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(54) IMPROVED SEPARATION OF HEAVY HYDROCARBONS AND NGLS FROM NATURAL GAS IN INTEGRATION WITH LIQUEFACTION OF NATURAL GAS

(57) Described herein is a method of and system for fractionating and liquefying a natural gas feed stream. The natural gas is first fractionated in a scrub column. The overhead vapor from the scrub column is cooled, condensed and divided to form a first, a second and at least one further stream of liquefied first overhead. The first stream of liquefied first overhead is returned to the scrub column as a reflux stream. The second stream of liquefied first overhead forms an LNG product. The further stream of liquefied first overhead is used to provide or generate reflux for a de-methanizer column used to fractionate the bottoms liquid from the scrub column.

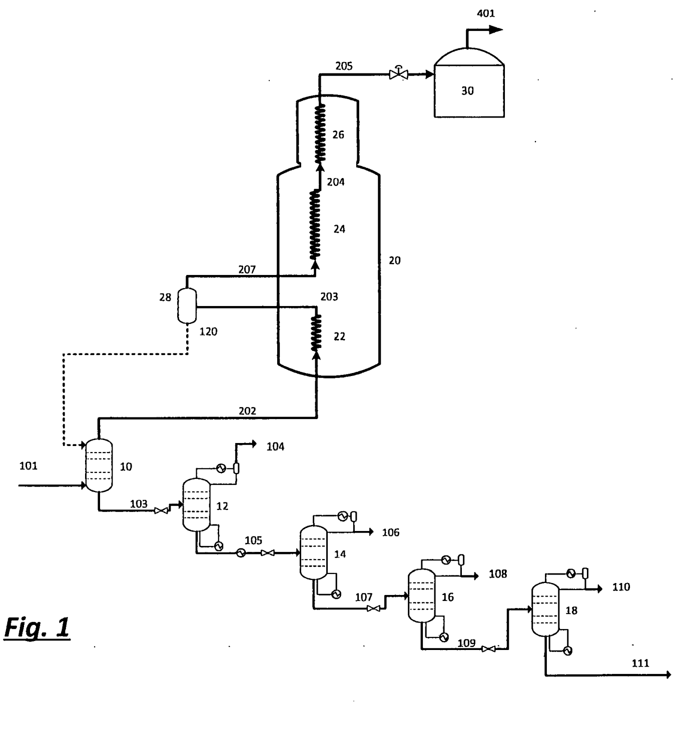

Fig. 1

EP 3 048 400 A2

Description

BACKGROUND

[0001] The present invention relates to a method of and system for fractionating and liquefying a natural gas feed stream.

[0002] Removal of the heavy hydrocarbons (HHCs), such as C6+ hydrocarbons (hydrocarbons having 6 or more carbon atoms), from natural gas prior to liquefaction of the natural gas is, typically, essential in order to lower the concentration of these components in the natural gas down to a level where freeze-out of these components in the main heat exchanger will not occur. C2-C5+ hydrocarbons (hydrocarbons having 2 to 5 or more carbon atoms), also referred to in the art as Natural Gas Liquids (NGLs), are typically also separated from natural gas since they have a high market value, and can therefore be sold separately. Additionally, as NGLs have a higher heating value than methane it may be necessary to reduce the levels of NGL components in the natural gas in order that the LNG product meets stipulated product specifications. Where the refrigerant used in the natural gas liquefaction process comprises one or more hydrocarbon refrigerants, such as, in particular, where a cascade or mixed refrigerant cycle using ethane and/or propane is employed for the liquefaction process, it may also be desirable to use separated NGL components (such as ethane or propane) as refrigerant make-up. Traditionally, distillation columns have been used for this purpose.

[0003] Figure 1 depicts, schematically, a conventional arrangement for fractionating and liquefying a natural gas feed stream. Natural gas feed stream, 101, which has been pre-treated to remove acid gases, water and mercury, and which may optionally also have been pre-cooled in one or more heat exchangers, is introduced into scrub column, 10, in which it is separated into a methane-rich overhead vapor and a bottoms liquid enriched in hydrocarbons heavier than methane. A stream of the overhead vapor, 202, is withdrawn from the top of the scrub column, and a stream of the bottoms liquid, 103, is withdrawn from the bottom of the scrub column.

[0004] The stream of overhead vapor, 202, is sent to the warm bundle, 22, of a coil-wound main heat exchanger, 20, in which the stream is partially condensed. The partially condensed stream, 203, is then withdrawn from the warm bundle and separated in a phase separator, 28, into its liquid and vapor phases to produce a liquid stream, 120, and vapor stream, 207. The vapor stream, 207, is sent to the middle bundle, 24, of the main heat exchanger in which the stream is further cooled and liquefied, and the liquefied stream, 204, is then sub-cooled in the cold bundle, 26, of the main heat exchanger, producing an LNG product stream, 205. The LNG product stream, 205, may be flashed and sent to an LNG storage tank, 30, with the boil-off gas (BOG) or flash gas, 401, from the tank being sent to a fuel header, flared, or recycled (not shown) to the overhead vapor stream, 202, fed to the main heat exchanger. The liquid stream, 120, from the phase separator, 28, is returned to the top of the scrub column, 10, as a reflux stream in order to provide the necessary reflux for operation of the scrub column. If the quantity of reflux generated is larger than required for the scrub column, a portion of liquid stream, 120, may be mixed with stream 207 and sent to the middle bundle, 24, of the main heat exchanger.

[0005] The stream of bottoms liquid, 103, from the scrub column, 10, which is rich in NGLs and HHCs, is expanded to partially vaporize the stream, and is then sent to the de-methanizer column of a fractionation unit in which the stream is subjected to further fractionation/separation. In the arrangement illustrated in Figure 1, the fractionation unit comprises a de-methanizer column (also referred to herein as a DeC1 column), a de-ethanizer column (also referred to herein as a DeC2 column), a de-propanizer column (also referred to herein as a DeC3 column), and a de-butanizer column (also referred to herein as a DeC4 column). Typically, these columns contain multiple stages to enhance the separation of the HHCs and NGLs from methane and lighter components of the natural gas.

[0006] The de-methanizer column, 12, separates the bottoms liquid, 103, from the scrub column into an overhead vapor rich in methane, and a bottoms liquid enriched in hydrocarbons heavier than methane. The overhead vapor is partially condensed in an overhead condenser to produce a liquid reflux stream that is returned to the de-methanizer column, 12, with the remaining vapor portion being withdrawn as from the de-methanizer column as an overhead vapor stream, 104. A portion of the bottoms liquid is heated in a re-boiler to provide boil-up for the de-methanizer column, 12, and the remainder of the bottoms liquid is withdrawn as stream 105, expanded to partially vaporizer the stream, and sent to the de-ethanizer column 14.

[0007] De-ethanizer column, 14, in turn separates the bottoms liquid, 105, from the de-methanizer column into an overhead vapor enriched in ethane, and a bottoms liquid enriched in hydrocarbons heavier than ethane. The overhead vapor is condensed in an overhead condenser, with a portion of the condensed overhead being returned to the de-ethanizer column, 14, as a reflux stream, and the remainder being withdrawn as a liquefied overhead stream, 106, enriched in ethane. A portion of the bottoms liquid is heated in a re-boiler to provide boil-up for the de-ethanizer column, 14, and the remainder of the bottoms liquid is withdrawn as stream 107, expanded, and sent to the de-propanizer column 16.

[0008] The de-propanizer column, 16, operating in a similar manner to the de-ethanizer column, then separates the bottoms liquid, 107, from the de-ethanizer column to provide a liquefied overhead stream, 108, enriched in propane and a bottoms liquid stream, 109, enriched in hydrocarbons heavier than propane. Likewise, the de-butanizer column, 18, operating in a similar manner to the de-ethanizer column, then separates the bottoms liquid, 109, from the de-propanizer column to provide a liquefied overhead stream, 110, enriched in butane and a bottoms liquid stream, 111, enriched in hydrocarbons heavier than butane.

[0009] As the liquefied overhead streams, 106, 108 and 110, from columns DeC2, DeC3 and DeC4 mainly comprise ethane, propane and butane, respectively, and the bottoms liquid 111 from column DeC4 is a C5+ (pentane and heavier hydrocarbon) rich stream, these NGL streams may, as discussed above, be sold or, as and where appropriate, used as refrigerant make-up. In some cases, a fraction of one or more of these streams may also be re-injected into the LNG product stream to adjust the heating value of the LNG product stream to an optimal value.

