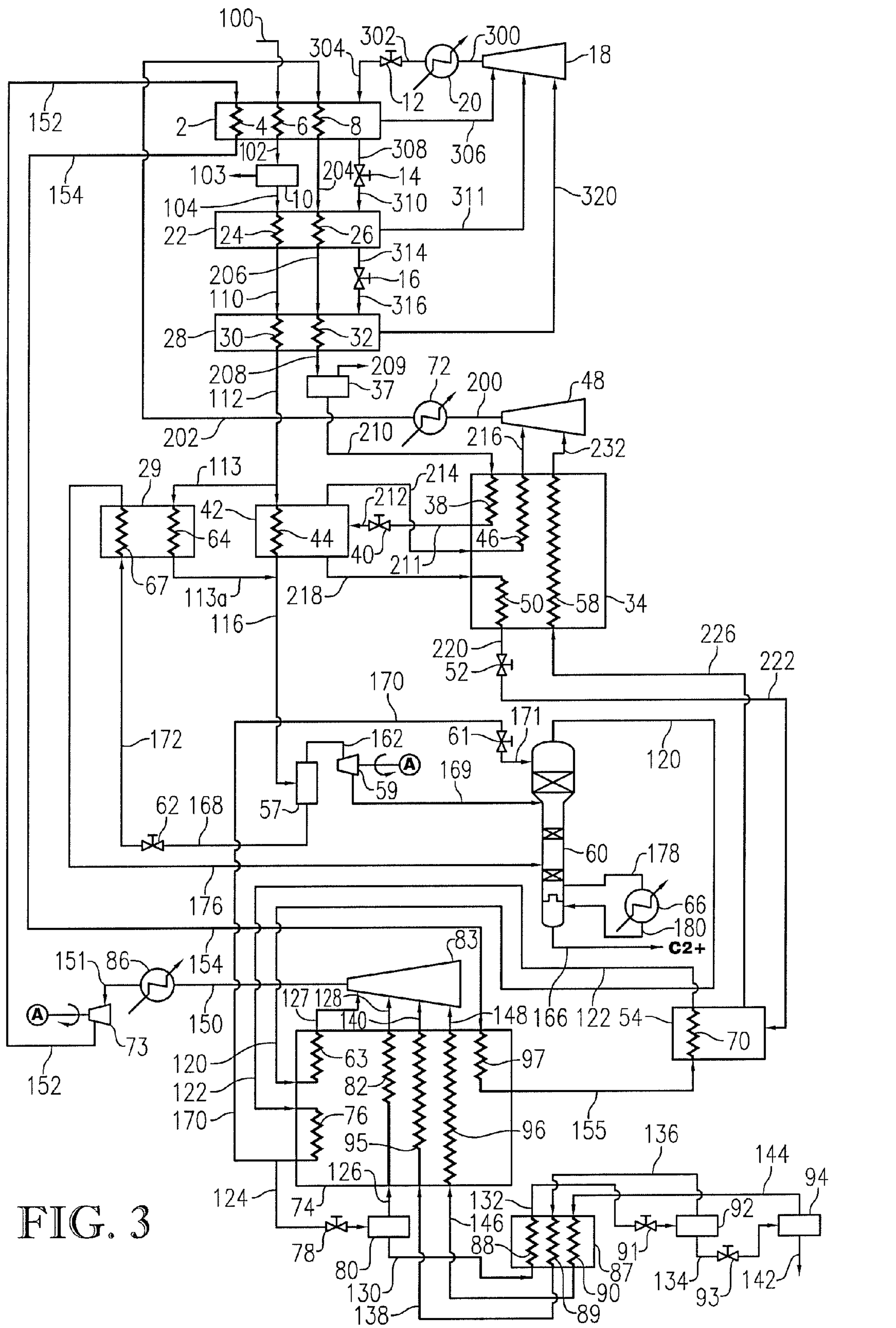
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FIG. 3

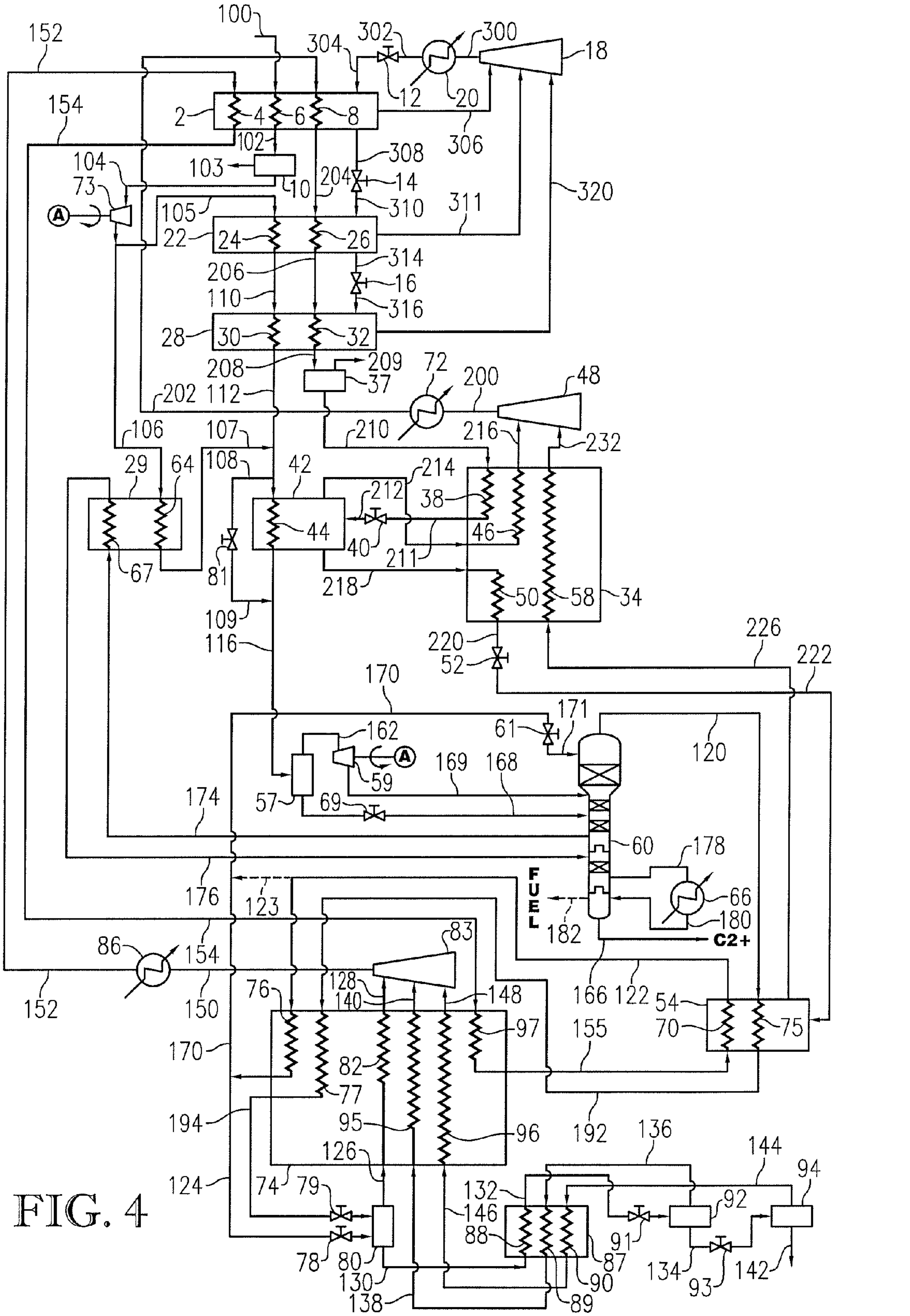

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FIG. 4

INTERMEDIATE PRESSURE LNG REFLUXED NGL RECOVERY PROCESS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention generally relates to a method and apparatus for liquefying natural gas. In another aspect, the invention concerns a process for recovering natural gas liquids (NGL) from processed gas streams using an intermediate pressure distillation column.

