

(51) Int Cl.: *F25J 1/02* ^(2006.01) *F25J 3/02* ^(2006.01)

(22) Date of filing: **16.07.2007**

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EP 1 881 283 A2

Description

BACKGROUND OF THE INVENTION

[0001] Raw natural gas comprises primarily methane and also contains numerous minor constituents which may include water, hydrogen sulfide, carbon dioxide, mercury, nitrogen, and light hydrocarbons typically having two to six carbon atoms. Some of these constituents, such as water, hydrogen sulfide, carbon dioxide, and mercury, are contaminants which are harmful to downstream steps such as natural gas processing or the production of liquefied natural gas (LNG), and these contaminants must be removed upstream of these processing steps. The hydrocarbons heavier than methane typically are condensed and recovered as natural gas liquids (NGL) and fractionated to yield valuable hydrocarbon products.

[0002] The first step in the NGL recovery process utilizes a distillation column or scrub column to separate the hydrocarbons heavier than methane from the pretreated natural gas feed to yield purified methane for liquefaction and NGL for separation and recovery. This process utilizes cooling, partial condensation, and fractionation steps that require significant amounts of refrigeration. This refrigeration may be provided by work expansion of pressurized natural gas feed and vaporization of the resulting condensed hydrocarbons. Additional refrigeration typically is provided by external closed-loop refrigeration using a refrigerant such as propane and/or a mixed refrigerant to liquefy the methane in the main heat exchanger. Reflux for the NGL scrub column may utilize a portion of the partially-liquefied natural gas from the main heat exchanger.

[0003] It is desirable to recover NGL from pressurized natural gas without reducing the natural gas feed pressure significantly. This allows the natural gas product (for example, pipeline gas or LNG) to be provided at or slightly below the feed pressure so that feed and/or product recompression is not required. It is also desirable to eliminate the need for scrub column overhead compression and to simplify the main heat exchanger design when a portion of the liquefied natural gas is withdrawn from the main heat exchanger for use as scrub column reflux. These needs are addressed by the embodiments of the present invention described below and defined by the claims that follow.

BRIEF SUMMARY OF THE INVENTION

[0004] An embodiment of the invention relates to a process for the liquefaction of natural gas and the recovery of components heavier than methane from the natural gas. The process comprises

(a) cooling a natural gas feed to provide a cooled natural gas feed and introducing the cooled natural gas feed into a first distillation column;

(b) withdrawing from the first distillation column an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;

(c) cooling and condensing at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream;

(d) separating the bottoms stream in one or more additional distillation columns to provide one or more product streams selected from a residual vapor stream comprising methane, a liquid stream enriched in ethane, a liquid stream enriched in propane, a liquid stream enriched in butane, and a liquid stream enriched in pentane;

(e) withdrawing as recovered hydrocarbons all or a portion of any of the one or more product streams; and

(f) introducing one or more reflux streams into the first distillation column. The one or more reflux streams comprise either

(f1) a liquefied methane-containing reflux stream and a stream of unrecovered liquid hydrocarbons that is pumped to a pressure in the first distillation column or

(f2) a combined stream comprising the liquefied methane-containing reflux stream and the stream of unrecovered liquid hydrocarbons that is pumped to the pressure in the first distillation column.

[0005] The liquefied methane-containing reflux stream may be provided by a method selected from

(1) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and withdrawing a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream,

(2) cooling and totally condensing a portion of the first overhead vapor stream to provide the liquefied methane-containing reflux stream, and

(3) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and warming a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream.

[0006] The stream of unrecovered liquid hydrocarbons may comprise any of the following: (1) a portion of the liquid stream enriched in ethane; (2) a portion of the liquid

stream enriched in propane; (3) a portion of the liquid stream enriched in butane; (4) a portion of the liquid stream enriched in pentane; and (5) all or a portion of the residual vapor stream dissolved in a portion of the liquid stream enriched in propane and/or a portion of the liquid stream enriched in butane and/or a portion of the liquid stream enriched in pentane.

[0007] The liquefied methane-containing reflux stream may be introduced into the top of the first distillation column. The stream of unrecovered liquid hydrocarbons may be introduced into the top of the first distillation column. Alternatively, the combined stream comprising the liquefied methane-containing reflux stream and the stream of unrecovered liquid hydrocarbons may be introduced into the top of the first distillation column. In another alternative, the stream of unrecovered liquid hydrocarbons may be introduced into the first distillation column at a location below the top of the column and above a location at which the cooled natural gas feed is introduced into the column.

[0008] The cooling and condensing of at least a portion of the overhead vapor stream may be effected in a main heat exchanger by indirect heat exchange with a first vaporizing refrigerant provided by reducing the pressure of a first cooled multicomponent liquid refrigerant. A portion of the overhead vapor stream may be condensed in a heat exchanger separate from the main heat exchanger by indirect heat exchange with a stream of vaporizing refrigerant provided by withdrawing and reducing the pressure of a portion of the first cooled multicomponent liquid refrigerant.

[0009] The first cooled multicomponent liquid refrigerant may be provided by cooling a saturated multicomponent liquid refrigerant in the main heat exchanger and wherein the warming of the portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream is effected in a heat exchanger separate from the main heat exchanger by indirect heat exchange with a portion of the saturated multicomponent liquid refrigerant. At least a portion of the condensed methane-enriched stream may be subcooled to provide a pressurized liquefied natural gas product, wherein the subcooling is effected in the main heat exchanger by indirect heat exchange with a second vaporizing refrigerant provided by reducing the pressure of a second cooled multicomponent liquid refrigerant. The cooling of the natural gas feed to provide the cooled natural gas feed may be effected by indirect heat exchange with the overhead vapor stream enriched in methane.

[0010] The stream of unrecovered liquid hydrocarbons may contain greater than 50 mole % of hydrocarbons having three or more carbon atoms. Alternatively, the stream of unrecovered liquid hydrocarbons may contain greater than 50 mole % of pentane. In another alternative, the stream of unrecovered liquid hydrocarbons may comprise a portion of the liquid stream enriched in propane and a portion of the liquid stream enriched in butane. In this alternative, the stream of unrecovered liquid hydro-

carbons may comprise a portion of the liquid stream enriched in ethane. The stream of unrecovered liquid hydrocarbons may comprise a portion of the residual vapor stream comprising methane dissolved in a liquid comprising hydrocarbons heavier than methane. The molar flow rate of the unrecovered liquid hydrocarbons may be less than 25% of the molar flow rate of the liquefied methane reflux stream.

[0011] Another embodiment of the invention includes an apparatus for the liquefaction of natural gas and the recovery of components heavier than methane from the natural gas, wherein the apparatus comprises

(a) a cooling system adapted to cool a natural gas feed to provide a cooled natural gas feed;

(b) a first distillation column adapted to separate the cooled natural gas feed into an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;

(c) a main heat exchanger adapted to cool and condense at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream;

(d) one or more additional distillation columns adapted to separate the bottoms stream into one or more product streams selected from a residual vapor stream comprising methane, a liquid stream enriched in ethane, a liquid stream enriched in propane, a liquid stream enriched in butane, and a liquid stream enriched in pentane;

(e) piping adapted to withdraw all or a portion of any of the one or more product streams as recovered hydrocarbons;

(f) piping adapted to introduce one or more reflux streams into the first distillation column, wherein the one or more reflux streams comprise either (f1) a liquefied methane-containing reflux stream and a stream of unrecovered liquid hydrocarbons that is pumped to a pressure in the first distillation column or (f2) a combined stream comprising the liquefied methane-containing reflux stream and the stream of unrecovered liquid hydrocarbons that is pumped to the pressure in the first distillation column; and

(g) piping and pump or pumps adapted to transfer unrecovered liquid hydrocarbons from the one or more additional distillation columns to the piping adapted to introduce one or more reflux streams into the first distillation column.

[0012] The apparatus also may comprise a heat exchanger separate from the main heat exchanger that is adapted to condense a portion of the overhead vapor stream from the first distillation column by indirect heat

exchange with a stream of vaporizing refrigerant. The main heat exchanger may be a wound coil heat exchanger and may comprise a first bundle adapted to cool and condense at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream and a second bundle adapted to further cool the condensed methane-enriched stream to provide a subcooled liquid product.