[0010] As noted above, each of columns DeC1, DeC2, DeC3 and DeC4 is equipped with an overhead condenser that generates reflux for the column by condensing at least a portion of the overhead vapor, thereby providing a liquid reflux stream that is returned to the top of the column. Having these overhead condensers adds to the capital cost of setting up and maintaining the system. However, eliminating the overhead condensers would lead to carryover of unwanted components into the overhead vapor streams. The condensers improve separation efficiency, and it is especially beneficial to have such condensers on the DeC1 and DeC2 columns. The temperature of the cold reflux stream needed depends on the composition of the natural gas stream. The lower the NGL content, the colder the reflux stream needs to be to efficiently knock out the desired NGL and HHC components into the liquid condensate stream. Eliminating the overhead condensers from the DeC1 and DeC2 columns would result in carryover of ethane and propane into, respectively, the overhead vapor streams from DeC1 and DeC2. This will result in ethane being lost with the DeC1 overhead and likewise in additional propane being present in the DeC2 overhead, thus negatively affecting both the purity of ethane in the DeC2 overhead (which likewise adversely affects its use as make-up refrigerant and/or value as a commercial product).

[0011] Typically, propane is used as a refrigerant for providing the cooling duty for the overhead condenser used with the DeC1 column. Such an arrangement has, in particular, been considered in fractionation and liquefaction systems where a propane pre-cooled mixed refrigerant (C3MR) cycle is being used, and in which propane refrigeration is therefore easily available.

[0012] US 2012/0090350 A1 describes a system and method of controlling the heating value of an LNG product in a natural gas liquefaction plant. The natural gas feed stream, after initial pre-treatment, is introduced into a scrub column to separate the natural gas feed into a C5+ depleted overhead vapor and a C3+ enriched bottoms liquid. Reflux for the scrub column is provided, in part, by an overhead condenser that uses low pressure propane refrigeration. A stream of the overhead vapor from the scrub column is sent to a liquefaction plant for liquefaction, and a stream of bottoms liquid is fractionated in an NGL fractionation unit to provide a C3 rich liquid stream and a C4+ rich liquid stream.

[0013] US 6,662,589 and US 2006/0260355 A1 describe processes in which a natural gas feed stream, after initial pre-treatment, is introduced into a scrub column to separate the natural gas feed into an overhead vapor and bottoms liquid. The overhead vapor stream withdrawn from the scrub column is cooled and partially condensed in the warm section of a main heat exchanger, and then separated in a phase separator into a liquid phase, which is returned to the top of the scrub column as a liquid reflux stream, and a remaining vapor phase which is further cooled and condensed in the cold section of the main heat exchanger to provide LNG product. The bottoms liquid stream withdrawn from the scrub column is fractionated in an NGL fractionation unit, comprising de-ethanizer, de-propanizer and de-butanizer columns, to provide C3, C4 and C5+ rich liquid streams, and a C1 and C2 rich vapor stream. The C1 and C2 rich vapor stream is condensed in the main heat exchanger to provide additional LNG product.

[0014] US 2008/0115532 A1 describes the operation of a scrub column used to remove heavier hydrocarbon components from a natural gas stream prior to liquefaction of the natural gas. Reflux for the scrub column can be provided by condensate from an overhead condenser and/or by a stream of LNG.

[0015] US 2008/0016910 A1 and US 2013/0061632 A1 describe processes in which a pre-treated natural gas feed stream is introduced into a scrub column to separate the natural gas feed into an overhead vapor and bottoms liquid. The overhead vapor stream withdrawn from the scrub column is cooled and condensed in the warm section of a main heat exchanger. The condensed stream is then divided into two streams, with one stream being returned to the top of the scrub column as a liquid reflux stream, and the other being sub-cooled in the cold section of the main heat exchanger to provide an LNG product stream. The bottoms liquid stream withdrawn from the scrub column is fractionated in an NGL fractionation system to provide C2, C3 and C4 product streams.

[0016] US 4,065,278, CA 1059425 and US 5,659,109 describe processes for producing LNG in which, similar to the processes described in US 6,662,589 and US 2006/0260355 A1, a pre-treated natural gas feed stream is fractionated in a scrub column, and reflux to the scrub column is provided by partially condensing the scrub column overhead in the main heat exchanger and returning the separated liquid phase to the scrub column as a liquid reflux stream, with at least a portion of the remaining vapor phase being further cooled and condensed to provide the LNG product.

[0017] US 4,445,917 describes a process for producing LNG in which, similar to the processes described in 2008/0016910 A1 and US 2013/0061632 A1, a pre-treated natural gas feed stream is fractionated in a scrub column, with the scrub column overhead being fully condensed and then divided to provide an LNG stream and a liquid reflux stream that is returned to the top of the scrub column.

[0018] US 5,956,971 teaches a process form producing LNG in which the natural gas feed is first processed in a fractionation column having a controlled freezing zone.

[0019] US2007012071 describes a process and system for producing LNG in which a pre-treated natural gas feed is separated in a fractionation column into a methane rich overhead and a C2+ rich bottoms liquid. The overhead stream is condensed, further cooled, and then flashed to generate a LNG stream and a flash gas. The flash gas is used as refrigerant in the main heat exchanger. A portion of the warmed flash gas is then re-compressed, cooled, condensed and introduced into the top of the fractionation column as a reflux stream.

[0020] US 5,588,308 describes a process of removing NGLs from a natural gas stream, in which the natural gas feed is partially condensed and separated into liquid and vapor phases, the vapor phase providing a natural gas product, and the liquid phase being introduced into and fractionated in a stripping column to provide an NGL stream.

[0021] US 2004/0200353 A1 describes a process for removing NGLs from a natural gas feed using a scrub column, reflux for which is provided by an overhead condenser.

[0022] It would be desirable to have improved methods and systems for fractionating and liquefying a natural gas feed stream.

BRIEF SUMMARY

[0023] According to a first aspect of the present invention, there is provided a method of fractionating and liquefying a natural gas feed stream, the method comprising:

(a) introducing the natural gas feed stream into a scrub column in which the natural gas feed stream is separated into a methane-rich vapor fraction collected as a first overhead vapor at the top of the scrub column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a first bottoms liquid at the bottom of the scrub column;

(b) withdrawing a stream of first overhead vapor from the top of the scrub column, and cooling, condensing and dividing said stream to form a first stream of liquefied first overhead, second stream of liquefied first overhead, and at least one further stream of liquefied first overhead;

(c) returning the first stream of liquefied first overhead to the scrub column as a reflux stream introduced into the top the scrub column, thereby providing reflux for the scrub column;

(d) forming a liquefied natural gas (LNG) product stream from the second stream of liquefied first overhead;

(e) withdrawing a stream of first bottoms liquid from the bottom of the scrub column, and introducing said stream into a de-methanizer column in which the stream of first bottoms liquid is separated into a methane-rich vapor fraction collected as a second overhead vapor at the top of the de-methanizer column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a second bottoms liquid at the bottom of the de-methanizer column; and

(f) providing reflux to the de-methanizer column by:

(1) introducing one of said further streams of liquefied first overhead as a reflux stream into the top of the de-methanizer column; and/or

(2) condensing, by indirect heat exchange with one of said further streams of liquefied first overhead, a portion of the second overhead vapor to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column.

[0024] According to a second aspect of the present invention, there is provided a system for fractionating and liquefying a natural gas feed stream, the system comprising:

a scrub column arranged and operable to receive the natural gas feed stream and separate said stream into a methane-rich vapor fraction collected as a first overhead vapor at the top of the scrub column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a first bottoms liquid at the bottom of the scrub column;

a set of conduits, one or more heat exchangers, and optionally one or more separators, arranged and operable to withdraw a stream of first overhead vapor from the top of the scrub column and to cool, condense and divide said stream to form a first stream of liquefied first overhead, second stream of liquefied first overhead, and at least one further stream of liquefied first overhead;

a conduit arranged and operable to return the first stream of liquefied first overhead to the scrub column as a reflux stream introduced into the top the scrub column, thereby providing reflux for the scrub column;

a conduit arranged and operable to withdraw from the system a liquefied natural gas (LNG) product stream formed from the second stream of liquefied first overhead;

a de-methanizer column arranged and operable to receive a stream of first bottoms liquid from the bottom of the scrub column and to separate said stream into a methane-rich vapor fraction collected as a second overhead vapor at the top of the de-methanizer column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a second bottoms liquid at the bottom of the de-methanizer column;
a conduit arranged and operable to withdraw the stream of first bottoms liquid from the bottom of the scrub column and introduce said stream into the de-methanizer column; and
one or both of:

(1) a conduit arranged and operable to introduce one of said further streams of liquefied first overhead as a reflux stream into the top of the de-methanizer column, thereby providing reflux for the de-methanizer column;
(2) a heat exchanger arranged and operable to condense, by indirect heat exchange with one of said further streams of liquefied first overhead, a portion of the second overhead vapor to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column, thereby providing reflux for the de-methanizer column, and a conduit arranged and operable to introduce said further stream of liquefied first overhead into said heat exchanger.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025]

Figure 1 is a schematic flow diagram depicting a comparative natural gas fractionation and liquefaction system and method, not in accordance with the present invention.