[0003] 2. Description of the Prior Art

[0004] The cryogenic liquefaction of natural gas is routinely practiced as a means of converting natural gas into a more convenient form for transportation and/or storage. Generally, liquefaction of natural gas reduces its volume by about 600-fold, thereby resulting in a liquefied product that can be readily stored and transported at near atmospheric pressure.

[0005] Natural gas is frequently transported by pipeline from the supply source to a distant market. It is desirable to operate the pipeline under a substantially constant and high load factor, but often the deliverability or capacity of the pipeline will exceed demand while at other times the demand will exceed the deliverability of the pipeline. In order to shave off the peaks where demand exceeds supply or the valleys where supply exceeds demand, it is desirable to store the excess gas in such a manner that it can be delivered as the market dictates. Such practice allows future demand peaks to be met with material from storage. One practical means for doing this is to convert the gas to a liquefied state for storage and to then vaporize the liquid as demand requires.

[0006] The liquefaction of natural gas is of even greater importance when transporting gas from a supply source that is separated by great distances from the candidate market, and a pipeline either is not available or is impractical. This is particularly true where transport must be made by ocean-going vessels. Ship transportation of natural gas in the gaseous state is generally not practical because appreciable pressurization is required to significantly reduce the specific volume of the gas, and such pressurization requires the use of more expensive storage containers.

[0007] In view of the foregoing, it would be advantageous to store and transport natural gas in the liquid state at approximately atmospheric pressure. In order to store and transport natural gas in the liquid state, the natural gas is cooled to −240° F. to −260° F. where the liquefied natural gas (LNG) possesses a near-atmospheric vapor pressure.

[0008] Numerous systems exist in the prior art for the liquefaction of natural gas in which the gas is liquefied by sequentially passing the gas at an elevated pressure through a plurality of cooling stages whereupon the gas is cooled to successively lower temperatures until the liquefaction temperature is reached. Cooling is generally accomplished by indirect heat exchange with one or more refrigerants such as propane, propylene, ethane, ethylene, methane, nitrogen, carbon dioxide, or combinations of the preceding refrigerants (e.g., mixed refrigerant systems). A liquefaction methodology which may be particularly applicable to one or more embodiments of the present invention employs an open methane cycle for the final refrigeration cycle wherein a pressurized LNG-bearing stream is flashed and the flash vapors are subsequently employed as cooling agents, recompressed, cooled, combined with the processed natural gas feed stream and liquefied thereby producing the pressurized LNG-bearing stream.

[0009] In most LNG facilities it is necessary to remove heavy components (e.g., benzene, toluene, xylene, and/or cyclohexane) from the processed natural gas stream in order to prevent freezing of the heavy components in downstream heat exchangers. Further, it may be desirable to remove varying amounts of ethane and heavier components from the natural gas feed stream in order to affect one or more properties of the final LNG product, such as, for example heating value, Wobbe Index, and the like. Traditionally, the removal of components, particularly relatively volatile components such as ethane, from the processed natural gas stream required the use of a complex, expensive distillation configuration with one or more columns operated at or above the critical point of methane. At the critical point, the vapor and liquid phases of the predominantly methane processed natural gas stream become increasingly difficult to separate, which results in off-spec products and overall system instability.

[0010] Thus, a need exists for a cost-effective system capable of efficiently removing ethane and heavier components from the processed natural gas stream that avoids the problems associated with operating near or above the distilled fluid's critical point.

SUMMARY OF THE INVENTION

[0011] In one embodiment of the present invention, there is provided a process for liquefying a natural gas stream comprising: (a) cooling at least a portion of the natural gas stream; (b) expanding a vapor portion of the cooled natural gas stream in a turboexpander; (c) introducing a liquid portion of the cooled natural gas stream into a distillation column; and (d) using work produced by the turboexpander to compress at least a portion of the natural gas stream upstream of the distillation column.

[0012] In another embodiment of the present invention, there is provided a process for liquefying a natural gas stream comprising: (a) using a distillation column to separate at least a portion of the natural gas stream into an overhead stream and a bottom stream; (b) cooling at least a portion of the overhead stream via indirect heat exchange with a predominantly methane refrigerant stream; and (c) using at least a portion of the cooled overhead stream as a reflux stream in said distillation column.

[0013] In a further embodiment of the present invention, there is provided a process for liquefying a natural gas stream comprising: (a) using a distillation column to separate at least a portion of the natural gas stream into an overhead stream and a bottoms stream; (b) withdrawing a side stream from the distillation column; and (c) heating at least a portion of said side stream via indirect heat exchange with at least a portion of the natural gas stream.

[0014] In yet another embodiment of the present invention, there is provided a process for liquefying a natural gas stream comprising: (a) using a distillation column to separate at least a portion of the natural gas stream into an overhead stream and a bottoms stream; (b) introducing at least a portion of the overhead stream into a vapor/liquid separator; (c) compressing at least a portion of a predominantly vapor stream produced from the phase separator to thereby provide a high-pressure stream; (d) introducing a first fraction of the high-pressure stream into the distillation column; and (e) introducing a second fraction of the high-pressure stream into the vapor/liquid separator.

BRIEF DESCRIPTION OF FIGURES

[0015] A preferred embodiment of the present invention is described in detail below with reference to the attached figures, wherein:

[0016] FIG. **1** is a simplified schematic flow diagram of one embodiment of an LNG facility that employs an intermediate-pressure distillation column, particularly illustrating the use of a methane-rich reflux stream, a heated side draw, and a turboexpander that drives a compressor downstream of the column.

[0017] FIG. **2** is a simplified schematic flow diagram of another embodiment of an LNG facility that employs an intermediate-pressure distillation column, particularly illustrating the use of a heated side draw and a turboexpander that drives a compressor downstream of the column.

[0018] FIG. **3** is a simplified schematic flow diagram of a further embodiment of an LNG facility that employs an intermediate-pressure distillation column, particularly illustrating the use of a methane-rich reflux stream and a turboexpander that drives a compressor downstream of the column.

[0019] FIG. **4** is a simplified schematic flow diagram of yet another embodiment of an LNG facility that employs an intermediate-pressure distillation column, particularly illustrating the use of a methane-rich reflux and a turboexpander that drives a compressor upstream of the column.

DETAILED DESCRIPTION

[0020] The present invention can be implemented in a process/facility used to cool natural gas to its liquefaction temperature, thereby producing liquefied natural gas (LNG). The LNG process generally employs one or more refrigerants to extract heat from the natural gas and then reject the heat to the environment. In one embodiment, the LNG process employs a cascade-type refrigeration process that uses a plurality of multi-stage cooling cycles, each employing a different refrigerant composition, to sequentially cool the natural gas stream to lower and lower temperatures. In another embodiment, the LNG process is a mixed refrigerant process that employs at least one refrigerant mixture to cool the natural gas stream. In one embodiment, the LNG process/facility can additionally include the means to vaporize the LNG for use as vapor-phase natural gas.

[0021] Natural gas can be delivered to the LNG process at an elevated pressure in the range of from about 500 to about 3,000 pounds per square inch absolute (psia), about 500 to about 1,000 psia, or 600 to 800 psia. Depending largely upon the ambient temperature, the temperature of the natural gas delivered to the LNG process can generally be in the range of from about 0 to about 180° F., or about 20 to about 150° F., or 60 to 125° F.

[0022] In one embodiment, the present invention can be implemented in an LNG process that employs cascade-type cooling followed by expansion-type cooling. In such a liquefaction process, the cascade-type cooling may be carried out at an elevated pressure (e.g., about 650 psia) by sequentially passing the natural gas stream through first, second, and third refrigeration cycles employing respective first, second, and third refrigerants. In one embodiment, the first and second refrigeration cycles are closed refrigeration cycles, while the third refrigeration cycle is an open refrigeration cycle that utilizes a portion of the processed natural gas as a source of the refrigerant. Further, the third refrigeration cycle can include a multi-stage expansion cycle to provide additional cooling of the processed natural gas stream and reduce its pressure to near atmospheric pressure.

