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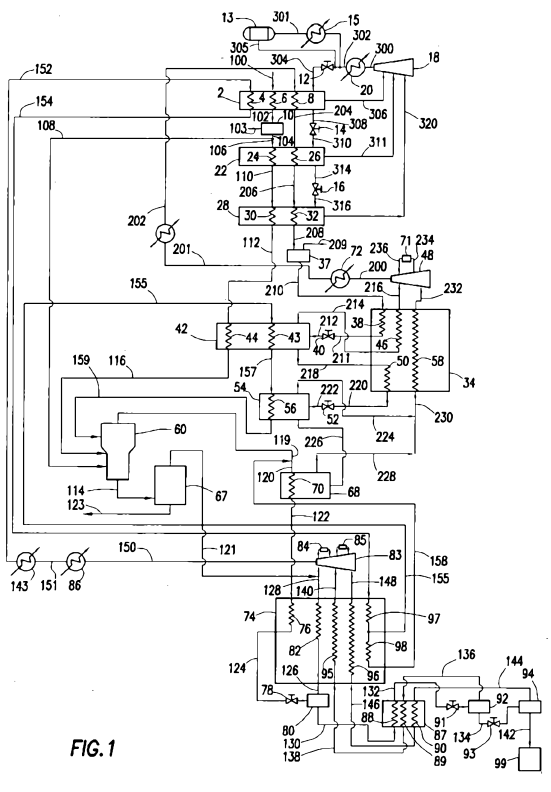

FIG. 1

(57) Abstract: The present invention relates to a process and apparatus for liquefying natural gas. In another aspect the present invention relates to the heat recovery from a turbine in a liquefied natural gas facility.

WO 2012/112692 A1

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INTEGRATED WASTE HEAT RECOVERY IN LIQUEFIED NATURAL GAS FACILITY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority benefit under 35 U.S.C. Section 119(e) to U.S. Provisional Patent Serial No. 61/443,523 filed on February 16, 2011 the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to a process and apparatus for liquefying natural gas. In another aspect the present invention relates to the heat recovery from a turbine in a liquefied natural gas facility.

BACKGROUND OF THE INVENTION

[0003] The cryogenic liquefaction of natural gas is routinely practiced as a means of converting natural gas into a more convenient form for transportation and storage. Such liquefaction reduces the volume of the natural gas by about 600-fold and results in a product which can be stored and transported at or near atmospheric pressure.

[0004] 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. However, often the deliverability or capacity of the pipeline will exceed demand while at other times the demand may exceed the deliverability of the pipeline. In order to shave off the peaks where demand exceeds supply or the valleys when supply exceeds demand, it is desirable to store the excess gas in such a manner that it can be delivered when demand exceeds supply. 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.

[0005] The liquefaction of natural gas is of even greater importance when transporting gas from a supply source, which 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 vessel. Ship transportation in the gaseous state is generally not practical because appreciable pressurization is required to significantly reduce the specific volume of the gas. Such pressurization requires the use of more expensive storage containers.

[0006] In order to store and transport natural gas in the liquid state, the natural gas is preferably cooled to -240°F to -260°F where the liquefied natural gas (LNG) possesses a near-atmospheric vapor pressure. 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).

[0007] In one example of the prior art, cooling is accomplished with a series of refrigerants. Such refrigerants, for example, can be categorized as a heavy refrigerant, an intermediate refrigerant and a light refrigerant. Each refrigerant is individually utilized in separate refrigeration cycles beginning with the heavy refrigerant and ending with the light refrigerant to condense the natural gas and produce LNG. Furthermore, each cycle has its own compressor drive (traditionally using gas turbines but could equally use electric drives powered by gas turbine generators). The "first" refrigeration cycle utilizes the heavy refrigerant to cool the natural gas, the "second" refrigeration cycle utilizes the intermediate refrigerant to further cool the natural gas, and the "final" refrigeration cycle utilizes the light refrigerant to further cool the natural gas.

[0008] In another prior art example, the integration of economizing exchangers are utilized to facilitate the removal of heat from the natural gas using sensible heat in the intermediate and light refrigeration systems rather than the latent heat of condensation in the heavy refrigeration systems.

[0009] Typically, the process for the production of LNG, as described above, requires substantial energy consumption for cooling and liquefaction of the natural gas. This energy is supplied by mechanical drives that use prime movers, such as gas turbines, gas engines and/or electric motors, to drive compressors for the necessary refrigeration processes. The prime movers are inherently inefficient and are known to typically convert only 25-40% of the energy supplied as fuel into useful compressive work for the refrigeration process. The majority of energy is lost to atmosphere in the form of heat.

[0010] Therefore, a need exits to utilize the energy lost during the refrigeration process and improve the overall thermal efficiency of the process.

SUMMARY OF THE INVENTION

[0011] In one embodiment of the present invention, a process for liquefying natural gas includes the following steps: (a) compressing a first refrigerant in a first compressor driven by a first gas turbine; (b) recovering waste heat from the first gas turbine; (c) cooling the natural gas with the first refrigerant in a first chiller; (d) using at least a portion of the waste heat recovered from the first gas turbine to further cool the natural gas with the first refrigerant, wherein the natural gas and the first refrigerant are further cooled by utilizing either a lithium bromide or an ammonia absorption chiller; (e) compressing a second refrigerant in a second compressor driven by a second gas turbine; (f) recovering waste hear from the second turbine; (g) cooling the natural gas with the second refrigerant in a second chiller; and (h) using at least a portion of the waste heat recovered from the second gas turbine to further cool the natural gas with the second refrigerant, wherein the natural gas and the second refrigerant are further cooled by utilizing either a lithium bromide or an ammonia adsorption chiller.