[0013] A further embodiment of the invention relates to a process for the liquefaction of natural gas comprising

(a) cooling a natural gas feed to provide a cooled natural gas feed and introducing the cooled natural gas feed into a first distillation column;

(b) withdrawing from the first distillation column an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;

(c) cooling and condensing at least a portion of the overhead vapor stream in a main heat exchanger to provide a condensed methane-enriched stream; and

(d) introducing a liquefied methane-containing reflux stream into the first distillation column, wherein the liquefied methane-containing reflux stream is provided by a method selected from

(1) dividing the overhead vapor stream into a first vapor portion and a second vapor portion, and cooling and totally condensing the first vapor portion to provide the liquefied methane-containing reflux stream, and

(2) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream, dividing the condensed methane-enriched stream into a first portion and a second portion, warming the first portion to provide a warmed first portion, and utilizing the warmed first portion to provide the liquefied methane-containing reflux stream.

[0014] The first vapor portion of the overhead vapor stream may be condensed in a heat exchanger separate from the main heat exchanger by indirect heat exchange with a stream of vaporizing refrigerant. The warming of the first portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream may be effected in a heat exchanger separate from the main heat exchanger. The subcooling of at least a portion of the condensed methane-enriched stream to provide a pressurized liquefied natural gas product may be effected in the main heat exchanger by indirect heat exchange with a stream of vaporizing refrigerant.

[0015] A related further embodiment includes an apparatus for the liquefaction of natural gas comprising

(a) a cooling system adapted to cool a natural gas feed to provide a cooled natural gas feed;

(b) a first distillation column adapted to separate the cooled natural gas feed into an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;

(c) a main heat exchanger adapted to cool and condense at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream; and

(d) piping adapted to introduce a liquefied methane-containing reflux stream into the first distillation column, wherein the liquefied methane-containing reflux stream provided by a method selected from

(1) cooling and totally condensing a portion of the overhead vapor stream to provide the liquefied methane-containing reflux stream, and

(2) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and warming a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream.

[0016] The apparatus may include a heat exchanger separate from the main heat exchanger that is adapted to condense the portion of the overhead vapor stream from the first distillation column by indirect heat exchange with a stream of vaporizing refrigerant. The apparatus may include a heat exchanger separate from the main heat exchanger that is adapted to warm the portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream.

[0017] The main heat exchanger may be a wound coil heat exchanger. The main heat exchanger may comprise a first bundle adapted to cool and condense at least a portion of the overhead vapor stream to provide the condensed methane-enriched stream and a second bundle adapted to further cool at least a portion of the condensed methane-enriched stream to provide a subcooled liquid product.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

[0018]

Fig. 1 is a schematic process flow diagram of an embodiment of the invention.

Fig. 2 is a schematic process flow diagram of another embodiment of the invention.

Fig. 3 is a schematic process flow diagram of an alternative embodiment of the invention.

Fig. 4 is a schematic process flow diagram of a process alternative that may be utilized with any embodiment of the invention.

Fig. 5 is a schematic process flow diagram an exemplary NGL fractionation system that may be utilized with any embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0019] The embodiments of the invention provide improved integrated processes for NGL recovery in the production of LNG that simplify the equipment configuration by eliminating the need for feed expansion and scrub column overhead compression. In addition, when the scrub column utilizes reflux comprising scrub column overhead that is condensed in a wound coil main heat exchanger, there is no need for splitting the warm bundle of the heat exchanger to partially condense the column overhead, and a phase separator to recover the liquid required for reflux is not required. In addition, there is no need for compression and condensation of deethanizer overhead vapor to provide scrub column reflux.

[0020] Reflux for the scrub column in the embodiments described below is provided by various combinations of condensed scrub column overhead vapor and unrecovered liquid hydrocarbons from the NGL recovery system. In the present disclosure, the terms "recovered hydrocarbon" and "recovered hydrocarbons" are equivalent and mean any hydrocarbon stream withdrawn from the integrated LNG production and NGL recovery system as a product that is exported from the integrated system. The recovered hydrocarbons may be exported as one or more product streams enriched in any of the hydrocarbons in the natural gas feed. The exported streams may include, for example, any of an enriched ethane stream, an enriched propane stream, an enriched butane plus isobutane stream, an enriched pentane plus isopentane stream, and a mixed methane-ethane stream enriched in ethane. The LNG product may be considered as a recovered hydrocarbon. The term "unrecovered liquid hydrocarbon" and "unrecovered liquid hydrocarbons" are equivalent and mean any liquid portion of the hydrocarbons separated in the NGL recovery system that are not immediately present in the product streams of the recovered hydrocarbons that are exported from the integrated LNG production and NGL recovery system. Unrecovered liquid hydrocarbons may be considered as internal recycle streams within the integrated LNG production and NGL recovery system.

[0021] The term "enriched" as applied to any stream withdrawn from a process means that the withdrawn stream contains a concentration of a particular component that is higher than the concentration of that component in the feed stream to the process. Reflux is defined

as a stream introduced into a distillation column at any location above the location at which the feed is introduced into the column, wherein the reflux comprises one or more components previously withdrawn from the column. Reflux typically is liquid but may be a vapor-liquid mixture.

[0022] The indefinite articles "a" and "an" as used herein mean one or more when applied to any feature in embodiments of the present invention described in the specification and claims. The use of "a" and "an" does not limit the meaning to a single feature unless such a limit is specifically stated. The definite article "the" preceding singular or plural nouns or noun phrases denotes a particular specified feature or particular specified features and may have a singular or plural connotation depending upon the context in which it is used. The adjective "any" means one, some, or all indiscriminately of whatever quantity. The term "and/or" placed between a first entity and a second entity means one of (1) the first entity, (2) the second entity, and (3) the first entity and the second entity.

[0023] A first embodiment of the invention is shown in the integrated LNG production and NGL recovery system illustrated by Fig. 1. Pretreated pressurized natural gas feed in line 100 contains primarily methane with heavier hydrocarbons in the C₂-C₆ range. Contaminants comprising water, CO₂, H₂S, and mercury are removed in an upstream pretreatment system (not shown) by known methods. The feed gas, typically provided at a pressure between 600 and 900 psia (4 and 6.25 MPa) and ambient temperature, is cooled in heat exchanger 110 to between -20°F (-29°C) and -35°F (-37°C) to provide a cooled feed stream in line 112. Heat exchanger 110 may include multiple stages of cooling by evaporating propane at different pressures; alternatively or additionally, other means of cooling may be used, such as vaporizing mixed refrigerant in a single exchanger. This stream, which may be further cooled in optional economizer heat exchanger 114, is introduced via line 116 to first distillation column or scrub column 118.

[0024] Scrub column 118 separates the feed provided via line 116 into a bottoms liquid product in line 134 that is enriched in hydrocarbons heavier than methane and an overhead vapor product in line 120 that is enriched in methane. A portion of the bottoms liquid may be withdrawn via line 130 and vaporized in reboiler 132 to provide boilup for the scrub column. The reboiler may cool a portion (not shown) of stream 100 to provide heat therein for vaporizing the liquid in line 130. The scrub column may also have an intermediate reboiler (not shown) above the bottom of the column and below the location of feed line 116, and this reboiler also may be heated by a portion of the feed stream.

[0025] The bottoms liquid in line 134 flows to generic NGL fractionation system 136. The NGL feed stream typically is reduced in pressure (not shown) and separated in or more additional distillation columns including any of a demethanizer, a deethanizer, a depropanizer, a debu-

tanizer, and a depentanizer to provide two or more hydrocarbon fractions. In the exemplary generic NGL fractionation system of Fig. 1, three streams of recovered hydrocarbons are withdrawn and exported from the integrated LNG production and NGL recovery system as C₂, C₃, and C₄ product streams representing streams enriched in ethane, propane, and butane plus isobutane, respectively. Unrecovered liquid hydrocarbons are withdrawn from the NGL recovery system via line 138.