[0023] In the sequence of first, second, and third refrigeration cycles, the refrigerant having the highest boiling point can be utilized first, followed by a refrigerant having an intermediate boiling point, and finally by a refrigerant having the lowest boiling point. In one embodiment, the first refrigerant has a mid-boiling point at standard temperature and pressure (i.e., an STP mid-boiling point) within about 20, about 10, or 5° F. of the STP boiling point of pure propane. The first refrigerant can contain predominately propane, propylene, or mixtures thereof. The first refrigerant can contain at least about 75 mole percent propane, at least 90 mole percent propane, or can consist essentially of propane. In one embodiment, the second refrigerant has an STP mid-boiling point within about 20° F., about 10° F., or 5° F. of the STP boiling point of pure ethylene. The second refrigerant can contain predominately ethane, ethylene, or mixtures thereof. The second refrigerant can contain at least about 75 mole percent ethylene, at least 90 mole percent ethylene, or can consist essentially of ethylene. In one embodiment, the third refrigerant has an STP mid-boiling point within about 20° F., about 10° F., or 5° F. of the STP boiling point of pure methane. The third refrigerant can contain at least about 50 mole percent methane, at least about 75 mole percent methane, at least 90 mole percent methane, or can consist essentially of methane. At least about 50 mole percent, about 75 mole percent, or 95 mole percent of the third refrigerant can originate from the processed natural gas stream.

[0024] The first refrigeration cycle can cool the natural gas in a plurality of cooling stages/steps (e.g., two to four cooling stages) by indirect heat exchange with the first refrigerant. Each indirect cooling stage of the refrigeration cycles can be carried out in a separate heat exchanger. In the one embodiment, core-and-kettle heat exchangers are employed to facilitate indirect heat exchange in the first refrigeration cycle. After being cooled in the first refrigeration cycle, the temperature of the natural gas can be in the range of from about −45 to about −10° F., or about −40 to about −15° F., or −20 to −30° F. A typical decrease in the natural gas temperature across the first refrigeration cycle may be in the range of from about 50 to about 210° F., about 75 to about 180° F., or 100 to 140° F.

[0025] The second refrigeration cycle can cool the natural gas in a plurality of cooling stages/steps (e.g., two to four cooling stages) by indirect heat exchange with the second refrigerant. In one embodiments the indirect heat exchange cooling stages in the second refrigeration cycle can employ separate, core-and-kettle heat exchangers. Generally, the temperature drop across the second refrigeration cycle can be in the range of from about 50 to about 180° F., about 75 to about 150° F., or 100 to 120° F. In the final stage of the second refrigeration cycle, the processed natural gas stream can be condensed (i.e., liquefied) in major portion, preferably in its entirety, thereby producing a pressurized LNG-bearing stream. Generally, the process pressure at this location is only slightly lower than the pressure of the natural gas fed to the first stage of the first refrigeration cycle. After being cooled in the second refrigeration cycle, the temperature of the natural gas may be in the range of from about −205 to about −70° F., about −175 to about −95° F., or −140 to −125° F.

[0026] The third refrigeration cycle can include both an indirect cooling section and an expansion-type cooling section. To facilitate indirect heat exchange, the third refrigeration cycle can employ at least one brazed-aluminum plate-fin heat exchanger. The total amount of cooling provided by indirect heat exchange in the third refrigeration cycle can be in the range of from about 5 to about 60° F., about 7 to about 50° F., or 10 to 40° F.

[0027] The expansion-type cooling section of the third refrigeration cycle can further cool the pressurized LNG-bearing stream via sequential pressure reduction to approximately atmospheric pressure. Such expansion-type cooling can be accomplished by flashing the LNG-bearing stream to thereby produce a two-phase vapor-liquid stream. When the third refrigeration cycle is an open refrigeration cycle, the expanded two-phase stream can be subjected to vapor-liquid separation and at least a portion of the separated vapor phase (i.e., the flash gas) can be employed as the third refrigerant to help cool the processed natural gas stream.

[0028] The expansion of the pressurized LNG-bearing stream to near atmospheric pressure can be accomplished by using a plurality of expansion steps (i.e., two to four expansion steps) where each expansion step is carried out using an expander. Suitable expanders include, for example, either Joule-Thomson expansion valves or hydraulic expanders.

[0029] In one embodiment, the third stage refrigeration cycle can employ three sequential expansion cooling steps, wherein each expansion step can be followed by a separation of the gas-liquid product. Each expansion-type cooling step can further cool the LNG-bearing stream in the range of from about 10 to about 60° F., about 15 to about 50° F., or 25 to 35° F. The reduction in pressure across the first expansion step can be in the range of from about 80 to about 300 psia, about 130 to about 250 psia, or 175 to 195 psia. The pressure drop across the second expansion step can be in the range of from about 20 to about 110 psia, about 40 to about 90 psia, or 55 to 70 psia. The third expansion step can further reduce the pressure of the LNG-bearing stream by an amount in the range of from about 5 to about 50 psia, about 10 to about 40 psia, or 15 to 30 psia. The liquid fraction resulting from the final expansion stage is the LNG product. Generally, the temperature of the LNG product can be in the range of from about −200 to about −300° F., about −225 to about −275° F., or −240 to −260° F. The pressure of the LNG product can be in the range of from about 0 to about 40 psia, about 10 to about 20 psia, or 12.5 to 17.5 psia.

[0030] The present invention provides a system for recovering ethane and heavier components (also referred to herein as "natural gas liquids" or "NGL") from the processed natural gas stream utilizing an intermediate-pressure distillation column. The use of an intermediate-pressure distillation column to separate heavy components from the predominantly-methane stream can avoid the operational instability and potential for off-spec products typically associated with operating the distillation near the critical point of the natural gas stream. Further, in one embodiment, the inventive system can employ a single distillation column in lieu of a plurality of distillation columns, which minimizes the capital cost associated with the entire facility. Due to the configuration of the inventive system, the potential exists for energy reduction through integration, as discussed in detail below.

[0031] In contrast to conventional distillation columns employed in LNG facilities for the recovery of NGL, in one embodiment, the distillation column of the present invention can be operated at a pressure below the critical point of methane and still achieve an ethane recovery of greater than about 60 percent, greater than about 75 percent, greater than about 90 percent, or greater than 92 percent. In another embodiment, the propane recovery can be greater than about 60 percent, greater than about 75 percent, greater than about 90 percent, or greater than 94 percent. In a further embodiment, the recovery of butane and heavier components can be greater than about 60 percent, greater than about 75 percent, greater than about 90 percent, or greater than 99 percent. Not only can operating below the critical point increase operating stability and separation efficiency, it can also allow for greater flexibility of key properties of the final LNG product (i.e., BTU content, Wobbe index, and the like). In addition, the system of the present invention can greatly reduce the carry-over of heavier hydrocarbons (i.e., C5+ and benzene), which minimizes freezing of heavy components in downstream equipment.

[0032] The flow schematic and apparatus illustrated in FIGS. **1** through **4** represent several embodiments of the inventive LNG facility employing an intermediate-pressure NGL recovery system. Those skilled in the art will recognized that FIGS. **1** through **4** are schematics only and, therefore, many items of equipment that would be needed in a commercial plant for successful operation have been omitted for the sake of clarity. Such items might include, for example, compressor controls, flow and level measurements and corresponding controllers, temperature and pressure controls, pumps, motors, filters, additional heat exchangers, and valves, etc. These items would be provided in accordance with standard engineering practice.

[0033] To facilitate an understanding of FIGS. **1** through **4**, the following numeric nomenclature was employed. Items numbered **1** through **99** are process vessels and equipment which are directly associated with the liquefaction process. Items numbered **100** through **199** correspond to flow lines or conduits that contain predominantly methane streams. Items numbered **200** through **299** correspond to flow lines or conduits that contain predominantly ethylene streams. Items numbered **300** through **399** correspond to flow lines or conduits that contain predominantly propane streams.