Figure 2 is a schematic flow diagram depicting a natural gas fractionation and liquefaction system and method in accordance with an embodiment of the present invention.

Figure 3 is a schematic flow diagram depicting a natural gas fractionation and liquefaction system and method in accordance with another embodiment of the present invention.

Figure 4 is a schematic flow diagram depicting a natural gas fractionation and liquefaction system and method in accordance with another embodiment of the present invention.

Figure 5 is a schematic flow diagram depicting a natural gas fractionation and liquefaction system and method in accordance with another embodiment of the present invention.

Figure 6 is a schematic flow diagram depicting a natural gas fractionation and liquefaction system and method in accordance with another embodiment of the present invention.

Figure 7 is a schematic flow diagram depicting a natural gas fractionation and liquefaction system and method in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION

[0026] This present invention provides novel options for providing reflux/condensing duty to the de-methanizer column in integration with the liquefaction of natural gas.

[0027] More specifically, and as noted above, according to the first aspect of the present invention a method of fractionating and liquefying a natural gas feed stream is provided, in which the overhead vapor from the top of the scrub column is cooled, condensed and divided to form a first stream of liquefied first overhead, second stream of liquefied first overhead, and at least one further stream of liquefied first overhead. The first stream of liquefied first overhead is reintroduced into the scrub column to provide reflux for the scrub column, the second stream of liquefied first overhead provides the desired LNG product, and the further stream of liquefied first overhead is used to provide or generate reflux for the de-methanizer column.

[0028] In particular, in a preferred embodiment the further stream of liquefied first overhead (i.e. the further stream of liquefied scrub column overhead) is introduced as a reflux stream into the top of the de-methanizer column, thereby providing reflux for said column.

[0029] This has the benefit, as compared to the conventional arrangement depicted in Figure 1 and described above, of allowing the overhead condenser for the de-methanizer column to be eliminated, thereby significantly reducing the capital cost of the method and system.

[0030] Furthermore, the liquefied first overhead (i.e. the liquefied scrub column overhead) will typically be colder than the condensed overhead that can be generated by condensing de-methanizer column overhead in a propane cooled overhead condenser. For example, the lowest temperature reflux stream attainable by using a propane kettle to condense overhead from the de-methanizer column is typically around -31 °C, whereas the reflux streams of -40°C or below are typically obtained when condensing, even if only partially, the scrub column overhead in the main heat exchanger or using the refrigerant used in the main heat exchanger. As such, using a stream of liquefied first overhead as a reflux stream in the de-methanizer column, rather than refluxing the de-methanizer column using a propane cooled overhead condenser, typically improves the separation of methane from ethane and heavier components in the de-methanizer column, which in turn improves the recovery of ethane in the bottoms liquid of the de-methanizer column.

[0031] In an another embodiment, reflux for the de-methanizer column is provided by condensing, by indirect heat exchange with the further stream of liquefied first overhead (i.e. the further stream of liquefied scrub column overhead), a portion of the second overhead vapor (i.e. the overhead vapor from the de-methanizer column) to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column.

[0032] In this embodiment, a dedicated overhead condenser for the de-methanizer column is still required, and so the capital cost savings provided by the previous embodiment are not obtained. However, this embodiment retains the benefit of using a, typically, colder stream to generate reflux for the de-methanizer, since the de-methanizer column is in this embodiment still using a stream of liquefied scrub column overhead to provide the cooling duty for refluxing the de-methanizer column, rather than using a propane refrigerant to provide said cooling duty. This embodiment is also beneficial when propane is not the pre-cooling refrigerant and may not be available. As such, this embodiment still provides the benefit of improving the separation of methane from ethane and heavier components in the de-methanizer column.

[0033] The articles "a" and "an", as used herein and unless otherwise indicated, 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 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.

[0034] As used herein, the term "natural gas feed stream" encompasses also streams comprising synthetic and/or substitute natural gases. The major component of natural gas is methane (which typically comprises at least about 85 mole%, more often at least about 90 mole%, and most typically about 95 mole% of the feed stream). The natural gas feed stream also contains smaller amounts of other, heavier hydrocarbons, such as ethane, propane, butanes, pentanes, etc. Other typical components of raw natural gas include one or more components such as nitrogen, helium, hydrogen, carbon dioxide and/or other acid gases, and mercury. However, the natural gas feed stream processed in accordance with the present invention will have been pre-treated if and as necessary to reduce the levels of any (relatively) high freezing point components, such as moisture, acid gases and mercury, down to such levels as are necessary to avoid freezing or other operational problems in the scrub column into which the natural gas feed stream is to be introduced.

[0035] As used herein, the term "methane-rich" refers to a stream, fraction or portion that comprises methane as its major component. The stream, fraction or portion may, in particular, have a concentration of methane that is similar to, or higher than, that of the natural gas feed stream. Thus, typically, the stream, fraction or portion will comprise at least about 85 mole%, more often at least about 90 mole%, and most typically about 95 mole% or more than about 95 mole% methane.

[0036] As used herein, the term "hydrocarbons heavier than methane" refers to hydrocarbons that have a lower volatility (i.e. higher boiling point) than methane. Similarly, the term "hydrocarbons heavier than ethane" refers to hydrocarbons that have a lower volatility (i.e. higher boiling point) than ethane, the term "hydrocarbons heavier than propane" refers to hydrocarbons that have a lower volatility (i.e. higher boiling point) than propane, and so on.

[0037] As used herein, the term "enriched in hydrocarbons heavier than methane" refers to a stream, fraction or portion that is enriched, relative to the natural gas feed stream, in hydrocarbons heavier than methane, and thus that has a higher mole % of hydrocarbons heavier than methane than that of the natural gas feed stream. Similarly, the term "enriched in ethane" refers to a stream, fraction or portion that is enriched, relative to the natural gas feed stream, in ethane, and so on.

[0038] As used herein, the term "indirect heat exchange" refers to heat exchange between two fluids where the two fluids are kept separate from each other by some form of physical barrier.

[0039] In one embodiment, step (b) of the method according to the first aspect comprises withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and partially condensing said stream, separating the resulting liquid and vapor phases, dividing the separated liquid phase to form the first stream of liquefied first overhead and at least one further stream of liquefied first overhead, and further cooling and condensing at least a portion of the separated vapor phase to form the second stream of liquefied first overhead. Preferably, the second stream of liquefied first overhead is then sub-cooled prior to forming the LNG product stream.

[0040] In another embodiment, step (b) of the method according to the first aspect comprises withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and partially condensing said stream, separating the resulting liquid and vapor phases, forming the first stream of liquefied first overhead from at least a portion of the separated liquid phase, further cooling and condensing at least a portion of the separated vapor phase, and dividing the resulting further cooled and condensed stream to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead. Preferably, the second stream of liquefied first overhead is then sub-cooled prior to forming the LNG product stream, or the cooled and condensed stream is sub-cooled prior to being divided to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead

[0041] In another embodiment, step (b) of the method according to the first aspect comprises a combination of the previous two embodiments.

[0042] In the above-mentioned embodiments, it is preferred that a coil-wound heat exchanger is used for further cooling and condensing the separated vapor phase. Thus, in one embodiment the stream of first overhead vapor from the top of the scrub column may be cooled and partially condensed in a warm bundle of a coil-wound main heat exchanger, and the at least a portion of the separated vapor phase is further cooled and condensed in a middle and/or cold bundle of the coil-wound main heat exchanger. In another embodiment the stream of first overhead vapor from the top of the scrub column may be cooled and partially condensed in an overhead condenser heat exchanger, and the at least a portion of the separated vapor phase is further cooled and condensed in a coil-wound main heat exchanger.