[0026] The overhead vapor stream enriched in methane is withdrawn from scrub column 118 via line 120 and may be warmed by indirect heat exchange with the feed stream in line 112 in economizer heat exchanger 114. The resulting warmed overhead vapor stream in line 122 is cooled, totally condensed, and optionally subcooled in passage 123 of the first or warm (lower) bundle of wound coil main heat exchanger 124 to provide a condensed methane-enriched stream in line 125. A first portion of the liquid in line 125 is withdrawn via line 126 from line 125 downstream of passage 123 and pumped by pump 127 to provide a liquefied methane-containing reflux stream. The liquefied methane-containing reflux stream is combined with the unrecovered liquid hydrocarbons in line 138 and returned to the top of scrub column 118 as a combined liquid reflux stream. Alternatively, liquefied methane-containing reflux stream from pump 127 may be introduced into the top of scrub column 118 and the unrecovered liquid hydrocarbons in line 138 may be introduced into scrub column 118 at a separate location (not shown) below the top of the column and above the location at which the cooled feed is introduced into the column via line 116. In another alternative, the liquefied methane-containing reflux stream from pump 127 and the unrecovered hydrocarbons in line 138 may be introduced into the top of scrub column 118 as separate streams (not shown).

[0027] Typically, depending on the composition of the feed in line 100, the molar flow rate of the unrecovered liquid hydrocarbons in line 138 is less than 25% of the molar flow rate of the methane-rich stream in line 126. If the natural gas feed in line 100 does not contain a sufficient amount of the components needed to provide the unrecovered liquid hydrocarbon stream in line 138, the necessary components may be imported from any appropriate source.

[0028] The second portion of the condensed methane-enriched stream in line 125 is further cooled in passage 128 the second or cold (upper) bundle of wound coil main heat exchanger 124 and withdrawn as LNG product via line 129. The LNG may be reduced in pressure before and/or after subcooling in the cold bundle if desired. If the LNG product is stored at high pressure (PLNG), there is no need for subcooling, and the cold bundle is not required. It is possible to use a portion of the LNG product in line 129 as a methane-rich reflux to scrub column 118 if desired, but such a configuration would waste refrigeration by providing reflux at a temperature much lower than required.

[0029] The temperature of the liquefied methane-containing reflux stream withdrawn from main heat exchanger 124 via line 126 and pump 127 in Fig. 1 may be lower than that actually required based on the temperature at the top of scrub column 118. In order to match the temperature of the methane-rich reflux to the temperature at the top of scrub column 118, the warm bundle of main heat exchanger 124 would have to be split to allow the withdrawal of a methane-rich reflux stream at an intermediate location. In addition, a phase separator would be required when the withdrawn stream is a mixed vapor-liquid stream. The thermodynamic inefficiency of providing the reflux at a temperature colder than required in the embodiment of Fig. 1, however, is compensated for by eliminating the need to split the warm bundle of main heat exchanger 124.

[0030] Refrigeration to main heat exchanger 124 may be provided by any known refrigeration system used in the production of LNG. For example, as shown in Fig. 1, a single mixed refrigerant (MR) system may be used in which a liquid refrigerant is provided via line 152 and a vapor refrigerant is provided via line 156. The vapor in line 156 is condensed and cooled in main heat exchanger 124 and expanded through throttling valve 158 to provide a first vaporizing refrigerant to the cold (upper) bundle of the exchanger and subsequently to the warm (lower) bundle of the exchanger. Liquid refrigerant 152 is cooled in main heat exchanger 124 to yield subcooled liquid refrigerant in line 153, expanded through throttling valve 154, and combined with vaporizing refrigerant from the cold (upper) bundle at a location near the cold end of the warm bundle of the main heat exchanger. As an alternative to throttling valves 154 and/or 158, as well as the LNG product letdown valve, expansion may be effected by isentropic dense fluid expanders (hydraulic turbines).

[0031] The refrigerant streams are completely vaporized and leave main heat exchanger 124 as refrigerant vapor via line 150. The mixed refrigerant vapor flows to a refrigeration system (not shown) where it is compressed, cooled by multiple stages of vaporizing propane, and separated to provide liquid refrigerant 152 and lighter vapor refrigerant 156.

[0032] Any other refrigeration system or a combination of systems known in the art may be used to provide refrigeration to main heat exchanger 124. For example, the pure fluid cascade and isentropic vapor expansion process may be used as described in U.S. Patent 6,308,531.

[0033] Using a portion of condensed scrub column overhead as methane-enriched reflux via line 126 in the embodiment of Fig. 1 avoids breaking the warm bundle of the main heat exchanger 124 into two separate bundles to withdraw a methane-rich stream for use as reflux. It also eliminates the potential need for separating a two-phase methane-rich stream in a phase separator if the methane-rich stream is a vapor-liquid mixture in order to use the liquid portion as reflux and redistribute the vapor portion for further condensation in the main heat exchanger. A smaller phase separator may be required at

startup as explained below. Using economizer heat exchanger 114 ensures that the overhead stream in line 122 enters main heat exchanger 124 at about the same temperature as the refrigerant streams in lines 152 and 156, which typically are generated by propane refrigeration.

[0034] The use of unrecovered liquid hydrocarbons via line 138 as additional reflux to scrub column 118 eliminates the need for expanding the column feed and recompressing the column overhead. To minimize power consumption, the natural gas feed pressure should be significantly above the critical pressure of methane. At the same time, the scrub column must be operated below the critical pressure of the feed mixture in order to achieve separation. A common solution known in the art is to isentropically expand the scrub column feed and then to recompress the overhead vapor product. Work obtained from the isentropic expansion of the feed can be used to at least partially drive the overhead compressor or compressors. Such a solution is shown, for example, in U.S. Patent 4,065,267 and in Fig. 2 of a paper by Elliot, Qualls, Huang, Chen, Lee, Yao, and Zhang entitled "Benefits of Integrating NGL Extraction and LNG Liquefaction Technology" presented at the AIChE Spring Meeting, April 2005.

[0035] Another embodiment of the invention is illustrated in Fig. 2. In this embodiment, a portion of the scrub column overhead vapor in line 120 is withdrawn via line 220 and condensed in heat exchanger 200 to produce a liquefied methane-containing reflux stream that is combined with the unrecovered liquid hydrocarbons in line 138 and introduced as a combined stream via line 221 to the top of scrub column 118. The liquefied methane-containing reflux stream from heat exchanger 200 may be pumped if necessary.

[0036] Alternatively, the liquefied methane-containing reflux stream from heat exchanger 200 may be introduced into the top of scrub column 118 and the unrecovered liquid hydrocarbons in line 138 may be introduced into scrub column 118 at a separate location (not shown) below the top of the column and above the location at which the cooled feed is introduced into the column via line 116. In another alternative, the liquefied methane-containing reflux stream from heat exchanger 200 and the unrecovered liquid hydrocarbons in line 138 may be introduced into the top of scrub column 118 as separate streams (not shown).

[0037] Refrigeration for main heat exchanger 124 is provided in the same manner as described above with reference to Fig. 1 to provide liquid refrigerant 152 and vapor refrigerant 156. Refrigeration for heat exchanger 200 is provided by withdrawing a portion of the liquid mixed refrigerant in line 153 via line 252, reducing the pressure of the refrigerant through throttling valve 254, and introducing the reduced-pressure refrigerant into the heat exchanger. Vaporized mixed refrigerant from heat exchanger 200 is combined with vaporized mixed refrigerant from main heat exchanger 124 to provide the va-

porized refrigerant in line 150. Alternatively, refrigerant in line 252 may be withdrawn from line 152 prior to main heat exchanger 124, expanded to an intermediate pressure or pressures, vaporized in heat exchanger 200, and returned to the mixed refrigerant compressor (not shown) at an appropriate stage location or locations. All other process features of Fig. 2 are identical to those described above with reference to Fig. 1.

In an alternative version of the process described above with reference to Fig. 2, situations may arise in which it is desirable to export all hydrocarbons recovered in the bottoms from scrub column 118 and fractionated in the NGL fractionation system. In this case, the flow rate of the unrecovered hydrocarbon stream in line 138 would be zero, and scrub column 118 would utilize reflux in line 221 provided by condensing the portion of the scrub column 118 overhead stream in line 220 in heat exchanger 200.

[0038] An alternative embodiment of the invention is illustrated in Fig. 3. In this embodiment, the liquefied methane-containing reflux stream from pump 127 is warmed in heat exchanger 300 by indirect heat exchange with a portion of mixed refrigerant liquid withdrawn from line 152 via line 352. In this case, the combined reflux stream is closer to its optimum temperature when it is introduced into scrub column 118. Cooled refrigerant from heat exchanger 300 flows via line 302 and is combined with the refrigerant in line 153 prior to throttling valve 154.