[0034] The LNG facilities illustrated in FIGS. **1** thorough **4** cool the natural gas to its liquefaction temperature using cascade-type cooling in combination with expansion-type cooling. The cascade-type cooling is carried out in three mechanical refrigeration cycles: a propane refrigeration cycle, followed by an ethylene refrigeration cycle, followed by a methane refrigeration cycle. The methane refrigeration cycle includes a heat exchange cooling section followed by an expansion cooling section.

[0035] Referring to FIG. **1**, one embodiment of the LNG facility of the present invention is illustrated. The main components of the propane refrigeration cycle include a propane compressor **18**, a propane cooler **20**, a high-stage propane chiller **2**, an intermediate-stage propane chiller **22**, and a low-stage propane chiller **28**. The main components of the ethylene refrigeration cycle include an ethylene compressor **48**, an ethylene cooler **72**, a high-stage ethylene chiller **42**, a low-stage ethylene chiller **54**, and an ethylene economizer **34**. The main components of the methane refrigeration cycle's heat exchange cooling section include a methane compressor

83, a methane cooler 86, a secondary methane compressor 73, a main methane economizer 74, and a secondary methane economizer 87. The main components of the methane refrigeration cycle's expansion cooling section include a high-stage methane expander 78, a high-stage methane flash drum 80, an intermediate-stage methane expander 91, an intermediate-stage methane flash drum 92, a low-stage methane expander 93, and a low-stage methane flash drum 94. The LNG facility of FIG. 1 also includes an intermediate-pressure NGL recovery section downstream of high-stage ethylene chiller 42 operated to remove ethane and heavier hydrocarbon components from the natural gas stream. The main components of the NGL recovery section include a distillation column 60, a vapor/liquid separator 57, a turboexpander 59, and a side reboiler 29.

[0036] The operation of the inventive LNG facility illustrate in FIG. 1 will now be described in more detail, beginning with the propane refrigeration cycle. Propane is compressed in multi-stage (e.g., three-stage) propane compressor 18 driven by, for example, a gas turbine driver (not illustrated). The three stages of compression preferably exist in a single unit, although each stage of compression may be a separate unit and the units mechanically coupled to be driven by a single driver. Upon compression, the propane is passed through conduit 300 to propane cooler 20, wherein the stream is cooled and liquefied via indirect heat exchange with an external fluid (e.g., air or water). A representative pressure and temperature of the liquefied propane refrigerant exiting cooler 20 is about 100° F. and about 190 psia. The stream from propane cooler 20 is passed through conduit 302 to a pressure reduction means, illustrated as expansion valve 12, wherein the pressure of the liquefied propane is reduced thereby evaporating or flashing a portion thereof. The resulting two-phase stream then flows through conduit 304 into high-stage propane chiller 2 to cool the incoming methane refrigerant stream in conduit 152, the natural gas feed stream in conduit 100, and ethylene refrigerant stream in conduit 202 via indirect heat exchange means 4, 6, and 8, respectively. Cooled methane refrigerant gas exits high-stage propane chiller 2 via conduit 154 and is routed to main methane economizer 74, which will be discussed in greater detail in a subsequent section.

[0037] The vaporized propane refrigerant from high-stage propane chiller 2 returns to the high-stage suction port of propane compressor 18 via conduit 306. The remaining liquefied propane exits high-stage propane chiller 2 via conduit 308 to a pressure reduction means, illustrated here as expansion valve 14, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting two-phase stream flows via conduit 310 into intermediate-stage propane chiller 22, wherein it cools the ethylene refrigerant stream leaving high-stage propane chiller 2 in conduit 204 via indirect heat exchange means 26. In addition, the cooled natural gas stream (also referred to herein as the methane-rich stream) exits high-stage propane chiller 2 via conduit 102 and enters a separation vessel 10, wherein gas and liquid phases are separated. The liquid phase, which can be rich in C_{3+} components, is removed via conduit 103. The vapor portion is removed via conduit 104 and enters intermediate-stage propane chiller 22, wherein the stream is cooled via indirect heat exchange means 24 by the previously-discussed liquefied propane stream entering propane chiller 22 via conduit 310.

[0038] The vaporized portion of the propane stream exits intermediate-stage propane chiller 22 via conduit 311 and is routed into the intermediate-stage suction port of propane compressor 18. The remaining liquefied propane stream exits intermediate-stage propane chiller 22 and is routed via conduit 314 to a pressure reduction means, illustrated here as expansion valve 16, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting two-phase stream is routed via conduit 316 into low-stage propane chiller 28, wherein it acts as a coolant via respective indirect heat exchange means 32, 30 for the ethylene refrigerant stream and the predominantly methane stream exiting intermediate-stage propane chiller via conduits 206 and 110, respectively.

[0039] The predominantly vaporized propane stream exits low-stage propane chiller 28 via conduit 320, whereupon it is routed to the low-stage suction port of propane compressor 18 to be recycled as previously discussed. The cooled ethylene stream exits low-stage propane chiller 28 via conduit 208 and enters vapor/liquid separator 37. If present, the vapor portion is routed via conduit 209 to further processing and/or storage. The liquid stream exits vapor/liquid separator 37 via conduit 210. The ethylene refrigerant at this location in the process is generally at a temperature of about −24° F. ad a pressure of about 285 psia. The stream then enters ethylene economizer 34, wherein it is further cooled via indirect heat exchange means 38. The resulting stream in conduit 211 exits ethylene economizer 34 and is routed to a pressure reduction means, illustrated here as expansion valve 40, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting stream enters high-stage ethylene chiller 42 and acts as a coolant for the methane-rich stream exiting low-stage propane chiller 28 via conduit 112.

[0040] Prior to entering high-stage ethylene chiller 42, the predominantly methane stream exiting low-stage propane chiller 28 splits into a first portion and a second portion. The first portion enters high-stage ethylene chiller 42, wherein it is cooled via indirect heat exchange means 44. The second portion is routed via conduit 113 to side reboiler 29, wherein it is cooled by indirect heat exchange with a yet-to-be-discussed stream in conduit 174 via indirect heat exchange means 64. The resulting cooled stream exits side reboiler 29 via conduit 113*a* and subsequently recombines with the cooled methane-rich stream exiting high-stage ethylene chiller 42 in conduit 116.

[0041] The vaporized portion of the ethylene refrigerant in high-stage ethylene chiller 42 is routed via conduit 214 to ethylene economizer 34, wherein it is heated via indirect heat exchange means 46 prior to entering the high-stage suction port of ethylene compressor 48 by way of conduit 216. The remaining primarily liquid ethylene refrigerant exits high-stage ethylene chiller 42 via conduit 218 and enters ethylene economizer 34, wherein it is further cooled via indirect heat exchange means 50. The resulting cooled ethylene refrigerant stream in conduit 220 enters a pressure reduction means, illustrated here as expansion valve 52, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting two-phase stream then enters low-stage ethylene chiller 54 via conduit 222. Low-stage ethylene chiller 54 will be discussed in more detail in a subsequent section.

[0042] The methane-rich stream in conduit 116 enters vapor/liquid separator 57, whereupon it is separated into a liquid phase and a vapor phase. The predominantly vapor phase exiting vapor/liquid separator **57** via conduit **162** is expanded by turboexpander **59**. In one embodiment, turboexpander **59** can be a hydraulic expander providing substantially isoentropic expansion of the predominantly vapor, methane-rich stream. According to the embodiment illustrated in FIG. **1** the power generated by turboexpander **59** can be used to drive a yet-to-be-discussed secondary methane compressor **73**, as depicted by the encircled A. The expanded stream enters the upper portion of distillation column **60** via conduit **169**. In one embodiment, the expanded stream in conduit **169** can have a vapor fraction in the range of from about 0.7 to about 1.0, about 0.8 to about 0.995, about 0.9 to about 0.99, or 0.95 to about 0.985.