[0012] In another embodiment of the present invention, a process for liquefying natural gas includes the following steps: (a) compressing a first refrigerant in a first compressor driven by a first gas turbine; (b) recovering waste heat from the first gas turbine; (c) using at least a portion of the waste heat recovered from the first gas turbine to further cool the natural gas with the first refrigerant; (d) compressing a second refrigerant in a second compressor driven by a second gas turbine; (e) recovering waste heat from the second turbine; and (f) using at least a portion of the waste heat recovered from the second gas turbine to further cool the natural gas with the second refrigerant.

[0013] In another embodiment, a process for liquefying natural gas, the process includes the following steps: (a) compressing a first refrigerant in a first compressor driven by a first gas turbine; (b) recovering waste heat from the first gas turbine; (c) using at least a portion of the waste heat recovered from the first gas turbine to further cool the natural gas; (d) compressing a second refrigerant in a second compressor driven by a second gas turbine; (e) recovering waste heat from the second turbine; and (f) using at least a portion of the waste heat recovered from the second gas turbine to further cool the natural gas.

[0014] In yet another embodiment of the present invention, an apparatus for liquefying natural gas employing multiple refrigerants in multiple refrigeration cycle for cooling the natural gas in multiple stage, includes: (a) a first compressor for compressing a first refrigerant of a first refrigeration cycle; (b) a first gas turbine for driving the first compressor, wherein waste heat is recovered from the first gas turbine, wherein at least a portion of the waste heat further cools the natural gas and the first refrigerant; (c) a second compressor for compressing a second refrigerant of a second refrigeration cycle; and (d) a second gas turbine for driving the second compressor, wherein waste heat is recovered from the second gas turbine, wherein at least a portion of the waste heat further cools the natural gas and the second refrigerant.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

[0016] FIG. 1 is a simplified flow diagram of a cascaded refrigeration process for LNG production which employs an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0017] Reference will now be made in detail to embodiments of the present invention, one or more examples of which are illustrated in the accompanying drawings. Each example is provided by way of explanation of the invention, not as a limitation of the invention. It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment can be used on another embodiment to yield a still further embodiment. Thus, it is intended that the present invention cover such modifications and variations that come within the scope of the appended claims and their equivalents.

[0018] A cascade refrigeration process uses one or more refrigerants for transferring heat energy from the natural gas stream to the refrigerant and ultimately transferring said heat energy to the environment. In essence, the overall refrigeration system functions as a heat pump by removing heat energy from the natural gas stream as the stream is progressively cooled to lower and lower temperatures. The design of a cascade refrigeration process involves the balancing of thermodynamic efficiencies and capital costs. In heat transfer processes, thermodynamic irreversibilities are reduced as the temperature gradients between heating and cooling fluids become smaller. However, obtaining such small temperature gradients generally requires (1) significant increases in the amount of heat transfer area; (2) major modifications to various process equipment; and (3) the proper selection of flowrates through such equipment so as to ensure both flowrates, approach temperatures and outlet temperatures are compatible with the required heating/cooling duty.

[0019] One of the most efficient and effective means of liquefying natural gas is via an optimized cascade-type operation in combination with expansion-type cooling. Such a liquefaction process involves the cascade-type cooling of a natural gas stream at an elevated pressure, (e.g., about 650 psia) by sequentially cooling the gas stream via passage through a multistage propane or propylene cycle, a multistage ethane or ethylene cycle, and an open-loop methane cycle which utilizes a portion of the feed gas as a source of methane and which includes therein a multistage expansion cycle to further cool the same and reduce the pressure to near-atmospheric pressure. In another embodiment, the methane cycle can be a closed loop system. In the sequence of cooling cycles, the refrigerant having the highest boiling point is utilized first followed by a refrigerant having an intermediate boiling point and finally by a refrigerant having the lowest boiling point. As used herein, the terms "upstream" and "downstream" shall be used to describe the relative positions of various components of a natural gas liquefaction plant along the flow path of natural gas through the plant.

[0020] In cryogenic processing of a natural gas stream an important consideration is contamination. The raw natural gas feed stream suitable for the process of the invention may comprise natural gas obtained from a crude oil well (associated gas) or from a gas well (non-associated gas). The composition of natural gas can vary significantly. While methane is the major desired component of natural gas streams, the typical raw natural gas stream also contains ethane (C_2), higher hydrocarbons (C_3+), and minor amounts of contaminants such as water, carbon dioxide, hydrogen sulfide, nitrogen, butane, hydrocarbons of six or more carbon atoms, dirt, iron sulfide, wax, and crude oil. The solubilities of these contaminants vary with temperature, pressure, and composition. At cryogenic temperatures, CO_2, water, and other contaminants can form solids, which can plug flow passages in cryogenic heat exchangers.