[0039] Alternatively, the condensed methane-rich stream from heat exchanger 300 may be introduced into the top of scrub column 118 and the unrecovered hydrocarbons in line 138 may be introduced into scrub column 118 at a location (not shown) below the top of the column and above the location at which the cooled feed is introduced into the column via line 116. In another alternative, the liquefied methane-containing reflux stream from heat exchanger 300 and the unrecovered liquid hydrocarbons in line 138 may be introduced into the top of scrub column 118 as separate streams (not shown). All other process features of Fig. 3 are identical to those described above with reference to Fig. 1.

[0040] In an alternative version of the process described above with reference to Fig. 3, situations may arise in which it is desirable to export all hydrocarbons recovered in the bottoms from scrub column 118 and fractionated in the NGL fractionation system. In this case, the flow rate of the unrecovered hydrocarbon stream in line 138 would be zero, and scrub column 118 would utilize reflux provided by warming in heat exchanger 300 the portion provided by pump 127 of the totally condensed overhead from scrub column 118.

[0041] Fig. 4 shows an optional configuration that can be used to return the condensed methane-enriched stream in line 126 to scrub column 118. The condensed methane-enriched stream in line 126 is reduced in pressure through throttle valve 426 to its bubble point, introduced into drum 427 that maintains some vapor inven-

tory, and pumped by pump 127 to the scrub column pressure. A portion of the pumped stream is recycled to drum 427 through valve 428 to maintain the liquid level in the drum and the remaining portion flows to scrub column 118 through optional valve 429. During plant startup, excess vapor may be vented (not shown) from the top of drum 427 and flared or compressed and recovered. Since the condensed methane-enriched stream in line 126 is only a small portion of the total LNG stream and there is no net vapor flow during normal operations, drum 127 is much smaller than a reflux drum typically used in a conventional plant to separate a partially condensed methane-rich stream withdrawn from the main heat exchanger to provide reflux liquid to the scrub column.

[0042] Throttling valve 426 and drum 427 can be avoided by detecting liquid in line 126 (for example with a thermocouple) and redirecting vapor or two-phase flow from the main heat exchanger 124 at a startup situation (at normal operation it is subcooled liquid) to another existing drum such as helium recovery or fuel gas flash drum or simply by flaring it. In another alternative, the system can be simplified by using a type of pump 127 that can tolerate two-phase flow at off-design conditions, such as a cryogenic gear or screw pump or a centrifugal pump with a high-performance inducer.

[0043] An exemplary NGL recovery system that can be used with embodiments of the present invention is illustrated in Fig. 5 and comprises four distillation columns including demethanizer 501, deethanizer 503, depropanizer 505, and debutanizer 507 operating in series. Bottoms liquid from scrub column 118 via line 134 is cooled in heat exchanger 510 to approximately ambient temperature and flows to demethanizer column 501. Overhead vapor containing methane and some ethane is withdrawn from the top of the demethanizer as a recovered hydrocarbon stream via line 509 and may be used as fuel or liquefied and reinjected into the LNG product. A bottoms liquid enriched in ethane and heavier hydrocarbons is withdrawn via line 511 and is partially vaporized in heat exchanger 513, boilup vapor is returned to the column via line 517, and the remaining stream flows via line 519 and valve 521 into deethanizer column 503.

[0044] High purity ethane vapor is withdrawn from the column via line 523 and is condensed in overhead condenser 525. A portion of the condensed liquid is returned as reflux via line 527 and another portion is withdrawn via line 529 as a recovered hydrocarbon comprising high purity ethane typically containing greater than 98 mole % ethane. The bottoms liquid from the deethanizer via line 531 is partially vaporized in heat exchanger 533, boilup vapor is returned to the column via line 535, and the remaining stream flows via line 537 and valve 539 into depropanizer column 505. High purity propane vapor is withdrawn from the column via line 541 and is condensed in overhead condenser 543. A portion of the condensed liquid is returned as reflux via line 545 and another portion is withdrawn via line 547 as a recovered hydrocarbon comprising high purity propane typically containing great-

er than 98 mole % propane.

[0045] The bottoms liquid from the depropanizer via line 549 is partially vaporized in heat exchanger 551, boilup vapor is returned to the column via line 553, and the remaining stream flows via line 555 and valve 557 into debutanizer column 507. High purity butane (plus isobutane if present) vapor is withdrawn from the column via line 559 and is condensed in overhead condenser 561. A portion of the condensed liquid is returned as reflux via line 563 and another portion is withdrawn via line 565 as a recovered hydrocarbon comprising high purity butane (plus isobutane if present) typically containing greater than 98 mole % butane plus isobutane. The bottoms liquid from the debutanizer is withdrawn via line 567 and partially vaporized in heat exchanger 569, boilup vapor is returned to the column via line 571, and the remaining stream is withdrawn via line 573 as a recovered hydrocarbon comprising pentane (plus isopentane if present) and heavier hydrocarbons.

[0046] In this illustration, propane and butane liquid streams may be withdrawn as unrecovered liquid hydrocarbons via lines 575 and 577, respectively, and mixed in line 579. The mixed unrecovered liquid hydrocarbon stream is cooled to temperature of vaporizing propane refrigerant in heat exchanger 581, is pumped to scrub column pressure in pump 583, and flows via line 138 to the scrub column in any of the embodiments of Figs. 1, 2, and 3. Optionally, a portion of the ethane liquid from the deethanizer may be withdrawn as unrecovered liquid hydrocarbon via line 585 and combined with the unrecovered propane and/or butane in line 579. Optionally, a portion of the overhead vapor in line 509 from demethanizer 501 may be withdrawn via line 587 and absorbed in the unrecovered liquid propane and/or butane in line 579. No compression of the demethanizer overhead vapor is needed in this option. In one alternative, all butane from the debutanizer is recovered via line 565 and none is withdrawn as unrecovered liquid hydrocarbon via line 577. In another alternative, all propane from the depropanizer is recovered via line 547 and none is withdrawn as unrecovered liquid hydrocarbon via line 575. In general, any of the dissolved overhead from demethanizer 501 and the condensed ethane, propane, and butane overhead streams from deethanizer 503, depropanizer 505, and debutanizer 507, respectively, may be wholly or partially withdrawn as unrecovered liquid hydrocarbons for return to scrub column 118 as long as the withdrawn hydrocarbon product requirements are satisfied.

[0047] Other NGL fractionation systems may be used depending on the particular hydrocarbons to be recovered. For example, the system may utilize a depentanizer column to recover high purity pentanes and a residual product containing hydrocarbons heavier than pentane. A portion of the pentanes may be returned as an unrecovered hydrocarbon to scrub column 118. In another alternative, the demethanizer is not used and the deethanizer is operated to withdraw the ethane liquid product at an intermediate stage and to withdraw a mixture of

methane and ethane vapor from the reflux drum as a recovered hydrocarbon product. A portion of this vapor may be withdrawn as an unrecovered hydrocarbon product and dissolved in the unrecovered liquid hydrocarbon mixture as described above.

The following Example illustrates an embodiment of the present invention but does not limit embodiments of the invention to any of the specific details described therein.

EXAMPLE

[0048] A process simulation was carried out to illustrate the embodiment of Fig. 1. A pre-purified natural gas stream in line 100 has a flow rate of 100,000 lbmol/h (45,000 kgmol/h) and pressure of 960 psia (6.6 MPa) and contains (in mole %) 1.9% helium, 5.8% nitrogen, 83.2% methane, 7.1 % ethane, 2.3% propane, 0.4% isobutane, 0.6% butane, 0.1 % isopentane, 0.2% pentane, and 0.2% hexanes. The stream is cooled by three stages of propane cooling to -29°F (-34.5°C), is further cooled in the economizer heat exchanger to -62.8°F (-52.5°C), and is fed to scrub column 118. The column operates at an average pressure of 886 psia (6.1 MPa). Column overhead in line 120 at a flow rate of 104,770 lbmol/h (47500 kgmol/h) is warmed from -73°F (-58°C) to -32°F (-36°C) against the feed in heat exchanger 114. The resulting stream in line 122 is cooled and liquefied in passage 123 of the warm bundle of main heat exchanger 124 to provide a condensed methane-enriched stream in line 125. A portion of this liquid is withdrawn via line 126 at a flow rate of 10,943 lbmol/h (4963.5 kgmol/h) and temperature of -197.6°F (-127.5°C). The stream is pumped in pump 127 to the scrub column pressure, since the liquid head typically is not sufficient to overcome the pressure drop in heat exchanger 124. The remainder of the liquid in line 125 is subcooled in passage 128 and withdrawn from the cold bundle of the exchanger as a liquefied natural gas product in line 129 at a flow rate of 93,827 lbmol/h (42559 kgmol/h) and a temperature of -228.8°F (-144.9°C). The product stream may be further processed to recover helium before being reduced in pressure to the storage pressure.