[0043] The liquid portion of the methane-rich stream exits vapor/liquid separator **57** and is routed via conduit **168**, to a pressure reduction means, illustrated here as expansion valve **69**, wherein the pressure of the liquefied stream is reduced thereby evaporating or flashing a portion thereof. The resulting stream enters distillation column **60** at a location lower than the location of the expanded vapor stream entering the column **60** via conduit **169**, as illustrated in FIG. **1**.

[0044] Distillation column **60** can be any device known in the art for the separation of vapor and liquid phases. In one embodiment, distillation column **60** may comprise internals, such as, for example trays and/or packing. In general, the number and type of internals in a distillation column are determined by the number of theoretical stages of vapor/liquid equilibrium required to achieve the final product specifications. In one embodiment, distillation column **60** can have in the range of from about 5 to about 50 theoretical stages, or 9 to 20 theoretical stages. As discussed previously, in accordance with one embodiment of the present invention, distillation column **60** can be operated at a pressure below the critical pressure of methane. In one embodiment, the pressure of distillation column **60** can be less than about 550 psia, less than about 525 psia, less than about 500 psia, or less than 490 psia.

[0045] In the embodiment illustrated in FIG. **1**, distillation column **60** may be operably coupled with side reboiler **29**. Side reboiler **29** heats a predominantly liquid side stream drawn from distillation column **60** via conduit **174** with the methane-rich stream in conduit **13** via indirect heat exchange means **67**. The warmed stream exits side reboiler **29** via conduit **176** and reenters distillation column **60** at a lower elevation than the elevation from which the stream in conduit **174** was withdrawn, as shown in FIG. **1**. Side reboiler **29** can help increase the separation efficiency of distillation column **60**.

[0046] As shown in the embodiment represented by FIG. **1**, distillation column **60** can be equipped with a bottoms reboiler **66**. A predominantly liquid stream in conduit **178** is drawn from distillation column **60** and enters bottoms reboiler **66**, wherein the stream is heated (reboiled) via indirect heat exchange with an external fluid (e.g., steam or heat transfer fluid). The resulting, at least partially vaporized stream flows via conduit **180** and enters distillation column **60** at a location below the location where the stream in conduit **178** was withdrawn, as illustrated in FIG. **1**.

[0047] Distillation column **60** produces a predominantly vapor overhead product and a predominantly liquid bottoms product. In one embodiment, the predominantly liquid bottoms product in conduit **166** can be primarily composed of ethane and heavier components and can typically be routed to downstream equipment (not illustrated) for further processing, fractionation, and/or storage. In one embodiment, the predominantly vapor overhead product comprises less than about 100 parts per million by volume (ppmv), less than about 1 ppmv, less than about 0.01 ppmv, or less than about 0.001 ppmv benzene. The overhead stream in conduit **120** exits distillation column **60** and is routed into main methane economizer **74**, wherein it is heated via indirect heat exchange means **63** prior to entering the methane compressor **83** via conduit **127** as a side feed.

[0048] The compressed, predominately methane stream flows via conduit **150** to methane cooler **86**, wherein the stream is cooled via indirect heat exchange with an external fluid (e.g., air or water). The resulting stream is routed via conduit **151** to secondary methane compressor **73**, which, as discussed previously, can be powered by energy generated by turboexpander **59**. This operable coupling of turboexpander **59** to compressor **73** can result in a significant energy savings.

[0049] The pressurized methane stream from secondary methane compressor **73** is routed by conduit **152** into high-stage propane chiller **2**, wherein it is cooled via indirect heat exchange means **2** and exits via conduit **154**, as previously mentioned. The stream in conduit **154** then enters main methane economizer **74** and is subsequently cooled via indirect heat exchange means **97**. The cooled, methane-rich stream exits main methane economizer **74** via conduit **155** prior to entering low-stage ethylene chiller **54**. In low-stage ethylene chiller **54**, the methane-rich stream in conduit **155** is further cooled in indirect heat exchange means **70** by the ethylene refrigerant entering low-stage ethylene chiller **54** via conduit **222**, as mentioned previously. The resulting methane-rich stream exits low-stage ethylene chiller **54** via conduit **122** and reenters main methane economizer **74**. The at least partially vaporized ethylene refrigerant in low-stage ethylene chiller **54** exits via conduit **226** and enters ethylene economizer **34**, wherein it is heated via indirect heat exchange means **58** prior to entering the low-stage suction port of ethylene compressor **48** via conduit **232**. Compressed ethylene vapor discharged from ethylene compressor **48** in conduit **200** enters ethylene cooler **72**, wherein the stream is cooled via indirect heat exchange with an external fluid (e.g., air or water). The resulting stream in conduit **202** enters high-stage propane chiller **2** and is subsequently cooled and recirculated throughout the ethylene refrigerant cycle as discussed previously.

[0050] The compressed, methane-rich stream in conduit **122**, of which at least a portion originated from the predominantly vapor overhead product of distillation column **60**, enters main methane economizer **74**, wherein it is further cooled via indirect heat exchange means **76**. The resulting cooled and at least partially condensed stream exits main methane economizer **74** and thereafter splits into a first portion and a second portion. The first portion in conduit **170** is routed to a pressure reduction means, illustrated here as expansion valve **61**, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting, two-phase stream enters the upper portion of distillation column **60** via conduit **171** as a reflux stream.

[0051] The second portion of the methane-rich stream exiting main methane economizer **74** enters conduit **124**, and is routed to a pressure reduction means, illustrated here as high-stage methane expander **78** wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting, two-phase stream enters high-stage methane flash drum **80**, wherein the vapor and liquid phases are separated. The vapor portion exits high-stage methane flash drum

80 via conduit 126 and enters main methane economizer, wherein the stream is heated via indirect heat exchange means 82. The resulting stream exits main methane economizer 74 via conduit 128 and enters the high-stage suction port of methane compressor 83. Similarly to propane compressor 18, methane compressor 83 is a multi-stage (e.g., three-stage) compressor driven by, for example, a gas turbine driver (not illustrated). The three stages of compression can exist in a single unit, although each stage of compression may be a separate unit and the units mechanically coupled to be driven by a single driver. The liquid portion exits high-stage methane flash drum 80 via conduit 130 and enters secondary methane economizer 87, wherein the stream is cooled via indirect heat exchange means 88. The resulting stream in conduit 132 flows to a pressure reduction means, illustrated here as intermediate-stage methane expander 91 wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting two-phase stream enters intermediate-stage methane flash drum 92, wherein vapor and liquid phases are separated.

[0052] The vapor portion exits intermediate-stage methane flash drum 92 via conduit 136 and enters secondary methane economizer 87, wherein it is heated via indirect heat exchange means 89. The resulting stream exits secondary methane economizer via conduit 138 and enters main methane economizer 74, wherein the stream is further heated via indirect heat exchange means 95 prior to entering the intermediate-stage suction port of methane compressor 83 via conduit 140. The liquid portion exits intermediate-stage methane flash drum via conduit 134, and flows to a pressure reduction means, illustrated here as low-stage methane expander 93, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof.

[0053] The resulting two-phase stream enters low-stage methane flash drum 94, whereupon its vapor and liquid portions are separated. The predominantly vapor phase exits high-stage methane flash drum 94 via conduit 144 and enters secondary methane economizer 87, wherein it is heated via indirect heat exchange means 90. The resulting stream then enters main methane economizer 74 via conduit 146 and is heated via indirect heat exchange means 96 prior to being routed into the low-stage suction port of methane compressor 83 via conduit 148. The liquid phase exiting low-stage methane flash drum 94 is the LNG product, which is now at approximately atmospheric pressure. The LNG product can then be routed via conduit 142 to storage or further processing (not shown).

[0054] FIG. 2 illustrates another embodiment of the inventive LNG facility capable of intermediate-pressure NGL recovery. The embodiment represented by FIG. 2 is similar to the embodiment illustrated in FIG. 1, except distillation column 60 illustrated in FIG. 2 does not employ a reflux stream. The main components of LNG facility represented by FIG. 2 are numbered the same as those listed previously for FIG. 1.