[0021] Various pretreatment steps provide a means for removing undesirable components, such as acid-gases, mercaptan, mercury, and moisture from the natural gas feed stream delivered to the LNG facility. The composition of this natural gas stream may vary significantly. As used herein, a natural gas stream is any stream principally comprised of methane which originates in major portion from a natural gas feed stream with the balance being ethane, higher hydrocarbons, nitrogen, carbon dioxide and minor amounts of other contaminants such as mercury, hydrogen sulfide, and mercaptan. The pretreatment steps may be separate steps located either upstream of the cooling cycles or located downstream of one of the early stages of cooling in the initial cycle. The following is a non-exclusive listing of some of the available means which are readily available to one skilled in the art: (a) acid gases and to a lesser extent mercaptan are routinely removed via a sorption process employing an aqueous amine-bearing solution; (b) a major portion of the water is routinely removed as a liquid via two-phase gas-liquid separation following gas compression and cooling upstream of the initial cooling cycle and also downstream of the first cooling stage in the initial cooling cycle; (c) mercury is routinely removed via mercury sorbent beds; and (d) residual amounts of water and acid gases are routinely removed via the use of properly selected sorbent beds such as regenerable molecular sieves.

[0022] As previously noted, the natural gas feed stream is cooled in a plurality of multistage (for example, three) cycles or steps by indirect heat exchange with a plurality of refrigerants, preferably three. The overall cooling efficiency for a given cycle improves as the number of stages increases but this increase in efficiency is accompanied by corresponding increases in net capital cost and process complexity. The natural gas feed stream is preferably passed through an effective number of refrigeration stages, nominally two, preferably two to four, and more preferably three stages, in the first refrigeration cycle, also referred herein as the first cooling cycle, utilizing a first refrigerant having relatively high boiling refrigerant. Such refrigerant is preferably comprised in major portion of propane, propylene or mixtures thereof, more preferably the refrigerant comprises at least about 75 mole percent propane, even more preferably at least 90 mole percent propane, and most preferably the refrigerant consists essentially of propane.

[0023] Thereafter, the processed natural gas feed stream flows through an effective number of stages, nominally two, preferably two to four, and more preferably two or three, in a second refrigeration cycle, also referred herein as the second cooling cycle, in heat exchange with a second refrigerant having a lower boiling point. Such refrigerant is preferably comprised in major portion of ethane, ethylene or mixtures thereof, more preferably the refrigerant comprises at least about 75 mole percent ethylene, even more preferably at least 90 mole percent ethylene, and most preferably the refrigerant consists essentially of ethylene. As previously noted, the processed natural gas feed stream is combined with one or more recycle streams at various locations in the second cycle thereby producing a liquefaction stream. In the last stage of the second cooling cycle, the liquefaction stream is 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 pretreated natural gas feed stream of the first stage of the first cycle.

[0024] Thereafter, the processed natural gas feed stream flows through an effective number of stages, nominally two, preferably two to four, and more preferably three, in a final refrigeration cycle in indirect heat exchange with a final refrigerant. The final refrigerant consists essentially of methane. In a particularly preferred embodiment, the predominately methane refrigerant comprises less than 10 mole percent nitrogen, most preferably less than 5 mole percent nitrogen. Each cooling stage comprises a separate cooling zone.

[0025] Generally, the natural gas feed stream will contain such quantities of C_2+ components so as to result in the formation of a C_2+ rich liquid in one or more of the cooling cycles. This liquid is removed via gas-liquid separation means, preferably one or more conventional gas-liquid separators. Generally, the sequential cooling of the natural gas stream in each stage is controlled so as to remove as much as possible of the C_2 and higher molecular weight hydrocarbons from the gas to produce a gas stream predominating in methane and a liquid stream containing significant amounts of ethane and heavier components. An effective number of gas/liquid separation means are located at strategic locations downstream of the cooling zones for the removal of liquids streams rich in C_2+ components. The exact locations and number of gas/liquid separation means, preferably conventional gas/liquid separators, will be dependant on a number of operating parameters, such as the C_2+ composition of the natural gas feed stream, the desired BTU content of the LNG product, the value of the C_2+ components for other applications and other factors routinely considered by those skilled in the art of LNG plant and gas plant operations. The C_2+ hydrocarbon stream or streams may be demethanized via a single stage flash or a fractionation column. In the latter case, the resulting natural gas stream can be directly returned at pressure to the liquefaction process. In the former case, this natural gas stream can be repressurized and recycled or can be used as fuel gas. The C_2+ hydrocarbon stream or streams or the demethanized C_2+ hydrocarbon stream may be used as fuel or may be further processed such as by fractionation in one or more fractionation zones to produce individual streams rich in specific chemical constituents (e.g., C_2, C_3, C_4 and C_5+).

[0026] The liquefaction process may use one of several types of cooling which include but is not limited to (a) indirect heat exchange, (b) vaporization, and (c) expansion or pressure reduction. Indirect heat exchange, as used herein, 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. Specific examples of indirect heat exchange means include heat exchange in a shell-and-tube heat exchanger, a core-in-kettle heat exchanger, and a brazed aluminum plate-fin heat exchanger. The physical state of the refrigerant and substance to be cooled can vary depending on the demands of the system and the type of heat exchanger chosen. Thus, a shell-and-tube heat exchanger will typically be utilized where the refrigerating agent is in a liquid state and the substance to be cooled is in a liquid or gaseous state or when one of the substances undergoes a phase change and process conditions do not favor the use of a core-in-kettle heat exchanger. As an example, aluminum and aluminum alloys are preferred materials of construction for the core but such materials may not be suitable for use at the designated process conditions. A plate-fin heat exchanger will typically be utilized where the refrigerant is in a gaseous state and the substance to be cooled is in a liquid or gaseous state. Finally, the core-in-kettle heat exchanger will typically be utilized where the substance to be cooled is liquid or gas and the cool stream undergoes a phase change from a liquid state to a gaseous state during the heat exchange.