[0049] The scrub column bottoms stream is withdrawn via line 134 at a flow rate of 1862 lbmol/h (844.5 kgmol/h) and is sent to NGL fractionation system 136, which is a series of distillation columns as shown in Fig. 5 comprising a demethanizer producing a methane-ethane mixture as a vapor overhead product, a deethanizer producing high purity ethane as a liquid overhead product, a depropanizer producing high purity propane as a liquid overhead product, and a debutanizer producing high purity butane as a liquid overhead product. The ethane, propane, and butane liquids have purities in excess of 98 mole %. The methane and ethane mixture from the demethanizer is withdrawn as a recovered hydrocarbon and is used as fuel.

[0050] Unrecovered liquid propane and butane in lines 575 and 577 are combined in line 138, cooled by propane

refrigeration to -32.3°F (-35.7°C) in heat exchanger 581, and pumped to the scrub column pressure in pump 583. The unrecovered propane in line 575 is 50% of the overhead stream in depropanizer overhead line 541 and the unrecovered butane in line 577 butane is 60% of the overhead stream in debutanizer overhead line 559. The combined unrecovered hydrocarbon stream in line 579 has a flow rate of 1116 lbmol/h (506 kgmol/h) and a composition (in mole %) of 39% propane, 60% butane plus isobutanes, and 1 % components heavier than butane. The pumped unrecovered liquid hydrocarbon is combined with the liquefied methane-containing reflux stream from pump 127 and the combined stream is introduced into the top of scrub column 118.

[0051] Although illustrated and described herein with reference to certain specific embodiments, the present invention is nevertheless not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope of the claims.

Claims

1. A process for the liquefaction of natural gas comprising:
 - cooling a natural gas feed to provide a cooled natural gas feed and introducing the cooled natural gas feed into a "first" column;
 - withdrawing from the first column an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;
 - cooling and totally condensing at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream; and
 - introducing at least a portion of said condensed methane-enriched stream into the first column as a liquefied methane-containing reflux stream.
2. A process of Claim 1, wherein said overhead vapor stream is cooled and totally condensed and a portion of the condensed methane-enriched stream is withdrawn to provide said liquefied methane-containing reflux stream.
3. A process of Claim 1, wherein a portion of said overhead vapor stream is cooled and totally condensed to provide the condensed methane-enriched stream and is introduced into the first column as said liquefied methane-containing reflux stream.
4. A process of Claim 1, wherein said overhead vapor stream is cooled and totally condensed to form the condensed methane-enriched stream and a portion thereof warmed to provide said liquefied methane-containing reflux stream.

5. A process of any one of the preceding claims, wherein a stream of liquid hydrocarbons separated from said bottoms stream is introduced into the first column as a reflux stream.

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6. A process of Claim 5, wherein said stream of liquid hydrocarbons is introduced into the first column separately from said liquefied methane-containing reflux stream.

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7. A process of Claim 5, wherein said stream of liquid hydrocarbons is combined with said liquefied methane-containing reflux stream and the combined stream introduced into the first column.

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8. A process of any one of the preceding claims, wherein said reflux stream or at least one of said separate reflux streams is pumped to the pressure of the first column.

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9. A process of any one of the preceding claims, wherein said bottoms stream is separated to provide one or more product streams selected from a residual vapor stream comprising methane, a liquid stream enriched in ethane, a liquid stream enriched in propane, a liquid stream enriched in butane, and a liquid stream enriched in pentane and all or a portion of any of the one or more product streams is withdrawn as recovered hydrocarbons.

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10. A process for the liquefaction of natural gas and the recovery of components heavier than methane from the natural gas, wherein the process comprises:

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(a) cooling a natural gas feed to provide a cooled natural gas feed and introducing the cooled natural gas feed into a "first" column;

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(b) withdrawing from the first column an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;

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(c) cooling and condensing at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream;

(d) separating the bottoms stream to provide one or more product streams selected from a residual vapor stream comprising methane, a liquid stream enriched in ethane, a liquid stream enriched in propane, a liquid stream enriched in butane, and a liquid stream enriched in pentane;

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(e) withdrawing as recovered hydrocarbons all or a portion of any of the one or more product streams; and

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(f) introducing one or more reflux streams into the first column, wherein the one or more reflux streams comprise either

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(f1) a liquefied methane-containing reflux

stream and a stream of unrecovered liquid hydrocarbons that is pumped to a pressure in the first column or

(f2) a combined stream comprising the liquefied methane-containing reflux stream and the stream of unrecovered liquid hydrocarbons that is pumped to the pressure in the first column,

and wherein the liquefied methane-containing reflux stream is provided by a method selected from

(1) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and withdrawing a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream,

(2) cooling and totally condensing a portion of the first overhead vapor stream to provide the liquefied methane-containing reflux stream, and (3) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and warming a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream.

11. A process of Claim 9 or Claim 10, wherein the stream of (unrecovered) liquid hydrocarbons comprises any of

(i) a portion of the liquid stream enriched in ethane,

(ii) a portion of the liquid stream enriched in propane,

(iii) a portion of the liquid stream enriched in butane,

(iv) a portion of the liquid stream enriched in pentane, and

(v) all or a portion of the residual vapor stream dissolved in a portion of the liquid stream enriched in propane and/or a portion of the liquid stream enriched in butane and/or a portion of the liquid stream enriched in pentane.

12. A process for the liquefaction of natural gas comprising

(a) cooling a natural gas feed to provide a cooled natural gas feed and introducing the cooled natural gas feed into a "first" column;

(b) withdrawing from the first column an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;

(c) cooling and condensing at least a portion of the overhead vapor stream to provide a con-

- condensed methane-enriched stream; and
 (d) introducing a liquefied methane-containing reflux stream into the first column, wherein the liquefied methane-containing reflux stream is provided by a method selected from -
- (1) dividing the overhead vapor stream into a "first" vapor portion and a "second" vapor portion, and cooling and totally condensing the first vapor portion to provide the liquefied methane-containing reflux stream, and
 - (2) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream, dividing the condensed methane-enriched stream into a "first" portion and a "second" portion, warming the first portion to provide a warmed first portion, and utilizing the warmed first portion to provide the liquefied methane-containing reflux stream.
13. A process of any one of the preceding claims, wherein said cooling and condensing of at least a portion of the overhead vapor stream to provide the condensed methane-enriched stream is effected in a "main" heat exchanger by indirect heat exchange with a stream of vaporizing refrigerant.
 14. A process of Claim 13, wherein stream of vaporizing refrigerant is a "first" vaporizing refrigerant provided by reducing the pressure of a "first" cooled multicomponent liquid refrigerant.
 15. A process of any one of Claims 1, 3 and 5 to 12, wherein said portion of the overhead vapor stream is condensed to provide the condensed methane-enriched stream in a heat exchanger separate from a "main" heat exchanger, in which main heat exchanger another portion of the overhead vapor stream is cooled and condensed; said condensation in the separate heat exchanger being by indirect heat exchange with a stream of vaporizing refrigerant.
 16. A process of Claim 15, wherein said cooling and condensing in the main heat exchanger is by indirect heat exchange with a "first" vaporizing refrigerant provided by reducing the pressure of a "first" cooled multicomponent liquid refrigerant and said vaporizing refrigerant in the separate heat exchanger is provided by withdrawing and reducing the pressure of a portion of the first cooled multicomponent liquid refrigerant.
 17. A process of Claim 13 or Claim 14, wherein a portion of the condensed methane-enriched stream is warmed to provide the liquefied methane-containing reflux stream in a heat exchanger separate from the main heat exchanger.
 18. A process of Claim 14, wherein the first cooled multicomponent liquid refrigerant is provided by cooling a saturated multicomponent liquid refrigerant in the main heat exchanger and a portion of the condensed methane-enriched stream is warmed to provide the liquefied methane-containing reflux stream by indirect heat exchange with a portion of the saturated multicomponent liquid refrigerant in a heat exchanger separate from the main heat exchanger.
 19. A process of any one of Claim 13 to 18, wherein at least a portion of the overhead vapor condensed in the main heat exchanger is subcooled to provide a pressurized liquefied natural gas product, wherein the subcooling is effected in the main heat exchanger by indirect heat exchange with a stream of vaporizing refrigerant.
 20. A process of any one of Claims 13 to 19, wherein at least a portion of the overhead vapor condensed in the main heat exchanger is subcooled to provide a pressurized liquefied natural gas product by indirect heat exchange with a "second" vaporizing refrigerant provided by reducing the pressure of a "second" cooled multicomponent liquid refrigerant.
 21. A process of any one of the preceding claims, wherein the cooling of the natural gas feed to provide the cooled natural gas feed is effected by indirect heat exchange with the overhead vapor stream enriched in methane.
 22. A process of any one of the preceding claims, wherein the stream of (unrecovered) liquid hydrocarbons contains greater than 50 mole % of hydrocarbons having three or more carbon atoms.
 23. A process of Claim 22, wherein the stream of (unrecovered) liquid hydrocarbons contains greater than 50 mole % of pentane.
 24. A process of any one of the preceding claims when dependent directly or indirectly on Claim 11, wherein the stream of (unrecovered) liquid hydrocarbons comprises a portion of the liquid stream enriched in propane and a portion of the liquid stream enriched in butane.
 25. A process of Claim 24, wherein the stream of unrecovered liquid hydrocarbons comprises a portion of the liquid stream enriched in ethane.
 26. A process of Claim 24, wherein the stream of unrecovered liquid hydrocarbons comprises a portion of the residual vapor stream comprising methane dissolved in a liquid comprising hydrocarbons heavier than methane.