[0055] The operation of the LNG facility illustrated in FIG. 2, as it differs from that previously discussed with respect to FIG. 1, will now be described in detail. In FIG. 2, the cooled methane-rich stream exits high-stage ethylene chiller 42 via conduit 116 and recombines with the portion of the methane-rich stream exiting side reboiler 29 in conduit 113*a*. The composite stream then enters vapor/liquid separator 57, whereupon vapor and liquid phases are separated. The liquid stream exiting separator 57 enters a pressure reduction means, illustrated here as expansion valve 69, wherein the pressure of the liquefied stream is reduced thereby evaporating or flashing a portion thereof. The resulting, two-phase stream enters distillation column 60 via conduit 168. Turboexpander 59 expands the vapor stream exiting separator 57 via conduit 162. The resulting stream then enters the upper portion of distillation column 60 via conduit 169. Similarly to the embodiment illustrated in FIG. 1, the power generated by turboexpander 59 in FIG. 2 can be used to drive secondary methane compressor 73, as depicted by the encircled A.

[0056] Similarly to the system illustrated in FIG. 1, distillation column 60 in FIG. 2 includes a side draw and a bottoms reboiler. The predominantly liquid bottom product from distillation column 60 in FIG. 2 can be primarily ethane and heavier components and can be routed via conduit 166 to further processing, fractionation, and/or storage (not shown). The predominantly vapor overhead product from distillation column 60 flows via conduit 120 into main methane economizer 74, wherein it is warmed via indirect heat exchange means 63 prior to being routed via conduit 127 into methane compressor 83. The resulting compressed stream is discharged into conduit 150 and subsequently cooled by methane cooler 86 via indirect heat exchange with an external fluid (e.g., air or water).

[0057] The cooled methane stream is compressed in conduit 151 by secondary methane compressor 73, which can be powered by energy generated by turboexpander 59. The compressed stream in conduit 152 is cooled by indirect heat exchange means 4 in high-stage propane chiller 2, by indirect heat exchange means 97 in main methane economizer 74, and by indirect heat exchange means 70 in low-stage ethylene chiller 54, as described in detail previously with respect to the embodiment illustrated in FIG. 1. In the embodiment illustrated in FIG. 2, the methane-rich stream entering main methane economizer 74 is cooled via indirect heat exchange means 76. The resulting cooled stream exits the main methane economizer 74 via conduit 124 and is routed in its entirety to the expansion-type cooling section of the methane refrigerant cycle, as previously described with respect to FIG. 1.

[0058] FIG. 3 illustrates yet another embodiment of the inventive LNG facility capable of intermediate-pressure NGL recovery. The embodiment represented by FIG. 3 is similar to the embodiment illustrated in FIG. 1. However, as illustrated in FIG. 3, side reboiler 29 functions as a heater for a stream entering distillation column 60, which does not employ a side draw in accordance with one embodiment. The main components of LNG facility represented by FIG. 3 are numbered the same as those listed previously for FIG. 1. In one embodiment, this configuration can be part of a revamp to an existing LNG facility.

[0059] The operation of the LNG facility illustrated in FIG. 3, as it differs from that previously discussed with respect to FIG. 1, will now be described in detail. The cooled methane-rich stream exits high-stage ethylene chiller 42 via conduit 116 and recombines with the portion of the stream exiting side reboiler 29 in conduit 113*a*. The composite stream enters vapor/liquid separator 57, whereupon vapor and liquid phases are separated. The vapor stream exiting separator 57 in conduit 162 is expanded via turboexpander 59, and the resulting two-phase stream enters the upper portion of distillation column 60 via conduit 169. Similarly to the embodiment illustrated in FIG. 1, the power generated by turboexpander 59 in FIG. 3 is used to drive secondary methane compressor 73, as depicted by the encircled A.

[0060] In lieu of a side stream being withdrawn from distillation column **60**, the embodiment of the inventive system illustrated in FIG. **3** routes the liquid portion exiting separator **57** in conduit **172** through indirect heat exchange means **67** as a coolant for the previously-described natural gas stream in side reboiler **29**. The warmed stream then exits side reboiler **29** via conduit **176** and flows into to distillation column **60** at a location lower than the location where the expanded vapor enters column **60** via conduit **169**. The cooled natural gas stream exits side reboiler **29** via conduit **113***a* and proceeds through the remainder of the refrigeration process as described previously.

[0061] FIG. **4** illustrates a further embodiment of the inventive LNG facility capable of intermediate-pressure NGL recovery. The embodiment of the inventive LNG facility represented by FIG. **4** varies slightly from the embodiment illustrated in FIG. **1**. For example, the system of FIG. **4** uses the power generated by turboexpander **59** to drive secondary methane compressor **73**, which is used to compress a process stream located upstream of turboexpander **59**. Further, the cooled overhead vapor product from distillation column **60** is routed to high-stage methane flash drum **80** and the vapor phase is fed to the high-stage suction port of methane compressor **83** rather than entering methane compressor **83** as a side feed, as illustrated in FIGS. **1-3**. In addition, the system illustrated in FIG. **4** includes an optional fuel draw near the bottom of distillation column **60** as well as an optional bypass of indirect heat exchange means **76** in order to control the temperature of the reflux stream in conduit **170**.

[0062] The main components of LNG facility represented by FIG. **4** are numbered the same as those listed previously for FIG. **1**. The operation of the LNG facility illustrated in FIG. **4**, as it differs from that previously detailed with respect to FIG. **1**, will now be described in detail. The vapor phase in conduit **104** exiting vapor/liquid separator **10** located downstream of high-stage propane chiller **2** is routed to the suction of secondary methane compressor **73**. As denoted by the encircled A, the secondary methane compressor **73** can be powered by energy generated by turboexpander **59**, which results in an increase in overall process efficiency.

[0063] The compressed gas stream exits compressor **73** and thereafter splits into two portions. The first portion is routed by conduit **106** to side reboiler **29**, wherein the stream is cooled via indirect heat exchange means **64**. The second portion of the compressed stream discharged from secondary methane compressor **73** flows via conduit **105** to intermediate-stage propane chiller **22**, wherein the stream is cooled via indirect heat exchange means **24**. In a like manner to the system described in FIG. **1**, the resulting cooled stream in FIG. **2** exits intermediate-stage propane chiller **22** via conduit **110** and enters low-stage propane chiller **28**, wherein the stream is further cooled via indirect heat exchange means **30**. The stream exits low-stage propane chiller **28** in conduit **112** and thereafter combines with the now-cooled first portion of the compressed methane-rich stream exiting side reboiler **29** via conduit **107**. The composite stream in conduit **112** again splits into two portions. The first portion enters high-stage ethylene chiller **42**, wherein the stream is cooled via indirect heat exchange means **44**. The second portion of the stream in conduit **112** flows via conduit **108** and enters a pressure reduction means, illustrated here as expansion valve **81**, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting two-phase stream in conduit **109** recombines with the cooled stream exiting high-stage ethylene chiller **42** in conduit **116**. The resulting stream in conduit **116** is then routed to vapor/liquid separator **57**, and enters distillation column **60** as previously described with respect to the system shown in FIG. **1**.

[0064] Distillation column **60** in FIG. **4** is operably coupled to side reboiler **29** and bottom reboiler **66**, as described with respect to FIG. **1**. In addition, distillation column **60** in FIG. **4** optionally includes a fuel side draw conduit **182**. In one embodiment, the composition of the fuel stream in conduit **182** can be greater than about 80 mole percent, greater than about 90 mole percent, or greater than about 93 mole percent ethane and heavier components. The predominantly vapor overhead stream from distillation column **60** is routed via conduit **120** into low-stage ethylene chiller **54**, wherein the stream is cooled via indirect heat exchange means **75**. The resulting, predominantly methane stream is routed via conduit **192** to main methane economizer **74**, wherein the stream is further cooled via indirect heat exchange means **77**. The resulting stream exits main methane economizer **74** via conduit **194** and, subsequently, enters a pressure reduction means, illustrated as expansion valve **79**, wherein the pressure of the stream is reduced thereby evaporating or flashing a portion thereof. The resulting, two-phase stream enters high-stage methane flash drum **80** and continues through the expansion-type cooling section as described with respect to FIG. **1**.