[0027] Vaporization cooling refers to the cooling of a substance by the evaporation or vaporization of a portion of the substance with the system maintained at a constant pressure. Thus, during the vaporization, the portion of the substance which evaporates absorbs heat from the portion of the substance which remains in a liquid state and hence, cools the liquid portion.

[0028] Finally, expansion or pressure reduction cooling refers to cooling which occurs when the pressure of a gas, liquid or a two-phase system is decreased by passing through a pressure reduction means. In one embodiment, this expansion means is a Joule-Thomson expansion valve. In another embodiment, the expansion means is either a hydraulic or gas expander. Because expanders recover work energy from the expansion process, lower process stream temperatures are possible upon expansion.

[0029] Referring to FIG. 1, during normal operation of the LNG facility, gaseous propane is compressed in a multistage (preferably three-stage) compressor 18 driven by 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. The compressed propane is discharged from propane compressor 18 and then passed through conduit 300 to propane condenser 20, wherein the stream is cooled and liquefied via indirect heat exchanger with an external fluid (e.g., air or water). A representative pressure and temperature of the liquefied propane refrigerant prior to flashing is about 100°F and about 190 psia. The stream in conduit 302 exits propane condenser 20, whereupon the stream is passed to a propane waste heat chiller 15, wherein the stream is subcooled via indirect heat exchanger with an external fluid (e.g., lithium bromide or ammonia). The additional chilling step driven in part by waste heat from the liquefaction step allows condensing of the propane refrigerant at a lower temperature and pressure. The impact of condensing at a lower pressure is a reduction in propane compression horsepower required for a given amount of refrigeration and to improve the overall thermal efficiency of the process. Upon exiting propane waste heat chiller 15 via conduit 301, the stream enters propane accumulator 13. A predominately liquid propane refrigerant stream exits propane accumulator 13 via conduit 305 and is delivered 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 product then flows through conduit 304 into a high-stage propane chiller 2 wherein gaseous methane refrigerant introduced via conduit 152, natural gas feed introduced via conduit 100, and gaseous ethylene refrigerant introduced via conduit 202 are respectively cooled via indirect heat exchange means 4, 6, and 8, thereby producing cooled gas streams respectively produced via conduits 154, 102, and 204. The gas in conduit 154 is fed to a main methane economizer 74, which will be discussed in greater detail in a subsequent section, and wherein the stream is cooled via indirect heat exchange means

97. A portion of the stream cooled in heat exchange means 97 is removed from methane economizer 74 via conduit 155 and subsequently used, after further cooling, as a reflux stream in a heavies removal column 60. The portion of the cooled stream from heat exchange means 97 that is not removed for use as a reflux stream is further cooled in indirect heat exchange means 98. The resulting cooled methane recycle stream produced via conduit 158 is then combined in conduit 120 with the heavies depleted (i.e., light-hydrocarbon rich) vapor stream from heavies removal column 60 and fed to an ethylene condenser 68.

[0030] The propane gas from chiller 2 is returned to compressor 18 through conduit 306. This gas is fed to the high-stage inlet port of compressor 18. The remaining liquid propane is passed through conduit 308, the pressure further reduced by passage through a pressure reduction means, illustrated as expansion valve 14, whereupon an additional portion of the liquefied propane is flashed. The resulting two-phase stream is then fed to an intermediate stage propane chiller 22 through conduit 310, thereby providing a coolant for chiller 22. The cooled feed gas stream from chiller 2 flows via conduit 102 to a knock-out vessel 10 wherein gas and liquid phases are separated. The liquid phase, which is rich in C_3 + components, is removed via conduit 103. The gaseous phase is removed via conduit 104 and then split into two separate streams which are conveyed via conduits 106 and 108. The stream in conduit 106 is fed to propane chiller 22. The stream in conduit 108 is employed as a stripping gas in refluxed heavies removal column 60 to aid in the removal of heavy hydrocarbon components from the processed natural gas stream. Ethylene refrigerant from chiller 2 is introduced to chiller 22 via conduit 204. In chiller 22, the feed gas stream, also referred to herein as a methane-rich stream, and the ethylene refrigerant streams are respectively cooled via indirect heat transfer means 24 and 26, thereby producing cooled methane-rich and ethylene refrigerant streams via conduits 110 and 206. The evaporated portion of the propane refrigerant is separated and passed through conduit 311 to the intermediate-stage inlet of compressor 18. Liquid propane refrigerant from chiller 22 is removed via conduit 314, flashed across a pressure reduction means, illustrated as expansion valve 16, and then fed to a low-stage propane chiller/condenser 28 via conduit 316.