27. A process of any one of the preceding claims, wherein the molar flow rate of the (unrecovered) liquid hydrocarbons is less than 25% of the molar flow rate of the liquefied methane reflux stream.
28. An apparatus for the liquefaction of natural gas by a process of Claim 1, said apparatus comprising
- a cooling system (110, 114) adapted to cool a natural gas feed to provide a cooled natural gas feed;
- a "first" column (118) for separating the cooled natural gas feed into an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;
- a heat exchanger (124) for cooling and totally condensing at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream; and
- a "first" flow system (126, 127) for introducing at least a portion of said condensed methane-enriched stream into the first column (118) as a liquefied methane-containing reflux stream.
29. An apparatus of Claim 28, comprising a "second" flow system (138) for introducing as a reflux stream into the first column a stream of liquid hydrocarbons separated from said bottoms stream.
30. An apparatus of Claim 29, wherein said second flow system (138) introduces said stream of liquid hydrocarbons separately from introduction of the liquefied methane-containing reflux stream by the first flow system.
31. An apparatus of Claim 29, wherein said second flow system (138) combines said stream of liquid hydrocarbons with said liquefied methane-containing reflux stream and the combined stream is introduced into the first column by said first flow system.
32. An apparatus of any one of Claims 28 to 31, comprising a pump (127) for pumping said reflux stream or at least one of said separate reflux streams to the pressure of the first column.
33. An apparatus of any one of Claims 28 to 32, comprising a separator system (136) for separating said bottoms stream to provide one or more product streams selected from a residual vapor stream comprising methane, a liquid stream enriched in ethane, a liquid stream enriched in propane, a liquid stream enriched in butane, and a liquid stream enriched in pentane and withdrawing all or a portion of any of the one or more product streams as recovered hydrocarbons.
34. An apparatus for the liquefaction of natural gas and
- the recovery of components heavier than methane from the natural gas, wherein the apparatus comprises
- (a) a cooling system (110, 114) for cooling a natural gas feed to provide a cooled natural gas feed;
- (b) a "first" column (118) for separating the cooled natural gas feed into an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;
- (c) a heat exchanger (124) for cooling and condensing at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream; (d) one or more additional columns adapted to separate the bottoms stream into one or more product streams selected from a residual vapor stream comprising methane, a liquid stream enriched in ethane, a liquid stream enriched in propane, a liquid stream enriched in butane, and a liquid stream enriched in pentane; (e) piping (C2, C3, C4) for withdrawing all or a portion of any of the one or more product streams as recovered hydrocarbons; (f) a first flow system (126, 127, 138) for introducing one or more reflux streams into the first column (118), wherein the one or more reflux streams comprise either
- (f1) a liquefied methane-containing reflux stream and a stream of unrecovered liquid hydrocarbons that is pumped to a pressure in the first column, wherein the liquefied methane-containing reflux stream is provided by a method selected from
- (1) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and withdrawing a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream,
- (2) cooling and totally condensing a portion of the first overhead vapor stream to provide the liquefied methane-containing reflux stream, and
- (3) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and warming a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream; or
- (f2) a combined stream comprising the liquefied methane-containing reflux stream

- and the stream of unrecovered liquid hydrocarbons that is pumped to the pressure in the first column; and
- (g) a second flow system for transferring unrecovered liquid hydrocarbons from the one or more additional columns to the first flow system.
- 35.** An apparatus for the liquefaction of natural gas comprising:
- (a) a cooling system (110, 114) for cooling a natural gas feed to provide a cooled natural gas feed;
 - (b) a "first" column (118) for separating the cooled natural gas feed into an overhead vapor stream enriched in methane and a bottoms stream enriched in components heavier than methane;
 - (c) a heat exchanger (124) for cooling and condensing at least a portion of the overhead vapor stream to provide a condensed methane-enriched stream; and
 - (d) a flow system (126, 127) for introducing a liquefied methane-containing reflux stream into the first column (118), wherein the liquefied methane-containing reflux stream is provided by a method selected from
 - (1) cooling and totally condensing a portion of the overhead vapor stream to provide the liquefied methane-containing reflux stream, and
 - (2) cooling and totally condensing the overhead vapor stream to form the condensed methane-enriched stream and warming a portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream.
- 36.** An apparatus process of any one Claims 28 to 35, comprising a "main" heat exchanger (124) in which at least a portion of the overhead vapor stream is cooled and condensed to provide the condensed methane-enriched stream by indirect heat exchange with a stream of vaporizing refrigerant.
- 37.** An apparatus of Claim 36, wherein the heat exchanger (200) providing the condensed methane-enriched stream is separate from the main heat exchanger (124).
- 38.** An apparatus of Claim 36 or Claim 37, wherein the main heat exchanger (124) is a wound coil heat exchanger.
- 39.** An apparatus of Claim 38, wherein the main heat exchanger (124) comprises a first bundle (123) for
- cooling and condensing at least a portion of the overhead vapor stream to provide the condensed methane-enriched stream and a second bundle (128) for further cooling the condensed methane-enriched stream to provide a subcooled liquid product.
- 40.** An apparatus of any one of Claims 36 to 39, comprising a heat exchanger (300), separate from the main heat exchanger (124), for warming the portion of the condensed methane-enriched stream to provide the liquefied methane-containing reflux stream.