[0043] In another embodiment, step (b) of the method according to the first aspect comprises withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and condensing said stream, and dividing the cooled and condensed stream to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead.

[0044] The cooled and condensed stream may, in this embodiment, be sub-cooled prior to being divided to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead. Alternatively, the cooled and condensed stream may be divided to form the first stream of liquefied first overhead and another liquid stream that is then sub-cooled prior to being divided to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead. Alternatively, the second stream of liquefied first overhead may be sub-cooled prior to forming the LNG product stream.

[0045] In this embodiment, it is preferred that a coil-wound heat exchanger is used for cooling and condensing the stream of first overhead vapor from the top of the scrub column.

[0046] In the method according to the first aspect, it is preferred that the first stream of liquefied first overhead, used as a reflux stream in step (c), and the further stream(s) of liquefied first overhead, used in step (f), have a flow ratio of at least about 9:1.

[0047] Thus, it is preferred that the flow rate of the first stream of liquefied first overhead, used as a reflux stream in step (c), is about nine times or more than nine times greater than the flow rate of the further stream(s) of liquefied first overhead, used in step (f), compared on a like-for-like basis (e.g. mass flow rate to mass flow rate, or molar flow rate to molar flow rate, etc.). In those embodiments where the method uses in step (f) both a further stream of liquefied first overhead as a reflux stream and a further stream of liquefied first overhead to condense, by indirect heat, a portion of the second overhead vapor, it is preferred that flow rate of the first stream of liquefied first overhead, used as a reflux stream in step (c), is about nine times or more than nine times greater than the combined flow rate of both of said further streams of liquefied first overhead used in step (f).

[0048] In the method according to the first aspect, it is preferred that the first stream of liquefied first overhead, used as a reflux stream in step (c), and the further stream(s) of liquefied first overhead, used in step (f), each have a temperature of or below about -40°C.

[0049] In a preferred embodiment, the first overhead vapor and second overhead vapor each comprise at least about 95 mole % methane.

[0050] In a preferred embodiment, the second bottoms liquid comprises less than about 5 mole % methane.

[0051] In one embodiment, the method further comprises: withdrawing a stream of second overhead vapor from the top of the de-methanizer column; cooling and condensing all or a portion of said stream to form additional LNG product; and/or using all or a portion of said stream as a fuel stream; and/or exporting all or a portion of said stream as a gaseous natural gas product stream.

[0052] In one embodiment, the method further comprises withdrawing a stream of second bottoms liquid from the bottom of the de-methanizer column and fractionating the stream of second bottoms liquid to provide one or more natural gas liquids (NGL) streams.

[0053] In one embodiment, the step of fractionating the stream of second bottoms liquid comprises: introducing said stream into a de-ethanizer column in which the stream of second bottoms liquid is separated into ethane-enriched fraction, collected as a third overhead vapor at the top of the de-ethanizer column, and a fraction enriched in hydrocarbons heavier than ethane, collected as a third bottoms liquid at the bottom of the de-ethanizer column. The method may further comprise: withdrawing a stream of third overhead vapor from the top of the de-ethanizer column, and cooling and condensing said stream to form an NGL stream; and/or withdrawing a stream of third bottoms liquid from the bottom of the de-ethanizer column, and forming one or more NGL streams therefrom. The method may further comprise providing reflux to the de-ethanizer column by condensing, by indirect heat exchange with a further stream of liquefied first overhead, a portion of the third overhead vapor to form a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the de-ethanizer column. Preferably, the third overhead vapor comprises at least about 95% ethane. Preferably, the third bottoms liquid comprises less than about 5 mole % ethane. The third bottoms liquid may, if desired, be further fractionated, such as in a de-propanizer column and/or in a de-butanizer column, to further separate the third bottoms liquid into a propane-enriched fraction, a butane-enriched fraction, and/or a fraction enriched in pentanes and heavier hydrocarbons.

[0054] As is well known in the art, the terms "scrub column", "de-methanizer column" and "de-ethanizer column", "de-propanizer column" and "de-butanizer column" refer to types of distillation column. The term "distillation column" refers to a column containing one or more separation stages, composed of devices such as packing or trays, that increase contact and thus enhance mass transfer between upward rising vapor and downward flowing liquid flowing inside the column. In this way, the concentration of lighter (i.e. higher volatility and lower boiling point) components increases in the rising vapor that collects as overhead vapor at the top of the column, and the concentration of heavier (i.e. lower volatility and higher boiling point) components increases in the descending liquid that collects as bottoms liquid at the bottom of the column. The "top" of the distillation column refers to the part of the column at or above the top-most separation stage. The "bottom" of the column refers to the part of the column at or below the bottom-most separation stage. An "intermediate location" of the column refers to a location between the top and bottom of the column, between two separation stages.

[0055] In the case of the scrub column, the natural gas feed stream is introduced (as a gaseous stream or as a partially condensed, two-phase stream) into the scrub column at an intermediate location of the column or, more typically, at the bottom of the column. The upward rising vapor from the feed stream is then brought into contact, as it passes through one or more separation stages inside the scrub column, with a downward flowing liquid reflux stream, thereby "scrubbing" components heavier than methane from said vapor (i.e. removing at least some of said less volatile components from the vapor). This results, as noted above, in the natural gas feed stream being separated into a methane-rich vapor fraction collected as an overhead vapor (referred to herein as a "first overhead vapor") at the top of the scrub column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a bottoms liquid (referred to herein as a "first bottoms liquid") at the bottom of the scrub column.

[0056] In the case of the de-methanizer column, the stream of first bottoms liquid from the scrub column is, as noted above, further separated into a methane-rich vapor fraction, collected as an overhead vapor ("second overhead vapor") at the top of the de-methanizer column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a bottoms liquid ("second bottoms liquid") at the bottom of the de-methanizer column. The stream of first bottoms liquid is typically partially vaporized (via heating and/or expansion of the stream) prior to being introduced into the de-methanizer column as a two-phase stream. Typically the stream is introduced into the de-methanizer column at an intermediate location of the column, so that upward rising vapor from the stream is brought into contact, as it passes through one or more separation stages, with a downward flowing liquid reflux stream thereby scrubbing components heavier than methane from said vapor, and so that downward flowing liquid from the stream is brought into contact, as it passes through one or more separation stages, with upward rising vapor (typically provided by boiling a portion of the bottoms liquid collected at the bottom of the column) thereby "stripping" methane and components lighter than methane from the said liquid (i.e. removing at least some of said more volatile components from the liquid).

[0057] In the case of the de-ethanizer column, the stream of second bottoms liquid from the de-methanizer column is, as noted above, further separated into an ethane-enriched fraction, collected as an overhead vapor ("third overhead vapor") at the top of the de-ethanizer column, and a fraction enriched in hydrocarbons heavier than ethane, collected as a bottoms liquid ("third bottoms liquid") at the bottom of the de-ethanizer column. Operation of the de-ethanizer column is typically similar to that of the de-methanizer column, insofar as the stream of second bottoms liquid is typically partially vaporized prior to being introduced into the de-ethanizer column at an intermediate location of the column, so that upward rising vapor from the stream is scrubbed by a downward flowing reflux liquid of components heavier than ethane, and so that downward flowing liquid from the stream is stripped by upward rising vapor of ethane and components lighter than ethane.

[0058] As used herein, the term "separator" or "phase separator" refers to a device, such as drum or other form of vessel, in which a two phase stream can be introduced in order to separate the stream into its constituent vapor and liquid phases.

[0059] The system according to the second aspect of the present invention is suitable for carrying out the methods of the first aspect, and therefore the above-mentioned benefits of the method according to the first aspect of the invention apply equally to the systems according to the second aspect of the invention.

[0060] According to one embodiment of the second aspect, the set of conduits, one or more heat exchangers, and one or more separators arranged and operable to withdraw, cool, condense and divide the stream of first overhead vapor comprise: a conduit arranged and operable to withdraw the stream of first overhead vapor from the top of the scrub column; a heat exchanger or section of a heat exchanger arranged and operable to cool and partially condense said stream; a separator arranged and operable to separate the resulting liquid and vapor phases; a set of conduits arranged and operable to divide the separated liquid phase to form the first stream of liquefied first overhead and a further stream of liquefied first overhead; and a heat exchanger or section of a heat exchanger arranged and operable to receive, further cool and condense at least a portion of the separated vapor phase to form the second stream of liquefied first overhead.