[0031] As illustrated in FIG. 1, the methane-rich stream flows from intermediate-stage propane chiller 22 to the low-stage propane chiller/condenser 28 via conduit 110. In chiller 28, the stream is cooled via indirect heat exchange means 30. In a like manner, the ethylene refrigerant stream flows from the intermediate-stage propane chiller 22 to low-stage propane chiller/condenser 28 via conduit 206. In the latter, the ethylene refrigerant is totally condensed or condensed in nearly its entirety via indirect heat exchange means 32. The vaporized propane is removed from low-stage propane chiller/condenser 28 and returned to the low-stage inlet of compressor 18 via conduit 320.

[0032] As illustrated in FIG. 1, the methane-rich stream exiting low-stage propane chiller 28 is introduced to high-stage ethylene chiller 42 via conduit 112. Ethylene refrigerant exits low-stage propane chiller 28 via conduit 208 and is preferably fed to a separation vessel 37 wherein light components are removed via conduit 209 and condensed ethylene is removed via conduit 210. The ethylene refrigerant at this location in the process is generally at a temperature of about -24°F and a pressure of about 285 psia. The ethylene refrigerant then flows to an ethylene economizer 34 wherein it is cooled via indirect heat exchange means 38, removed via conduit 211, and passed to a pressure reduction means, illustrated as an expansion valve 40, whereupon the refrigerant is flashed to a preselected temperature and pressure and fed to high-stage ethylene chiller 42 via conduit 212. Vapor is removed from chiller 42 via conduit 214 and routed to ethylene economizer 34 wherein the vapor functions as a coolant via indirect heat exchange means 46. The ethylene vapor is then removed from ethylene economizer 34 via conduit 216 and feed to the high-stage inlet of ethylene compressor 48. The ethylene refrigerant which is not vaporized in high-stage ethylene chiller 42 is removed via conduit 218 and returned to ethylene economizer 34 for further cooling via indirect heat exchange means 50, removed from ethylene economizer via conduit 220, and flashed in a pressure reduction means, illustrated as expansion valve 52, whereupon the resulting two-phase product is introduced into a low-stage ethylene chiller 54 via conduit 222.

[0033] After cooling in indirect heat exchange means 44, the methane-rich stream is removed from high-stage ethylene chiller 42 via conduit 116. The stream in conduit 116 is then carried to a feed inlet of heavies removal column 60 wherein heavy hydrocarbon components are removed from the methane-rich stream. A heavies-rich liquid stream containing a significant concentration of C_4 + hydrocarbons, such as benzene, toluene, xylene, cyclohexane, other aromatics, and/or heavier hydrocarbon components, is removed from the bottom of heavies removal column 60 via conduit 114. The heavies-rich stream in conduit 114 is subsequently separated into liquid and vapor portions or preferably is flashed or fractionated in vessel 67. In either case, a second heavies-rich liquid stream is produced via conduit 123 and a second methane-rich vapor stream is produced via conduit 121. In the preferred embodiment, which is illustrated in FIG. 1, the stream in conduit 121 is subsequently combined with a second stream delivered via conduit 128, and the combined stream fed to the high-stage inlet port of the methane compressor 83. High-stage ethylene chiller 42 also includes an indirect heat exchanger means 43 which receives and cools the stream withdrawn from methane economizer 74 via conduit 155, as discussed above. The resulting cooled stream from indirect heat exchanger means 43 is conducted via conduit 157 to low-stage ethylene chiller 54. In low-stage ethylene chiller 54 the stream from conduit 157 is cooled via indirect heat exchange means 56. After cooling in indirect heat exchange means 56, the stream exits low-stage ethylene chiller 54 and is carried via conduit 159 to a reflux inlet of heavies removal column 60 where it is employed as a reflux stream.

[0034] As previously noted, the gas in conduit 154 is fed to main methane economizer 74 wherein the stream is cooled via indirect heat exchange means 97. A portion of the cooled stream from heat exchange means 97 is then further cooled in indirect heat exchange means 98. The resulting cooled stream is removed from methane economizer 74 via conduit 158 and is thereafter combined with the heavies-depleted vapor stream exiting the top of heavies removal column 60 and fed to a low-stage ethylene condenser 68. In low-stage ethylene condenser 68, this stream is cooled and condensed via indirect heat exchange means 70 with the liquid effluent from low-stage ethylene chiller 54 which is routed to low-stage ethylene condenser 68 via conduit 226. The condensed methane-rich product from low-stage condenser 68 is produced via conduit 122. The vapor from low-stage ethylene chiller 54, withdrawn via conduit 224, and low-stage ethylene condenser 68, withdrawn via conduit 228, are combined and routed, via conduit 230, to ethylene economizer 34 wherein the vapors function as a coolant via indirect heat exchange means 58. The stream is then routed via conduit 232 from ethylene economizer 34 to the low-stage inlet of ethylene compressor 48.

[0035] As noted in FIG. 1, the compressor effluent from vapor introduced via the low-stage side of ethylene compressor 48 is removed via conduit 234, cooled via inter-stage cooler 71, and returned to compressor 48 via conduit 236 for injection with the high-stage stream present in conduit 216. Preferably, the two-stages are a single module although they may each be a separate module and the modules mechanically coupled to a common driver. The compressed ethylene product from compressor 48 is routed to a downstream cooler 72 via conduit 200. The product from cooler 72 flows via conduit 201 and is introduced to an ethylene waste heat chiller 73 to provide additional cooling to the refrigerant via indirect heat exchange with an external fluid (e.g., lithium bromide or ammonia). Additional sensible heat is removed via the waste heat refrigeration system due to the lower temperatures available, which has the effect of reducing the duty required to be removed in the main propane chillers, which can reduce power requirements (or increase capacity) in the propane system. Upon exiting the ethylene waste heat chiller 73 via conduit 202, the stream is delivered to high-stage propane chiller 2.