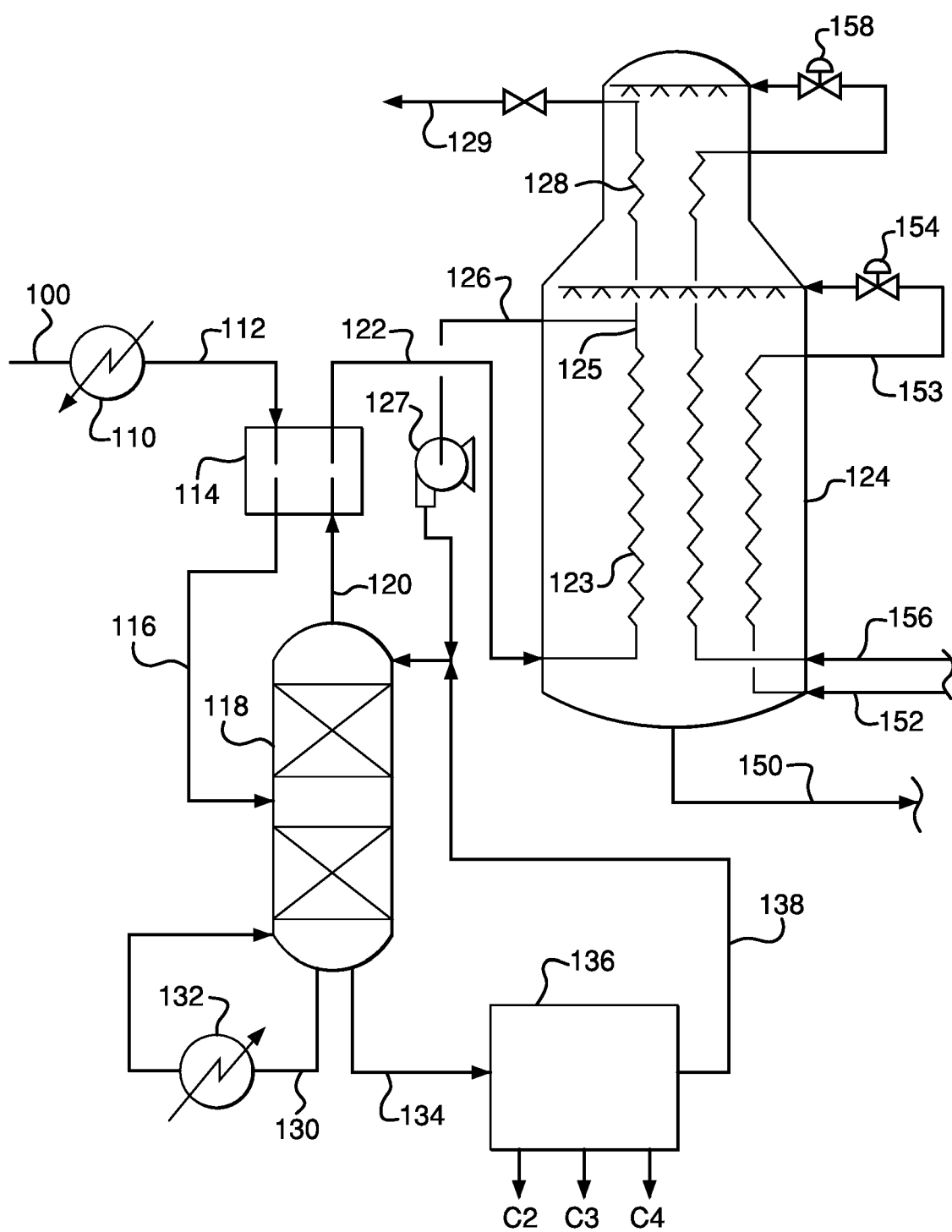


FIG. 1

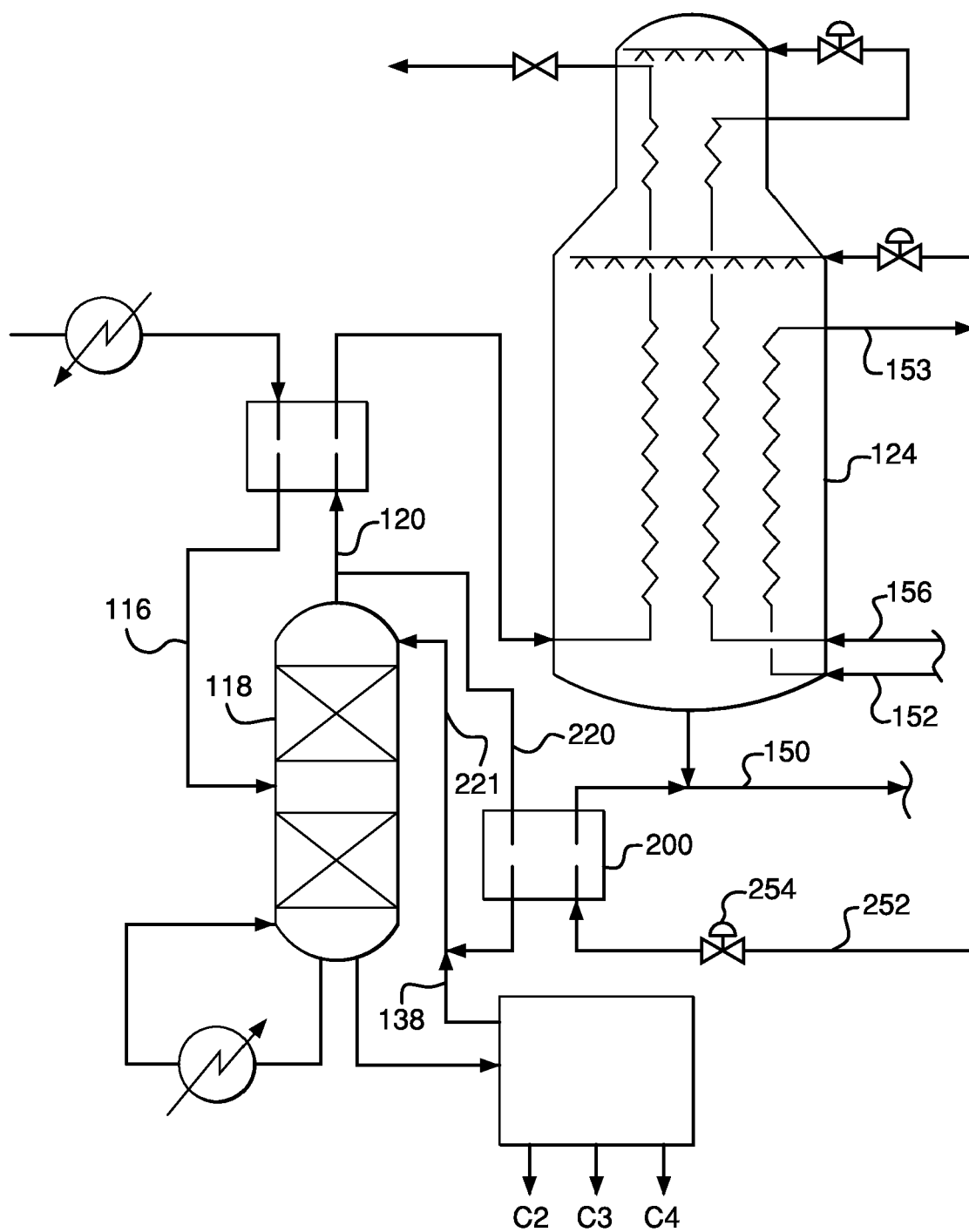


FIG. 2

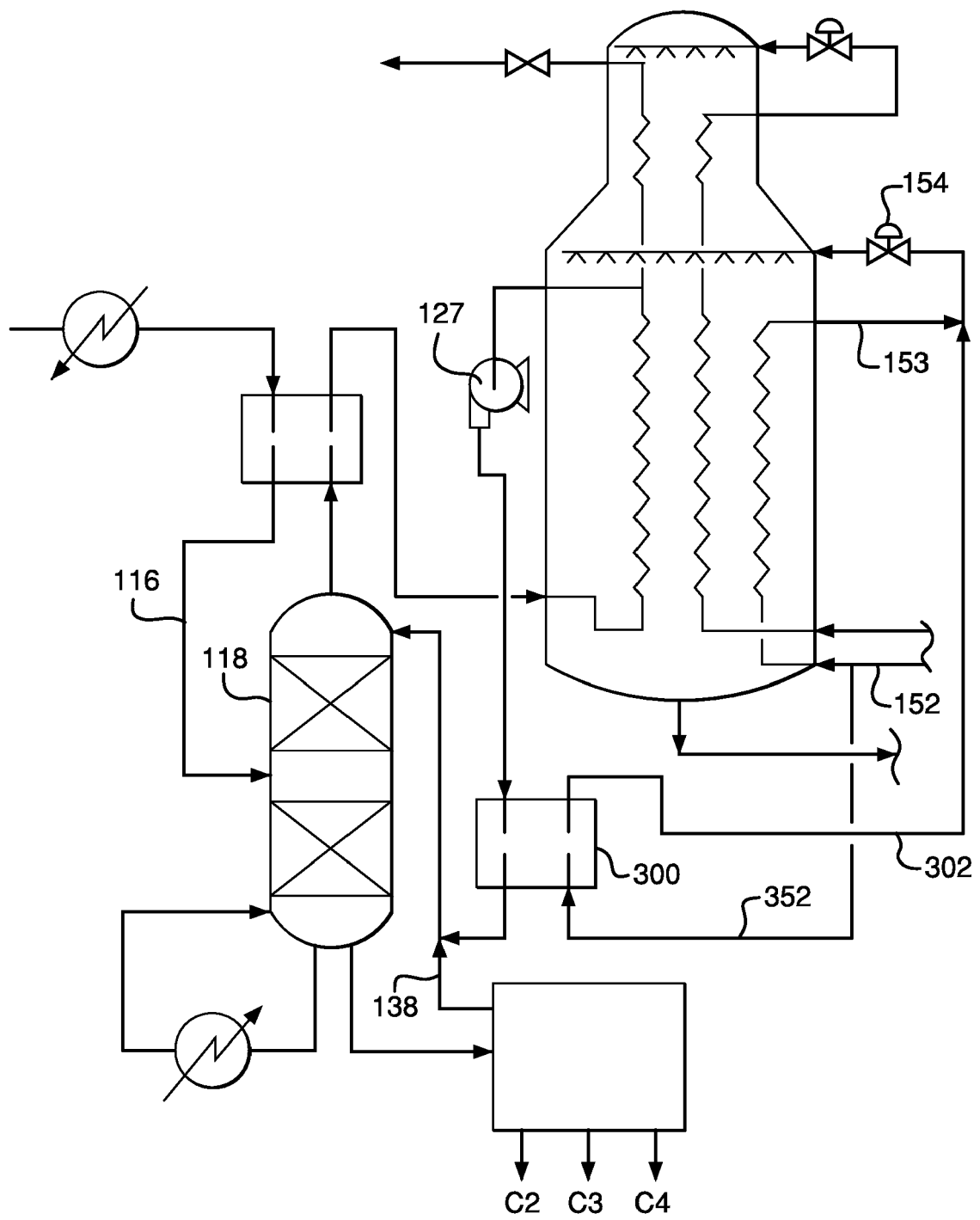


FIG. 3