[0065] According to the embodiment of the inventive LNG facility illustrated in FIG. **4**, methane compressor **83** discharges a compressed, predominantly methane stream into conduit **150**, which is thereafter cooled in methane cooler **86** via indirect heat exchange with an external fluid (e.g., air or water). The resulting stream is then further cooled by indirect heat exchange means **4** in high-stage propane chiller **2**, by indirect heat exchange means **97** in main methane economizer **74**, and by indirect heat exchange means **70** in low-stage ethylene chiller **54**, as described in detail previously with respect to the embodiment illustrated in FIG. **1**. The stream in conduit **122** exiting low-stage ethylene chiller **54** is thereafter optionally split into two portions. The first portion is cooled in main methane economizer **74** by indirect heat exchange mean **76** and is either refluxed to distillation column **60** via conduit **171** or is routed to the expansion-type cooling section of the process via conduit **124**, as described with respect to FIG. **1**. The optional second portion of the stream in conduit **122** enters conduit **123** and can combine with the methane-rich stream in conduit **170**, prior to being employed as reflux in distillation column **60**. This introduction of the relatively warmer stream in conduit **123** to the cooler stream in conduit **170** increases the overall operating flexibility of distillation column **60**.

[0066] In one embodiment of the present invention, the LNG production systems illustrated in FIGS. **1** through **4** can be simulated on a computer using conventional process simulation software in order to produce a set of simulation results. In one embodiment, the simulation results can be in the form of a computer print out. In another embodiment, the simulation results can be displayed on a screen, monitor, or other viewing device. In a further embodiment, the simulation results may be inputs for another program or spreadsheet used to make decisions regarding the optimal values for key facility operation parameters. In yet another embodiment, the simulation results may be converted into signals directly communicated to system controllers for direct control and/or optimization of the inventive LNG system.

[0067] Ultimately, the simulation results can be used to manipulate the LNG system. In one embodiment, the simulation results can be used to design a new LNG facility and/or revamp or expand an existing LNG facility. In another embodiment, the simulation results can be used to optimize an existing LNG facility according to one or more operating parameters. In a further embodiment, the computer simulation can directly control the operation of the LNG facility by, for example, manipulating control valve output. Examples of suitable software for producing the simulation results include HYSYS™ or Aspen Plus® from Aspen Technology, Inc., and PRO/II® from Simulation Sciences Inc.

Numerical Ranges

[0068] The present description uses numerical ranges to quantify certain parameters relating to the invention. It should be understood that when numerical ranges are provided, such ranges are to be construed as providing literal support for claim limitations that only recite the lower value of the range as well as claims limitation that only recite the upper value of the range. For example, a disclosed numerical range of 10 to 100 provides literal support for a claim reciting "greater than 10" (with no upper bounds) and a claim reciting "less than 100" (with no lower bounds).

Definitions

[0069] As used herein, the terms "a," "an," "the," and "said" means one or more.

[0070] As used herein, the term "and/or," when used in a list of two or more items, means that any one of the listed items can be employed by itself, or any combination of two or more of the listed items can be employed. For example, if a composition is described as containing components A, B, and/or C, the composition can contain A alone; B alone; C alone; A and B in combination; A and C in combination; B and C in combination; or A, B, and C in combination.

[0071] As used herein, the term "bottoms reboiler" refers to an indirect heat exchange means used to at least partially vaporize a stream withdrawn near the bottom of a distillation column.

[0072] As used herein, the term "bottoms stream" or "bottoms product" refers to an at least partially liquid stream withdrawn from at or near the bottom port of a distillation column.

[0073] As used herein, the term "cascade refrigeration process" means a refrigeration process that employs a plurality of refrigeration cycles, each employing a different pure component refrigerant to successively cool natural gas.

[0074] As used herein, the terms "comprising," "comprises," and "comprise" are open-ended transition terms used to transition from a subject recited before the term to one or elements recited after the term, where the element or elements listed after the transition term are not necessarily the only elements that make up of the subject.

[0075] As used herein, the terms "containing," "contains," and "contain" have the same open-ended meaning as "comprising," "comprises," and "comprise."

[0076] As used herein, the terms "distillation" or "fractionation" refer to the process of physically separating chemical components into a vapor phase and a liquid phase based on differences in the components' boiling points at specified temperature and pressure.

[0077] As used herein, the terms "economizer" or "economizing heat exchanger" refer to a configuration utilizing a plurality of heat exchangers employing indirect heat exchange means to efficiently transfer heat between process streams. Generally, economizers minimize outside energy inputs by heat integrating process streams with each other.

[0078] As used herein, the term "expansion-type cooling" refers to cooling which occurs when the pressure of a gas, liquid, or two-phase system is decreased by passage through a pressure reduction means. In one embodiment, the expansion means is a Joule-Thompson expansion valve. In another embodiment of the present invention, the expansion means is a hydraulic or gas expander.

[0079] As used herein, the terms "having," "has," and "have" have the same open-ended meaning as "comprising," "comprises," and "comprise."

[0080] As used herein, the terns "including," "includes," and "include" have the same open-ended meaning as "comprising," "comprises," and "comprise."

[0081] As used herein, the term "indirect heat exchange" refers to a process wherein the refrigerant cools the substance to be cooled without actual physical contact between the refrigerating agent and the substance to be cooled. Core-in-kettle heat exchangers and brazed aluminum plate-fin heat exchangers are specific examples of equipment that facilitate indirect heat exchange.

[0082] As used herein, the term "mid-boiling point" refers to the temperature at which half of the weight of a mixture of physical components has been vaporized (i.e., boiled off) at a specific pressure.

[0083] As used herein, the term "mixed refrigerant" means a refrigerant containing a plurality of different components, where no single component makes up more than 75 mole percent of the refrigerant.

[0084] As used herein, the term "natural gas" means a stream containing at least 85 mole percent methane, with the balance being ethane, higher hydrocarbons, nitrogen, carbon dioxide, and/or a minor amount of other contaminants such as mercury, hydrogen sulfide, and mercaptan.

[0085] As used herein, the terms "natural gas liquids" or "NGL" refer to mixtures of hydrocarbons whose components are, for example, typically ethane and heavier. Some examples of hydrocarbon components of NGL streams include propane, butane, and pentane isomers, benzene, toluene, and other aromatic molecules.

[0086] As used herein, the term "open-cycle cascaded refrigeration process" refers to a cascaded refrigeration process comprising at least one closed refrigeration cycle and one open refrigeration cycle, where the boiling point of the refrigerant employed in the open cycle is less than the boiling point of the refrigerant employed in the closed cycle, and a portion of the cooling duty to condense the open-cycle refrigerant is provided by one or more of the closed cycles. In one embodiment of the present invention, a predominately methane stream is employed as the refrigerant in the open refrigeration cycle. This predominantly methane stream originates from the processed natural gas feed stream and can include the compressed open methane cycle gas streams.

[0087] As used herein, the term "overhead stream" of "overhead product" refers to an at least partially vapor stream withdrawn from at or near the top port of a distillation column.

[0088] As used herein, the terms "predominantly," "primarily," "principally," and "in major portion," when used to describe the presence of a particular component of a fluid stream, means that the fluid stream comprises at least 50 mole percent of the stated component. For example, a "predominantly" methane stream, a "primarily" methane stream, a stream "principally" comprised of methane, or a stream comprised "in major portion" of methane each denote a stream comprising at least 50 mole percent methane.

[0089] As used herein, the term "pure component refrigerant" means a refrigerant that is not a mixed refrigerant.

[0090] As used herein, the term "reflux" refers to an at least partially liquid stream introduced into the upper portion of a distillation column in order to increase separation efficiency.