[0036] The pressurized LNG-bearing stream, preferably a liquid stream in its entirety, in conduit 122 is preferably at a temperature in the range of from about -200 to about -50°F, more preferably in the range of from about -175 to about -100°F, most preferably in the range of from -150 to -125°F. The pressure of the stream in conduit 122 is preferably in the range of from about 500 to about 700 psia, most preferably in the range of from 550 to 725 psia. The stream in conduit 122 is directed to main methane economizer 74 wherein the stream is further cooled by indirect heat exchange means/heat exchanger pass 76 as hereinafter explained. It is preferred for main methane economizer 74 to include a plurality of heat exchanger passes which provide for the indirect exchange of heat between various predominantly methane streams in the economizer 74. Preferably, methane economizer 74 comprises one or more plate-fin heat exchangers. The cooled stream from heat exchanger pass 76 exits methane economizer 74 via conduit 124. It is preferred for the temperature of the stream in conduit 124 to be at least about 10°F less than the temperature of the stream in conduit 122, more preferably at least about 25.degree. F. less than the temperature of the stream in conduit 122. Most preferably, the temperature of the stream in conduit 124 is in the range of from about -200 to about -160°F. The pressure of the stream in conduit 124 is then reduced by a pressure reduction means, illustrated as expansion valve 78, which evaporates or flashes a portion of the gas stream thereby generating a two-phase stream. The two-phase stream from expansion valve 78 is then passed to high-stage methane flash drum 80 where it is separated into a flash gas stream discharged through conduit 126 and a liquid phase stream (i.e., pressurized LNG-bearing stream) discharged through conduit 130. The flash gas stream is then transferred to main methane economizer 74 via conduit 126 wherein the stream functions as a coolant in heat exchanger pass 82. The predominantly methane stream is warmed in heat exchanger pass 82, at least in part, by indirect heat exchange with the predominantly methane stream in heat exchanger pass 76. The warmed stream exits heat exchanger pass 82 and methane economizer 74 via conduit 128.

[0037] The liquid-phase stream exiting high-stage flash drum 80 via conduit 130 is passed through a second methane economizer 87 wherein the liquid is further cooled by downstream flash vapors via indirect heat exchange means 88. The cooled liquid exits second methane economizer 87 via conduit 132 and is expanded or flashed via pressure reduction means, illustrated as expansion valve 91, to further reduce the pressure and, at the same time, vaporize a second portion thereof. This two-phase stream is then passed to an intermediate-stage methane flash drum 92 where the stream is separated into a gas phase passing through conduit 136 and a liquid phase passing through conduit 134. The gas phase flows through conduit 136 to second methane economizer 87 wherein the vapor cools the liquid introduced to economizer 87 via conduit 130 via indirect heat exchanger means 89. Conduit 138 serves as a flow conduit between indirect heat exchange means 89 in second methane economizer 87 and heat exchanger pass 95 in main methane economizer 74. The warmed vapor stream from heat exchanger pass 95 exits main methane economizer 74 via conduit 140, is combined with the first nitrogen-reduced stream in conduit 406, and the combined stream is conducted to the intermediate-stage inlet of methane compressor 83.

[0038] The liquid phase exiting intermediate-stage flash drum 92 via conduit 134 is further reduced in pressure by passage through a pressure reduction means, illustrated as an expansion valve 93. Again, a third portion of the liquefied gas is evaporated or flashed. The two-phase stream from expansion valve 93 are passed to a final or low-stage flash drum 94. In flash drum 94, a vapor phase is separated and passed through conduit 144 to second methane economizer 87 wherein the vapor functions as a coolant via indirect heat exchange means 90, exits second methane economizer 87 via conduit 146, which is connected to the first methane economizer 74 wherein the vapor functions as a coolant via heat exchanger pass 96. The warmed vapor stream from heat exchanger pass 96 exits main methane economizer 74 via conduit 148, is combined with the second nitrogen-reduced stream in conduit 408, and the combined stream is conducted to the low-stage inlet of compressor 83.

[0039] The liquefied natural gas product from low-stage flash drum 94, which is at approximately atmospheric pressure, is passed through conduit 142 to a LNG storage tank 99. In accordance with conventional practice, the liquefied natural gas in storage tank 99 can be transported to a desired location (typically via an ocean-going LNG tanker). The LNG can then be vaporized at an onshore LNG terminal for transport in the gaseous state via conventional natural gas pipelines.