[0061] The system may further comprise a heat exchanger or section of a heat exchanger arranged and operable to receive and sub-cool the second stream of liquefied first overhead. The section of a heat exchanger arranged and operable to cool and partially condense the stream of first overhead vapor may comprise a warm bundle of a coil-wound main heat exchanger, and the section of a heat exchanger arranged and operable to further cool and condense at least a portion of the separated vapor phase may comprise a middle and/or cold bundle of the coil-wound main heat exchanger. Alternatively, the heat exchanger arranged and operable to cool and partially condense the stream of first overhead vapor may comprise an overhead condenser heat exchanger, and the heat exchanger arranged and operable to further cool and condense at least a portion of the separated vapor phase may comprise a coil-wound main heat exchanger.

[0062] According to another embodiment of the second aspect, the set of conduits and one or more heat exchangers arranged and operable to withdraw, cool, condense and divide the stream of first overhead vapor comprise: a conduit arranged and operable to withdraw the stream of first overhead vapor from the top of the scrub column; a heat exchanger or section of a heat exchanger arranged and operable to cool and condense said stream; and a set of conduits arranged and operable to divide the cooled and condensed stream to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead.

[0063] The system may further comprise a heat exchanger or section of a heat exchanger arranged and operable to sub-cool the cooled and condensed stream prior to said stream being divided to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead. The system may further comprise a heat exchanger or section of a heat exchanger arranged and operable to sub-cool the second stream of liquefied first overhead.

[0064] In an embodiment of the second aspect, the system further comprises: a de-ethanizer column arranged and operable to receive a stream of second bottoms liquid from the bottom of the de-methanizer column and to separate said stream into an ethane-enriched fraction, collected as a third overhead vapor at the top of the de-ethanizer column, and a fraction enriched in hydrocarbons heavier than ethane, collected as a third bottoms liquid at the bottom of the de-ethanizer column; and a conduit arranged and operable to withdraw the stream of second bottoms liquid from the bottom of the de-methanizer column and introduce said stream into the de-ethanizer column. Said system may further comprise: a conduit arranged and operable to withdraw a stream of third overhead vapor from the top of the de-ethanizer column, and one or more heat exchangers arranged and operable to receive, cool and condense said stream to form an NGL stream; and/or a conduit arranged and operable to withdraw a stream of third bottoms liquid from the bottom of the de-ethanizer column, for forming one or more NGL streams therefrom. Said system may further comprise a heat exchanger arranged and operable to condense, by indirect heat exchange with a further stream of liquefied first overhead, a portion of the third overhead vapor to form a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the de-ethanizer column, thereby providing reflux for the de-ethanizer column, and a conduit arranged and operable to introduce said further stream of liquefied first overhead into said heat exchanger. The heat exchanger operable to cool and condense the stream of third overhead vapor to form an NGL stream, and the heat exchanger operable to condense a portion of the third overhead vapor to form a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the de-ethanizer column may be one and the same heat exchanger.

[0065] Further embodiments of the system according to the second aspect will be apparent from the foregoing discussion of embodiments of the method according to the first aspect.

[0066] Preferred aspects of the present invention include the following aspects, numbered #1 to #27:

#1. A method of fractionating and liquefying a natural gas feed stream, the method comprising:

(a) introducing the natural gas feed stream into a scrub column in which the natural gas feed stream is separated into a methane-rich vapor fraction collected as a first overhead vapor at the top of the scrub column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a first bottoms liquid at the bottom of the scrub column;

(b) withdrawing a stream of first overhead vapor from the top of the scrub column, and cooling, condensing and dividing said stream to form a first stream of liquefied first overhead, second stream of liquefied first overhead, and at least one further stream of liquefied first overhead;

(c) returning the first stream of liquefied first overhead to the scrub column as a reflux stream introduced into the top the scrub column, thereby providing reflux for the scrub column;

(d) forming a liquefied natural gas (LNG) product stream from the second stream of liquefied first overhead;

(e) withdrawing a stream of first bottoms liquid from the bottom of the scrub column, and introducing said stream into a de-methanizer column in which the stream of first bottoms liquid is separated into a methane-rich vapor fraction collected as a second overhead vapor at the top of the de-methanizer column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a second bottoms liquid at the bottom of the de-methanizer column; and
(f) providing reflux to the de-methanizer column by:

(1) introducing one of said further streams of liquefied first overhead as a reflux stream into the top of the de-methanizer column; and/or
(2) condensing, by indirect heat exchange with one of said further streams of liquefied first overhead, a portion of the second overhead vapor to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column.

#2. The method of Aspect #1, wherein step (b) comprises:

withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and partially condensing said stream, separating the resulting liquid and vapor phases, dividing the separated liquid phase to form the first stream of liquefied first overhead and at least one further stream of liquefied first overhead, and further cooling and condensing at least a portion of the separated vapor phase to form the second stream of liquefied first overhead; and/or
withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and partially condensing said stream, separating the resulting liquid and vapor phases, forming the first stream of liquefied first overhead from at least a portion of the separated liquid phase, further cooling and condensing at least a portion of the separated vapor phase, and dividing the resulting further cooled and condensed stream to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead.

#3. The method of Aspect #2, wherein:

the second stream of liquefied first overhead is sub-cooled prior to forming the LNG product stream; or
the cooled and condensed stream is sub-cooled prior to being divided to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead.

#4. The method of Aspect #2 or #3, wherein the stream of first overhead vapor from the top of the scrub column is cooled and partially condensed in a warm bundle of a coil-wound main heat exchanger, and the at least a portion of the separated vapor phase is further cooled and condensed in a middle and/or cold bundle of the coil-wound main heat exchanger.

#5. The method of Aspect #2 or #3, wherein the stream of first overhead vapor from the top of the scrub column is cooled and partially condensed in an overhead condenser heat exchanger, and the at least a portion of the separated vapor phase is further cooled and condensed in a coil-wound main heat exchanger.

#6. The method of Aspect #1, wherein step (b) comprises:
withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and condensing said stream, and dividing the cooled and condensed stream to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead.

#7. The method of Aspect #6, wherein:

the cooled and condensed stream is sub-cooled prior to being divided to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead; or
the cooled and condensed stream is divided to form the first stream of liquefied first overhead and another liquid stream that is then sub-cooled prior to being divided to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead; or
the second stream of liquefied first overhead is sub-cooled prior to forming the LNG product stream.

#8. The method of any one of Aspects #1 to #7, wherein the first stream of liquefied first overhead, used as a reflux stream in step (c), and the further stream(s) of liquefied first overhead, used in step (f), have a flow ratio of at least about 9:1.

#9. The method of any one of Aspects #1 to #8, wherein the first stream of liquefied first overhead, used as a reflux stream in step (c), and the further stream(s) of liquefied first overhead, used in step (f), each have a temperature of or below about -40°C.

#10. The method of any one of Aspects #1 to #9, wherein the first overhead vapor and second overhead vapor each comprise at least about 95 mole % methane, and the second bottoms liquid comprises less than about 5 mole % methane.

#11. The method of any one of Aspects #1 to #10, wherein the method further comprises: withdrawing a stream of second overhead vapor from the top of the de-methanizer column; cooling and condensing all or a portion of said stream to form additional LNG product; and/or using all or a portion of said stream as a fuel stream; and/or exporting all or a portion of said stream as a gaseous natural gas product stream.

#12. The method of any one of Aspects #1 to #11, wherein the method further comprises withdrawing a stream of second bottoms liquid from the bottom of the de-methanizer column and fractionating the stream of second bottoms liquid to provide one or more natural gas liquids (NGL) streams.

#13. The method of Aspect #12, wherein the step of fractionating the stream of second bottoms liquid comprises: introducing said stream into a de-ethanizer column in which the stream of second bottoms liquid is separated into ethane-enriched fraction, collected as a third overhead vapor at the top of the de-ethanizer column, and a fraction enriched in hydrocarbons heavier than ethane, collected as a third bottoms liquid at the bottom of the de-ethanizer column.

#14. The method of Aspect #13, wherein the method further comprises:

withdrawing a stream of third overhead vapor from the top of the de-ethanizer column, and cooling and condensing said stream to form an NGL stream; and/or
withdrawing a stream of third bottoms liquid from the bottom of the de-ethanizer column, and forming one or more NGL streams therefrom.