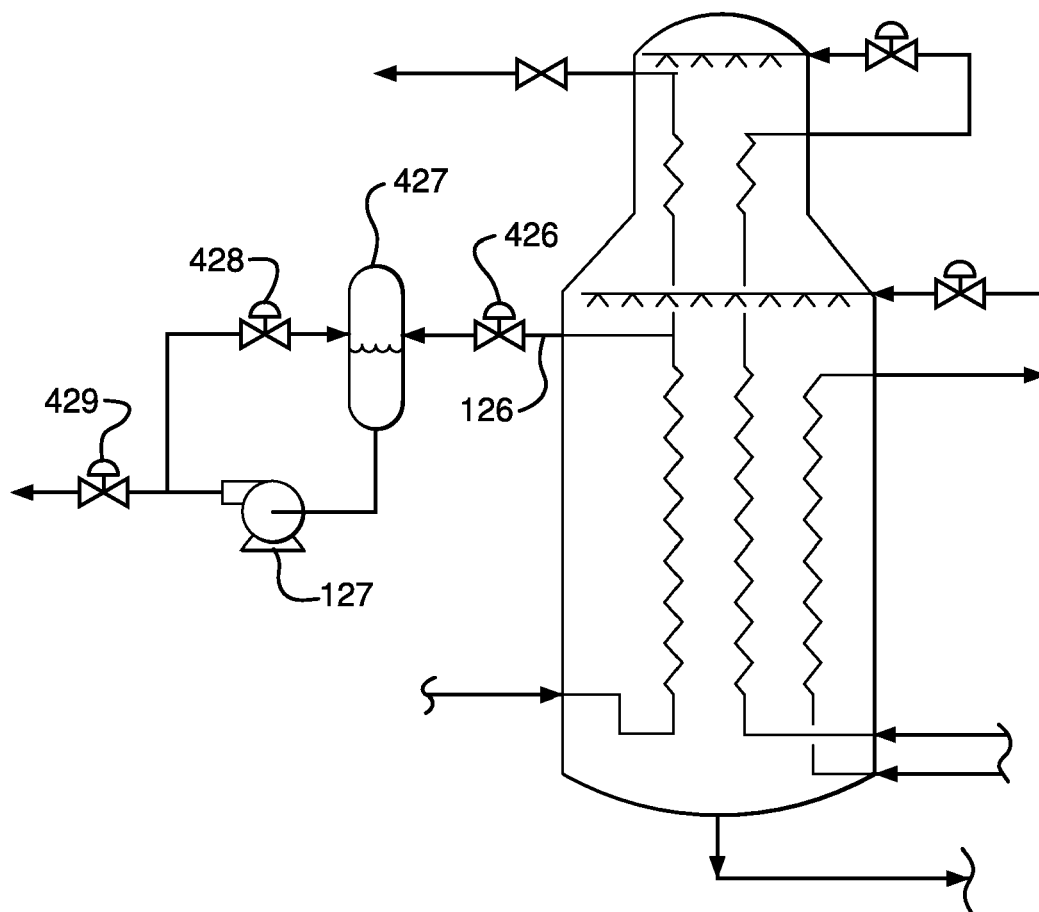


FIG. 4

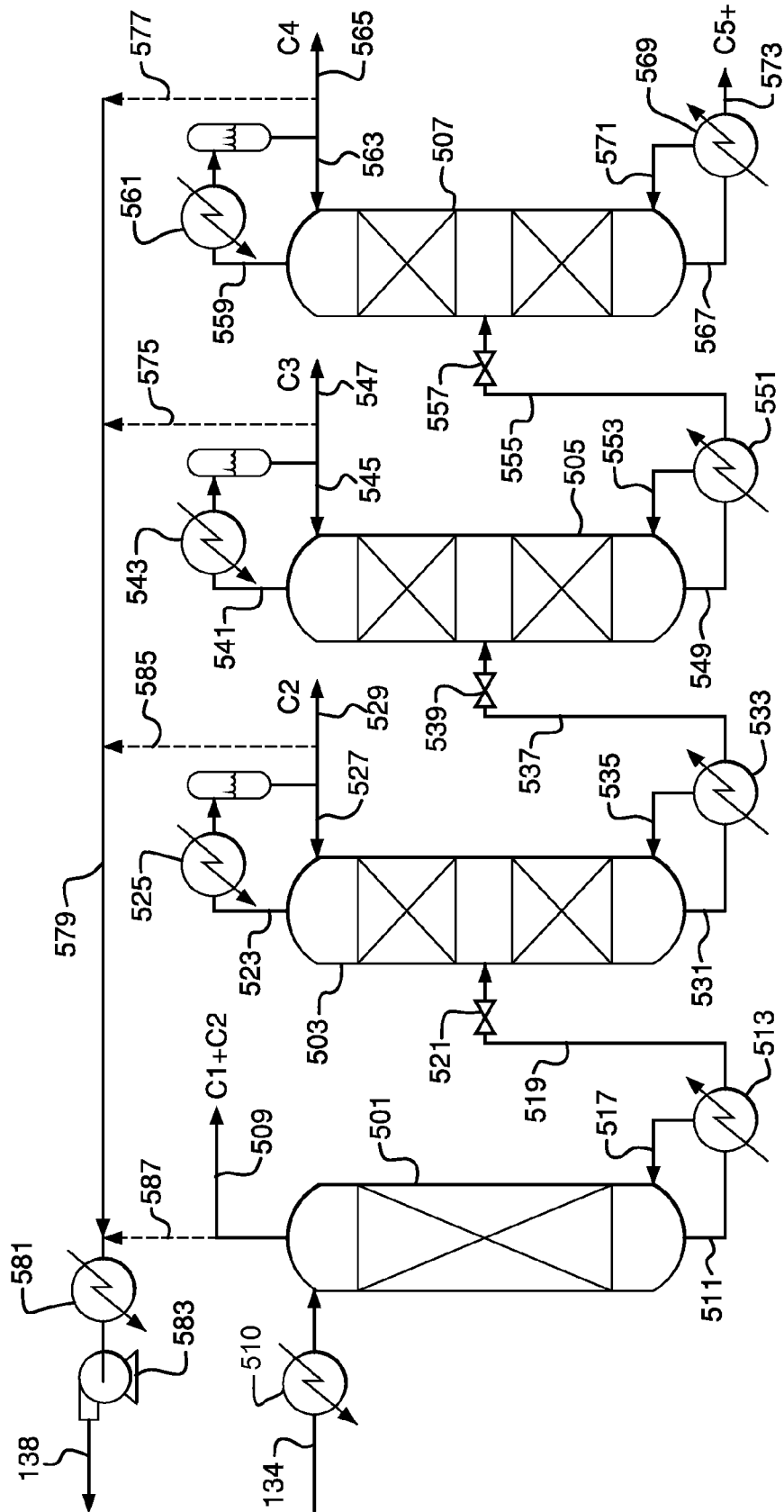


FIG. 5

REFERENCES CITED IN THE DESCRIPTION

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