[0040] As shown in FIG. 1, the high, intermediate, and low stages of compressor 83 are preferably combined as single unit. However, each stage may exist as a separate unit where the units are mechanically coupled together to be driven by a single driver. The compressed gas from the low-stage section passes through an inter-stage cooler 85 and is combined with the intermediate pressure gas in conduit 140 prior to the second-stage of compression. The compressed gas from the intermediate stage of compressor 83 is passed through an inter-stage cooler 84 and is combined with the high pressure gas provided via conduits 121 and 128 prior to the third-stage of compression. The compressed gas (i.e., compressed open methane cycle gas stream) is discharged from high stage methane compressor through conduit 150 and is cooled in cooler 86. The product from cooler 86 flows via conduit 151 and is introduced to methane waste heat chiller 143 to provide additional cooling to the refrigerant via indirect heat exchange with an external fluid (e.g., lithium bromide or ammonia). Additional sensible heat is removed via the waste heat refrigeration system due to the lower temperatures available. This has the effect of reducing the duty required to be removed in the main propane chillers, which can reduce power requirements (or increase capacity) in the propane system. Upon exiting the ethylene waste heat chiller 143 the stream is routed to the high pressure propane chiller 2 via conduit 152 as previously discussed. The stream is cooled in chiller 2 via indirect heat exchange means 4 and flows to main methane economizer 74 via conduit 154. The compressed open methane cycle gas stream from chiller 2 which enters the main methane economizer 74 undergoes cooling in its entirety via flow through indirect heat exchange means 98. This cooled stream is then removed via conduit 158 and combined with the processed natural gas feed stream upstream of the first stage of ethylene cooling.

[0041] The preferred embodiment of the present invention has been disclosed and illustrated. However, the invention is intended to be as broad as defined in the claims below. Those skilled in the art may be able to study the preferred embodiments and identify other ways to practice the invention that are not exactly as described in the present invention. It is the intent of the inventors that variations and equivalents of the invention are within the scope of the claims below and the description, abstract and drawings not to be used to limit the scope of the invention.

CLAIMS

1. A process for liquefying natural gas, the process comprising the steps of:
   a. compressing a first refrigerant in a first compressor driven by a first gas turbine;
   b. recovering waste heat from the first gas turbine;
   c. cooling the natural gas with the first refrigerant in a first chiller;
   d. using at least a portion of the waste heat recovered from the first gas turbine to further cool the natural gas with the first refrigerant, wherein the natural gas and the first refrigerant are further cooled by utilizing either a lithium bromide or an ammonia absorption chiller;
   e. compressing a second refrigerant in a second compressor driven by a second gas turbine;
   f. recovering waste hear from the second turbine;
   g. cooling the natural gas with the second refrigerant in a second chiller; and
   h. using at least a portion of the waste heat recovered from the second gas turbine to further cool the natural gas with the second refrigerant, wherein the natural gas and the second refrigerant are further cooled by utilizing either a lithium bromide or an ammonia adsorption chiller.
2. The process according claim 1, wherein the first refrigerant comprising in major portion a hydrocarbon selected from a group consisting of propane, propylene, ethane, ethylene, or combinations thereof.
3. The process according to claim 1, wherein the first refrigerant comprising in major portion propane or propylene.
4. The process according to claim 1, wherein the first refrigerant comprises in major portion of ethane or ethylene.
5. The process according to claim 1, wherein the second refrigerant comprising at least about 75 mole percent methane.
6. A process for liquefying natural gas, the process comprising the steps of:
   a. compressing a first refrigerant in a first compressor driven by a first gas turbine;
   b. recovering waste heat from the first gas turbine;

c. using at least a portion of the waste heat recovered from the first gas turbine to further cool the natural gas with the first refrigerant;
d. compressing a second refrigerant in a second compressor driven by a second gas turbine;
e. recovering waste heat from the second turbine; and
f. using at least a portion of the waste heat recovered from the second gas turbine to further cool the natural gas with the second refrigerant.

7. The process according to claim 6, wherein cooling step (c) utilizes either a lithium bromide or an ammonia absorption chiller.
8. The process according to claim 6, wherein cooling step (f) utilizes either a lithium bromide or an ammonia absorption chiller.
9. The process according to claim 6, wherein prior to step (c) cooling the natural gas with the first refrigerant in a first chiller.
10. The process according to claim 6, wherein prior to step (d) cooling the natural gas with the second refrigerant in a second chiller.
11. The process according claim 6, wherein the first refrigerant comprising in major portion a hydrocarbon selected from a group consisting of propane, propylene, ethane, ethylene, or combinations thereof.
12. The process according to claim 6, wherein the first refrigerant comprising in major portion propane or propylene.
13. The process according to claim 6, wherein the first refrigerant comprising in major portion ethane or ethylene.
14. The process according to claim 6, wherein the second refrigerant comprising at least about 75 mole percent methane.
15. A process for liquefying natural gas, the process comprising the steps of:
    a. compressing a first refrigerant in a first compressor driven by a first gas turbine;
    b. recovering waste heat from the first gas turbine;
    c. using at least a portion of the waste heat recovered from the first gas turbine to further cool the natural gas;
    d. compressing a second refrigerant in a second compressor driven by a second gas turbine;

e. recovering waste heat from the second turbine; and
f. using at least a portion of the waste heat recovered from the second gas turbine to further cool the natural gas.