#15. The method of Aspect #13 or #14, wherein the method further comprises providing reflux to the de-ethanizer column by condensing, by indirect heat exchange with a further stream of liquefied first overhead, a portion of the third overhead vapor to form a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the de-ethanizer column.

#16. The method of any one of Aspects #13 to #15, wherein the third overhead vapor comprises at least about 95% ethane, and the third bottoms liquid comprises less than about 5 mole % ethane.

#17. A system for fractionating and liquefying a natural gas feed stream, the system comprising:

a scrub column arranged and operable to receive the natural gas feed stream and separate said stream into a methane-rich vapor fraction collected as a first overhead vapor at the top of the scrub column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a first bottoms liquid at the bottom of the scrub column;
a set of conduits, one or more heat exchangers, and optionally one or more separators, arranged and operable to withdraw a stream of first overhead vapor from the top of the scrub column and to cool, condense and divide said stream to form a first stream of liquefied first overhead, second stream of liquefied first overhead, and at least one further stream of liquefied first overhead;
a conduit arranged and operable to return the first stream of liquefied first overhead to the scrub column as a reflux stream introduced into the top the scrub column, thereby providing reflux for the scrub column;
a conduit arranged and operable to withdraw from the system a liquefied natural gas (LNG) product stream formed from the second stream of liquefied first overhead;
a de-methanizer column arranged and operable to receive a stream of first bottoms liquid from the bottom of the scrub column and to separate said stream into a methane-rich vapor fraction collected as a second overhead vapor at the top of the de-methanizer column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a second bottoms liquid at the bottom of the de-methanizer column;

a conduit arranged and operable to withdraw the stream of first bottoms liquid from the bottom of the scrub column and introduce said stream into the de-methanizer column; and
one or both of:

(1) a conduit arranged and operable to introduce one of said further streams of liquefied first overhead as a reflux stream into the top of the de-methanizer column, thereby providing reflux for the de-methanizer column;
(2) a heat exchanger arranged and operable to condense, by indirect heat exchange with one of said further streams of liquefied first overhead, a portion of the second overhead vapor to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column, thereby providing reflux for the de-methanizer column, and a conduit arranged and operable to introduce said further stream of liquefied first overhead into said heat exchanger.

#18. A system according to Aspect #17, wherein the set of conduits, one or more heat exchangers, and one or more separators arranged and operable to withdraw, cool, condense and divide the stream of first overhead vapor comprise:

a conduit arranged and operable to withdraw the stream of first overhead vapor from the top of the scrub column;
a heat exchanger or section of a heat exchanger arranged and operable to cool and partially condense said stream;
a separator arranged and operable to separate the resulting liquid and vapor phases;
a set of conduits arranged and operable to divide the separated liquid phase to form the first stream of liquefied first overhead and a further stream of liquefied first overhead; and
a heat exchanger or section of a heat exchanger arranged and operable to receive, further cool and condense at least a portion of the separated vapor phase to form the second stream of liquefied first overhead.

#19. A system according to Aspect #18, wherein the system further comprises a heat exchanger or section of a heat exchanger arranged and operable to receive and sub-cool the second stream of liquefied first overhead.

#20. A system according to Aspect #18 or #19, wherein the section of a heat exchanger arranged and operable to cool and partially condense the stream of first overhead vapor comprises a warm bundle of a coil-wound main heat exchanger, and the section of a heat exchanger arranged and operable to further cool and condense at least a portion of the separated vapor phase comprises a middle and/or cold bundle of the coil-wound main heat exchanger.

#21. A system according to Aspect #18 or #19, wherein the heat exchanger arranged and operable to cool and partially condense the stream of first overhead vapor comprises an overhead condenser heat exchanger, and the heat exchanger arranged and operable to further cool and condense at least a portion of the separated vapor phase comprises a coil-wound main heat exchanger.

#22. A system according to Aspect #17, wherein the set of conduits and one or more heat exchangers arranged and operable to withdraw, cool, condense and divide the stream of first overhead vapor comprise:

a conduit arranged and operable to withdraw the stream of first overhead vapor from the top of the scrub column;
a heat exchanger or section of a heat exchanger arranged and operable to cool and condense said stream; and
a set of conduits arranged and operable to divide the cooled and condensed stream to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead.

#23. A system according to Aspect #22, wherein the system further comprises a heat exchanger or section of a heat exchanger arranged and operable to sub-cool the cooled and condensed stream prior to said stream being divided to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead.

#24. A system according to Aspect #22, wherein the system further comprises a heat exchanger or section of a heat exchanger arranged and operable to sub-cool the second stream of liquefied first overhead.

#25. A system according to any one of Aspects #17 to #24, wherein the system further comprises:

a de-ethanizer column arranged and operable to receive a stream of second bottoms liquid from the bottom of the de-methanizer column and to separate said stream into an ethane-enriched fraction, collected as a third overhead vapor at the top of the de-ethanizer column, and a fraction enriched in hydrocarbons heavier than ethane, collected as a third bottoms liquid at the bottom of the de-ethanizer column; and

a conduit arranged and operable to withdraw the stream of second bottoms liquid from the bottom of the de-methanizer column and introduce said stream into the de-ethanizer column.

#26. A system according to Aspect #25, wherein the system further comprises:

a conduit arranged and operable to withdraw a stream of third overhead vapor from the top of the de-ethanizer column, and one or more heat exchangers arranged and operable to receive, cool and condense said stream to form an NGL stream; and/or

a conduit arranged and operable to withdraw a stream of third bottoms liquid from the bottom of the de-ethanizer column, for forming one or more NGL streams therefrom.

#27. A system according to Aspect #25 or #26, wherein the system further comprises a heat exchanger arranged and operable to condense, by indirect heat exchange with a further stream of liquefied first overhead, a portion of the third overhead vapor to form a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the de-ethanizer column, thereby providing reflux for the de-ethanizer column, and a conduit arranged and operable to introduce said further stream of liquefied first overhead into said heat exchanger.

[0067] Solely by way of example, certain preferred embodiment of the invention will now be described with reference to Figures 2 to 7. In Figure 1, described above, and Figures 2 to 7, described below, where a feature is common to more than one Figure that feature has been assigned the same reference numeral in each Figure, for clarity and brevity.

[0068] In the embodiments depicted in Figures 2 to 7, the main heat exchanger, that is used to liquefy the natural gas, is shown as being a coil-wound heat exchanger. However, while the use of such a heat exchanger is preferred, the main exchanger may equally be a plate and fin heat exchanger or any other kind of heat exchanger known in the art. Likewise, although in the embodiments depicted the coil bundles of the main heat exchanger are shown as being housed in a single casing or shell forming a single unit, the main heat exchanger could equally comprise a series of two or more units, with each bundle having its own casing/shell, or with one or more of the bundles being housed in one casing/shellt, and with one or more other bundles being housed in one or more different casings/shells. The refrigerant cycle used to supply cold refrigerant to the main heat exchanger may likewise be of any type suitable for carrying out the liquefaction of natural gas. Exemplary cycles known and used in the art, and that could be employed in the present invention, include the propane pre-cooled mixed refrigeration cycle (C3MR), single mixed refrigerant cycle (SMR), nitrogen expander cycle, methane expander cycle, dual mixed refrigerant cycle (DMR), and cascade cycle.

[0069] Referring now to Figure 2, in one embodiment of the invention a natural gas feed stream, 101, which typically will have been pre-treated to remove acid gases, water and mercury, and which may optionally also have been pre-cooled in one or more heat exchangers, is introduced into the bottom of a scrub column, 10, which contains multiple separation stages. The scrub column, 10, separates the natural gas feed into a methane-rich vapor fraction collected as overhead vapor (also referred to herein as a the 'first overhead vapor' or 'scrub column overhead vapor') at the top of the column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as bottoms liquid (also referred to herein as the 'first bottoms liquid' or 'scrub column bottoms liquid') at the bottom of the column. A stream of the overhead vapor, 202, is withdrawn from the top of the scrub column, and a stream of the bottoms liquid, 103, is withdrawn from the bottom of the scrub column.