[0091] As used herein, the term "side reboiler" refers to an indirect heat exchange means used to heat and at least partially vaporize a stream withdrawn from between the upper and lower portions of a distillation column.

[0092] As used herein, the term "turboexpander" refers to any device for expanding a stream that is capable of generating useful work.

[0093] As used herein, the terms "upstream" and "downstream" refer to the relative positions of various components of a natural gas liquefaction facility along the main flow path of natural gas through the plant.

[0094] The preferred forms of the invention described above are to be used as illustration only, and should not be used in a limiting sense to interpret the scope of the present invention. Obvious modifications to the exemplary embodiments, set forth above, could be readily made by those skilled in the art without departing from the spirit of the present invention.

[0095] The inventors hereby state their intent to rely on the Doctrine of Equivalents to determine and assess the reasonably fair scope of the present invention as it pertains to any apparatus not materially departing from but outside the literal scope of the invention as set forth in the following claims:

What is claimed is:

1. A process for liquefying a natural gas stream, said process comprising:

(a) cooling at least a portion of said natural gas stream;

(b) expanding a vapor portion of the cooled natural gas stream in a turboexpander;

(c) introducing a liquid portion of the cooled natural gas stream into a distillation column; and

(d) using work produced by said turboexpander to compress at least a portion of said natural gas stream upstream of said distillation column.

2. The process of claim **1**, further comprising separating the cooled natural gas stream into said vapor and liquid portions upstream of said distillation column.

3. The process of claim **1**, further comprising introducing at least a portion of the expanded stream from said turboexpander into said distillation column at a location above the location where said liquid portion is introduced into said distillation column.

4. The process of claim **1**, further comprising introducing a reflux stream into said distillation column.

5. The process of claim **4**, wherein said reflux stream originates from an overhead stream produced from said distillation column.

6. The process of claim **5**, further comprising compressing and cooling at least a portion of said reflux stream prior to introduction into said distillation column.

7. The process of claim **6**, wherein at least a portion of said cooling of said reflux stream is provided by indirect heat exchange with a predominately methane stream.

8. The process of claim **1**, wherein said distillation column is the only distillation column employed in said process.

9. The process of claim **1**, wherein said process employs a first refrigeration cycle utilizing a predominately propane and/or propylene refrigerant, a second refrigeration cycle utilizing a predominately ethane and/or ethylene refrigerant, an open methane refrigeration cycle.

10. A process comprising: vaporizing LNG produced by the process of claim **1**.

11. A process comprising: using a computer to simulate the process of claim **1**.

12. A process for liquefying a natural gas stream, said process comprising:

(a) using a distillation column to separate at least a portion of said natural gas stream into an overhead stream and a bottom stream;

(b) cooling at least a portion of said overhead stream via indirect heat exchange with a predominately methane refrigerant stream; and

(c) using at least a portion of the cooled overhead stream as a reflux stream in said distillation column.

13. The process of claim **12**, further comprising compressing at least a portion of said overhead stream in a methane compressor, wherein at least a portion of said reflux stream is derived from the compressed overhead stream.

14. The process of claim **13**, wherein at least a portion of said cooling of said overhead stream with said predominately methane stream takes place after said compressing of said overhead stream.

15. The process of claim **12**, wherein at least a portion of said predominately methane refrigerant stream is derived from said overhead stream.

16. The process of claim **12**, further comprising cooling at least a portion of said overhead stream via indirect heat exchange with a second refrigerant stream having a higher boiling point than said predominately methane refrigerant stream.

17. The process of claim **16**, wherein said second refrigerant stream comprises predominately propane and/or propylene.

18. The process of claim **16**, further comprising cooling at least a portion of said overhead stream via indirect heat exchange with a third refrigerant stream having a boiling point lower than second refrigerant and higher than said predominately methane refrigerant stream.

19. The process of claim **18**, wherein said second refrigerant stream comprises predominately propane and/or propylene and said third refrigerant stream comprises predominately ethane and/or ethylene.

20. The process of claim **12**, further comprising using at least a portion of said overhead stream to cool at least a portion of said natural gas stream.

21. The process of claim **12**, further comprising separating at least a portion of said natural gas stream into a predominately vapor fraction and a predominately liquid fraction, introducing at least a portion of said predominately liquid fraction into said distillation column, expanding at least a portion of said predominately vapor fraction in a turboexpander, and introducing at least a portion of the resulting expanded stream into said distillation column.

22. A process comprising: vaporizing LNG produced by the process of claim **12**.

23. A process comprising: using a computer to simulate the process of claim **12**.

24. A process for liquefying a natural gas stream, said process comprising:

(a) using a distillation column to separate at least a portion of said natural gas stream into an overhead stream and a bottom stream;

(b) withdrawing a side stream from said distillation column; and

(c) heating at least a portion of said side stream via indirect heat exchange with at least a portion of said natural gas stream upstream of said distillation column to thereby produce a heated side stream.

25. The process of claim **24**, further comprising introducing at least a portion of said heated side stream into said distillation column at a location below the location where said side stream is withdrawn.

26. The process of claim **24**, wherein said heating of step (c) causes cooling of said natural gas stream.

27. The process of claim **24**, further comprising, separating at least a portion of said natural gas stream into a predominately vapor fraction and a predominately liquid fraction, introducing at least a portion of said predominately liquid fraction into said distillation column, expanding at least a portion of said predominately vapor fraction in a turboexpander, and introducing at least a portion of the resulting expanded stream into said distillation column.

28. The process of claim **27**, wherein said turboexpander produces useful work that is employed elsewhere in said process.

29. The process of claim **28**, wherein at least a portion of said useful work is used to compress a process stream.

30. The process of claim **29**, wherein said process stream comprises predominately methane.

31. The process of claim **24**, wherein said distillation column is equipped with a bottoms reboiler.

32. The process of claim **24**, wherein the overhead pressure of said distillation column is less than about 550 psia.

33. The process of claim **24**, wherein said distillation column is the only distillation column employed in said process.

34. The process of claim **24**, wherein said process is a cascade-type LNG process.

35. A process comprising: vaporizing LNG produced by the process of claim **24**.

36. A process comprising: using a computer to simulate the process of claim **24**.

37. A process for liquefying a natural gas stream, said process comprising:

(a) using a distillation column to separate at least a portion of said natural gas stream into an overhead stream and a bottom stream;

(b) introducing at least a portion of said overhead stream into a vapor/liquid separator;

(c) compressing at least a portion of a predominately vapor stream produced from said phase separator to thereby provide a high-pressure stream;

(d) introducing a first fraction of said high-pressure stream into said distillation column; and

(e) introducing a second fraction of said high-pressure stream into said vapor/liquid separator.

38. The process of claim **37**, wherein said first fraction of said high-pressure stream is provided as a reflux stream to said distillation column.

39. The process of claim **37**, further comprising expanding said second fraction prior to step (e).

40. The process of claim **37**, further comprising cooling and at least partially condensing at least a portion of said high-pressure stream prior to steps (d) and (e).

41. The process of claim **40**, wherein said at least a portion of said cooling of said high-pressure stream is provided by indirect heat exchange with a predominately methane refrigerant stream.

42. The process of claim **37**, wherein said at least a portion of said cooling of said high-pressure stream is provided by indirect heat exchange with a predominately propane and/or propylene refrigerant stream.

43. The process of claim **37**, wherein said at least a portion of said cooling of said high-pressure stream is provided by indirect heat exchange with a predominately ethane and/or ethylene refrigerant stream.

44. The process of claim **37**, further comprising, separating at least a portion of said natural gas stream into a predominately vapor fraction and a predominately liquid fraction, introducing at least a portion of said predominately liquid fraction into said distillation column, expanding at least a portion of said predominately vapor fraction in a turboexpander, and introducing at least a portion of the resulting expanded stream into said distillation column.

45. A process comprising: vaporizing LNG produced by the process of claim **37**.

46. A process comprising: using a computer to simulate the process of claim **37**.

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