16. The process according to claim 15, wherein cooling step (c) utilizes either a lithium bromide or an ammonia absorption chiller.
17. The process according to claim 15, wherein cooling step (f) utilizes either a lithium bromide or an ammonia absorption chiller.
18. The process according to claim 15, wherein prior to step (c) cooling the natural gas with the first refrigerant in a first chiller.
19. The process according to claim 15, wherein prior to step (d) cooling the natural gas with the second refrigerant in a second chiller.
20. The process according claim 15, wherein the first refrigerant comprising in major portion a hydrocarbon selected from a group consisting of propane, propylene, ethane, ethylene, or combinations thereof.
21. The process according to claim 15, wherein the first refrigerant comprising in major portion propane or propylene.
22. The process according to claim 15, wherein the first refrigerant comprising in major portion ethane or ethylene.
23. The process according to claim 15, wherein the second refrigerant comprising at least about 75 mole percent methane.
24. An apparatus for liquefying natural gas, the apparatus employing multiple refrigerants in multiple refrigeration cycle for cooling the natural gas in multiple stage, the apparatus comprising:
    a. a first compressor for compressing a first refrigerant of a first refrigeration cycle;
    b. a first gas turbine for driving the first compressor, wherein waste heat is recovered from the first gas turbine, wherein at least a portion of the waste heat further cools the natural gas and the first refrigerant;
    c. a second compressor for compressing a second refrigerant of a second refrigeration cycle; and

d. a second gas turbine for driving the second compressor, wherein waste heat is recovered from the second gas turbine, wherein at least a portion of the waste heat further cools the natural gas and the second refrigerant.

25. The apparatus according claim 24, wherein the first refrigerant comprising in major portion a hydrocarbon selected from a group consisting of propane, propylene, ethane, ethylene, or combinations thereof.
26. The apparatus according to claim 24, wherein the first refrigerant comprising in major portion propane or propylene.
27. The apparatus according to claim 24, wherein the first refrigerant comprising in major portion ethane or ethylene.
28. The process according to claim 24, wherein the second refrigerant comprising at least about 75 mole percent methane.

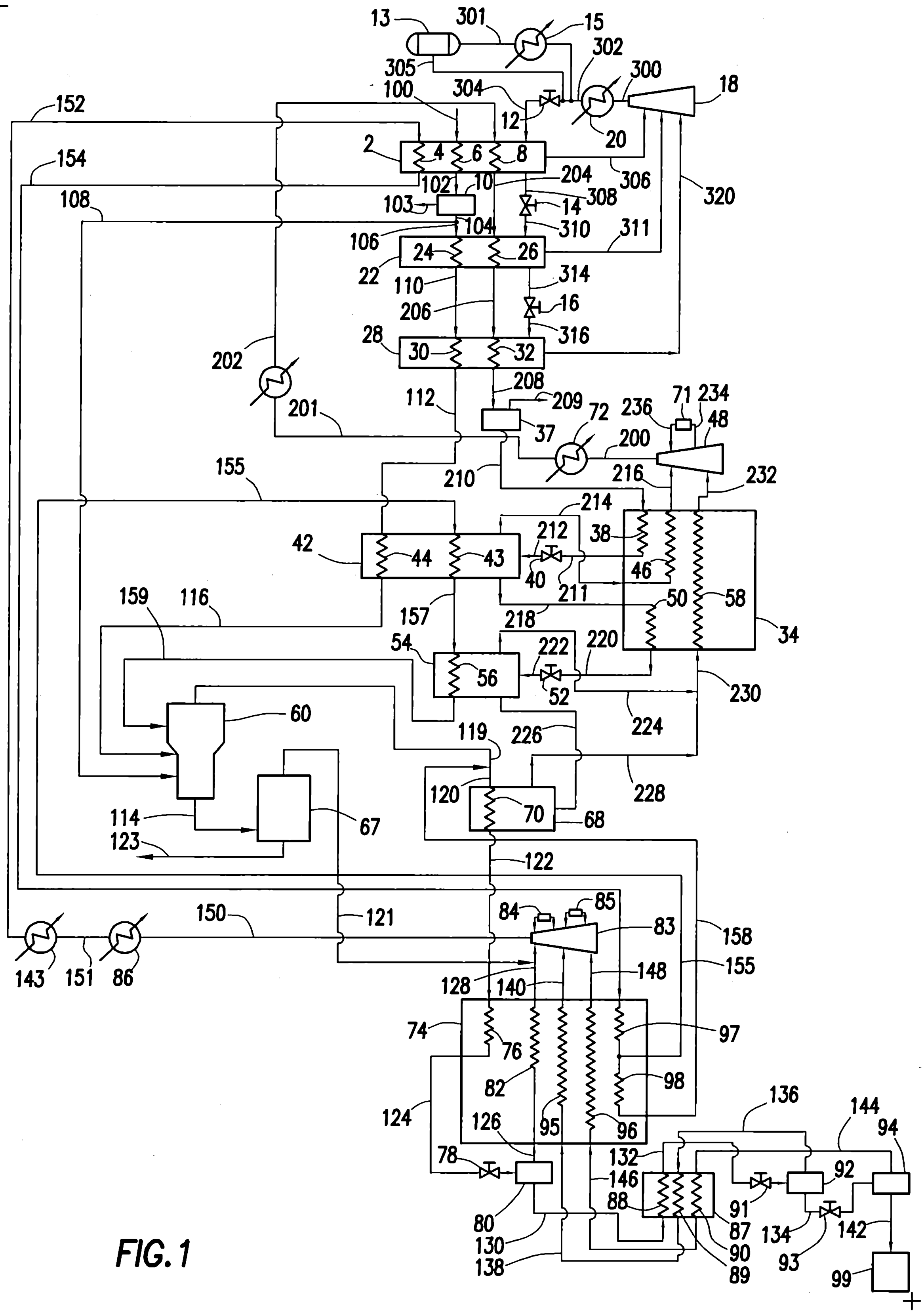
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FIG. 1