[0070] The stream of first overhead vapor, 202, is sent to a main heat exchanger, 20, for cooling and liquefaction. In the illustrated embodiment, the main heat exchanger, 20, is a coil-wound heat exchanger containing warm, 22, middle, 24, and cold, 26, bundles housed in a single shell casing. The main heat exchanger may be supplied with any suitable refrigerant (not shown) by any suitable refrigerant cycle effective for carrying out the liquefaction of natural gas. The stream of overhead vapor, 202, is introduced into the warm end of the main heat exchanger, 20, and is cooled and partially condensed in the warm bundle, 22, to form a partially condensed (two-phase) stream, 203. The partially condensed stream, 203, is then withdrawn from the warm bundle and separated in a phase separator, 28, into its liquid and vapor phases to produce a liquid stream, 120, and vapor stream, 207.

[0071] The vapor stream, 207, is returned to the main heat exchanger, 20, in which it is first further cooled and fully condensed in the middle bundle, 24, to form a stream of liquified first overhead, 204. This stream of liquified first overhead is then sub-cooled in the cold bundle, 26, thereby producing an LNG product stream, 205. The LNG product stream, 205, may, as shown, be flashed (for example by passing the stream through a J-T valve) and sent to an LNG storage tank, 30, for storage. Boil-off gas (BOG) or flash gas, 401, from the tank may be sent to a fuel header, flared, or recycled to the overhead vapor stream fed to the main heat exchanger (not shown).

[0072] The liquid stream, 120, from the phase separator, 28, which is typically at or between a temperature of about -40 °C to about -70 °C, is divided, thereby forming two streams of liquefied first overhead, 125 and 121. Stream 125 typically comprises the majority of the flow of stream 120, the flow ratio of stream 125 to stream 121 typically being about 9:1 (stream 125 therefore typically comprising at least 90% of stream 120, and stream 121 typically comprising less than 10% of stream 120). Stream 125 is returned (typically by pumping or gravity) to the scrub column, 10, as a reflux stream introduced into the top of the scrub column, so as to provide the necessary reflux for operation of the scrub column. Stream 121 is sent (typically of after being passed through a J-T valve) to the top of a de-methanizer column, 12, as a reflux stream in order to provide the necessary reflux for operation of the de-methanizer column, as will be described in further detail below.

[0073] The stream of first bottoms liquid, 103, withdrawn from the scrub column, 10, is expanded (for example by being passed, as shown, through a J-T valve) to partially vaporize the stream, and is then introduced into an intermediate location of the de-methanizer column, 12, which also contains multiple separation stages. The de-methanizer column, 12, separates the first bottoms liquid, 103, into a methane-rich vapor fraction collected as overhead vapor (also referred to herein as the 'second overhead vapor' or 'de-methanizer column overhead vapor') at the top of the column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as bottoms liquid (also referred to herein as the 'second bottoms liquid' or 'de-methanizer column bottoms liquid') at the bottom of the column. Reflux for the de-methanizer column is, in this embodiment, and as noted above, provided by introducing a stream of liquefied first overhead , 121, as a reflux stream into the top of the de-methanizer column. A portion of the de-methanizer column bottoms liquid is, as shown, heated in a re-boiler (which may use any suitable heat source) in order to provide boil-up for the de-methanizer column, 12. The remainder of the bottoms liquid is withdrawn as a stream of second bottoms liquid, 105.

[0074] The temperatures and pressures in the scrub column and de-methanizer column are typically controlled so that the first overhead vapor and second overhead vapor (i.e. the scrub column overhead vapor and de-methanizer column overhead vapor) each comprise at least about 95 mole % methane, and so that the second bottoms liquid (i.e. the de-methanizer column bottoms liquid) comprises less than 5 mole % methane. Doing so maximizes the recovery and concentration of the NLGs and HHCs (i.e. $C2_+$ hydrocarbons) in the stream of second bottoms liquid withdrawn from the de-methanizer column. The temperature at the top of the scrub column and de-methanizer column is controlled by the temperature of the reflux streams, 125 and 125, formed from the liquefied first overhead, which reflux streams typically have, as noted above, a temperature of about -40 °C or below. The temperature at the bottom of the de-methanizer column is controlled by the de-methanizer re-boiler. The pressures in the columns are dictated by the pressure of the natural gas feed stream, 101, and the degree of pressure let down when the stream of first bottoms liquid (i.e. the stream of scrub column bottoms liquid), 103, is expanded.

[0075] The de-methanizer column overhead vapor withdrawn from the top of the de-methanizer column as a stream of second overhead vapor, 104, may be put to any suitable or desired purpose. It may, for example, be used as a fuel stream, and/or sent to a pipeline or otherwise sold and exported as a gaseous natural gas product stream. Additionally or alternatively it may (not shown) be cooled and condensed in the main heat exchanger (separately from and/or in combination with the first overhead vapor) to form and provide additional LNG product.

[0076] The stream of second bottoms liquid, 105, withdrawn from the bottom of the de-methanizer column, 12, is further fractionated in a NGL fractionation system, that in this case comprises a de-ethanizer column, 14, de-propanizer column 16, and de-butanizer column, 18, in order to provide the desired NGL streams (that can, for example and as discussed above, be used as make-up refrigerant, sold as separate commercial products, and/or selectively re-combined with the LNG product to tailor the heating value of the LNG product).

[0077] More specifically, the stream of second bottoms liquid (de-methanizer column bottoms liquid) is first cooled (for example by being passed, as shown, through a heat exchanger using air, water or another ambient temperature cooling medium) and the cooled stream, 105, is then expanded (for example by being passed, as shown, through a heat exchanger and a J-T valve) to form a partially vaporized (two-phase) stream that is introduced into an intermediate location the de-ethanizer column, 14, which also contains multiple separation stages. The de-ethanizer column, 14, separates the second bottoms liquid, 105, into a ethane-enriched vapor fraction collected as overhead vapor (also referred to herein as 'third overhead vapor' or 'de-ethanizer column overhead vapor') at the top of the column, and a liquid fraction, enriched in hydrocarbons heavier than ethane, collected as bottoms liquid (also referred to herein as the 'third bottoms liquid' or 'de-ethanizer column bottoms liquid') at the bottom of the column. Reflux for the de-ethanizer column is provided by condensing the de-ethanizer column overhead vapor in an overhead condenser heat exchanger (which can be supplied with any suitable refrigerant), a portion of the condensed overhead being returned to the de-ethanizer column, 14, as a reflux stream, and the remainder being withdrawn as a stream of liquefied third overhead, 106. A portion of the de-ethanizer column bottoms liquid is, as shown, heated in a re-boiler (which may use any suitable heat source) in order to provide boil-up for the de-ethanizer column, 14. The remainder of the bottoms liquid is withdrawn as a stream of third bottoms liquid, 107.

[0078] Due to the fact that (as discussed above) only very small amounts of methane are, typically, present in the stream of second bottoms liquid (de-methanizer column bottoms liquid), 105, fed to the de-ethanizer column, and due to the fact that the recovery/yield of ethane (and other NGLs) in the second bottoms liquid is typically very good, the de-ethanizer column in this embodiment can produce an overhead vapor stream enriched in ethane that both is of high purity and is produced in relatively high volumes, thereby maximizing the amount of high purity ethane that is available as make-up refrigerant and/or as a NGL product stream for sale. Typically, the third overhead vapor (de-ethanizer column overhead vapor) comprises at least about 95 mole % ethane, and the third bottoms liquid (de-ethanizer column bottoms liquid) comprises less than about 5 mole % ethane.

[0079] The stream of third bottoms liquid (de-ethanizer column bottoms liquid), 107, is expanded (for example by being passed through a J-T valve) to form a partially vaporized (two-phase) stream that is introduced into an intermediate location the de-propanizer column, 16, which also contains multiple separation stages. The depropanizer column, 16, separates the third bottoms liquid, 107, into a propane-enriched vapor fraction collected as overhead vapor (also referred to herein as 'fourth overhead vapor' or 'de-propanizer column overhead vapor') at the top of the column, and a liquid fraction, enriched in hydrocarbons heavier than propane, collected as bottoms liquid (also referred to herein as the 'fourth bottoms liquid' or 'de-propanizer column bottoms liquid') at the bottom of the column. Reflux for the de-propanizer column is provided by condensing the de-propanizer column overhead vapor in an overhead condenser heat exchanger (supplied with any suitable refrigerant), with a portion of the condensed overhead being returned to the de-propanizer column, 16, as a reflux stream, and the remainder being withdrawn as a stream of liquefied fourth overhead, 108. A portion of the de-propanizer column bottoms liquid is, as shown, heated in a re-boiler (which may use any suitable heat source) in order to provide boil-up for the de-propanizer column, 16. The remainder of the bottoms liquid is withdrawn as a stream of fourth bottoms liquid, 109.

[0080] The stream of fourth bottoms liquid (de-propanizer column bottoms liquid), 109, is expanded (for example by being passed through a J-T valve) to form a partially vaporized (two-phase) stream that is introduced into an intermediate location the de-butanizer column, 18, which also contains multiple separation stages. The de-butanizer column, 18, separates the fourth bottoms liquid, 109, into a butane-enriched vapor fraction collected as overhead vapor (also referred to herein as 'fifth overhead vapor' or 'de-butanizer column overhead vapor') at the top of the column, and a liquid fraction, enriched in hydrocarbons heavier than butane, collected as bottoms liquid (also referred to herein as the 'fifth bottoms liquid' or 'de-butanizer column bottoms liquid') at the bottom of the column. Reflux for the de-butanizer column is provided by condensing the de-butanizer column overhead vapor in an overhead condenser (supplied with any suitable refrigerant), with a portion of the condensed overhead being returned to the de-butanizer column, 18, as a reflux stream, and the remainder being withdrawn as a stream of liquefied fifth overhead, 110. A portion of the de-butanizer column bottoms liquid is, as shown, heated in a re-boiler (which may use any suitable heat source) in order to provide boil-up for the de-butanizer column, 18. The remainder of the bottoms liquid is withdrawn as a stream of fifth bottoms liquid, 111.

[0081] In comparison to the conventional arrangement shown in Figure 1, the method and system of the embodiment of the present invention depicted in Figure 2 therefore differs in the manner in which reflux is provided to the de-methanizer column. In particular, whereas in the arrangement in Figure 1 the stream of overhead vapor withdrawn from the scrub column is cooled, condensed and divided to provide just two streams of liquefied overhead, one of which (steam 205) is taken as the LNG product and the other of which (stream 120) is used as a reflux stream for the scrub column, in the arrangement in Figure 2 the stream of overhead vapor withdrawn from the scrub column (i.e. the stream of first overhead vapor) is cooled, condensed and divided to provide at least three streams of liquefied first overhead. A first stream of liquefied first overhead (stream 125) is returned to the scrub column as a reflux stream, a second stream of liquefied first overhead (stream 204) is taken as the LNG product (stream 205), and at least one further stream of liquefied first overhead (stream 121) is introduced as a reflux stream into the top of the de-methanizer column. This provides the benefits, discussed above, of eliminating the need for a dedicated overhead condenser for the de-methanizer column, and (typically) providing colder reflux to the de-methanizer column (thereby enhancing the recovery of ethane in the de-methanizer column bottoms liquid).

[0082] Instead of refluxing the scrub column and de-methanizer column using liquid separated in phase separator 28 from a partially condensed stream of first overhead, 203, the reflux streams for the scrub column and/or de-methanizer column can, in an alternative arrangements, be obtained from one or more colder locations of the main heat exchanger.

[0083] Thus, referring now to Figure 3, an alternative embodiment of the invention is depicted in which the main heat exchanger has only two bundles, namely a warm bundle, 22, and a cold bundle, 26. The stream of first overhead vapor, 202, withdrawn from the top of the scrub column, 10, is again introduced into the warm bundle, 22, but in this case the warm bundle functions to cool and fully condense the overhead vapor stream to form a stream of liquefied first overhead that is then divided to form the first stream of liquefied first overhead, 125, second stream of liquefied first overhead, 204, and further stream of liquefied first overhead, 121. As in the embodiment shown in Figure 2, the first stream of liquefied first overhead, 125, is then returned to the top of the scrub column, 10, as a reflux stream, the second stream of liquefied first overhead, 204, is sub-cooled in the cold bundle, 26, to provide the LNG product stream, 205, and the further stream of liquefied first overhead, 121, is introduced as a reflux stream into the top of the de-methanizer column.

[0084] Equally, referring now to Figure 4, in yet another embodiment the main heat exchanger again has only two bundles, namely a warm bundle, 22, and a cold bundle, 26, but in this embodiment all of the stream, 202, of first overhead withdrawn from the scrub column, 10, is cooled and fully condensed in the warm bundle, 22, to form a stream of liquefied first overhead, 204, and all of this stream is then sub-cooled in the cold bundle, 26, to form a sub-cooled stream of liquefied first overhead that is then divided to form the first stream of liquefied first overhead, 125, second stream of liquefied first overhead, 205, and further stream of liquefied first overhead, 121. In this embodiment the second stream of liquefied first overhead, 205, can then be taken as the LNG product stream without need for further cooling or processing. As in the embodiment shown in Figure 2, the first stream of liquefied first overhead, 125, is returned as a reflux stream to the top of the scrub column, 10, and the further stream of liquefied first overhead, 121, is introduced as a reflux stream into the top of the de-methanizer column.

[0085] In the embodiments depicted in Figures 3 and 4, the first and further streams of liquefied first overhead, 125 and 121, are typically much colder than the first and further streams of liquefied first overhead, 125 and 121, generated in the embodiment depicted in Figure 2, due to said streams originating from a colder location of the main heat exchanger in Figures 3 and 4. In the embodiment shown in Figure 3, streams 125 and 121 are typically at or between a temperature of about -100 °C to about -135 °C. In the embodiment shown in Figure 4, streams 125 and 121 are typically at or between a temperature of about -130 °C to about -160 °C. Since these streams are at a colder temperature, relatively lower flowrates of these streams are needed and can be used to provide the necessary reflux to the scrub column, 10, and de-methanizer column, 12 (the required flow rates of streams 125 and 121 in Figure 4 being less than those in Figure 3; and likewise the required flow rates of streams 125 and 121 in Figure 3 being less than those in Figure 2). The arrangements depicted in Figures 3 and 4 also eliminate the need for phase separator 28 and reduce the number of bundles required in the main heat exchanger, thereby further reducing the capital cost of these arrangements.

[0086] In yet further embodiments (not shown), a combination of two or more of the arrangements depicted in Figures 2, 3 and 4 can be used to provide the reflux streams for the scrub column and de-methanizer column. For example, in one arrangement the first stream of liquefied first overhead, 125, that is used to reflux scrub column may be generated by partially condensing the stream of first overhead vapor, 202, withdrawn from the scrub column, separating the liquid phase in a phase-separator, 28, and using the liquid phase to form the first stream of liquefied first overhead, 125, in a similar manner to that shown in Figure 2, whereas the further stream of liquefied first overhead, 121, that is used to reflux the de-methanizer column, is instead generated by dividing the further cooled and liquefied stream or subcooled stream exiting the middle or cold bundles of the main heat exchanger to form the second stream of liquefied first overhead. 204/205, and further stream of liquefied first overhead, 121, in a similar manner to that depicted in Figure 3 or 4.

[0087] Equally, in another arrangement the reflux streams for the scrub column and/or de-methanizer column may be obtained from any other location downstream of the cold end of the main exchanger, such as from the LNG tank. They may also be obtained from an LNG stream which has been produced in another part of the plant such as an end-flash exchanger (not shown) which liquefies a portion of natural gas stream, 101, while warming up BOG or flash gas, stream, 401.

[0088] In yet another embodiment, the reflux provided to the scrub column and/or de-methanizer column by the first and further streams of liquefied first overhead may be supplemented by, or may be supplemental to, reflux provided to the column(s) by overhead condenser(s) supplied with refrigerant and operated to condense at least a portion of the overhead from said column(s).

[0089] Referring now to Figures 5 and 6, yet further embodiments of the invention are shown which differ from the embodiment shown in Figure 2 in that the initial cooling and partial condensation of the stream of first overhead vapor, 202, does not take place in the warm bundle of the main heat exchanger, but instead takes place in a separate overhead condenser heat exchanger that is supplied with refrigerant by the same refrigeration cycle that supplies the refrigerant and cooling duty for the main heat exchanger. In Figures 5 and 6 a two bundle coil-wound heat exchanger, supplied with refrigerant by a propane-precooled mixed refrigerant cycle (C3MR), is depicted. As previously noted, the main heat exchanger may be a heat exchanger of another type, and different types of refrigeration cycle can equally be employed, but here just a coil-wound heat exchanger and a C3MR cycle is shown, for simplicity.

[0090] In the embodiments depicted in Figures 5 and 6, the natural gas is pre-cooled with propane refrigerant in a pre-cooler heat exchanger, 34, prior to being introduced as natural gas feed stream, 101, into the scrub column. The first overhead vapor stream, 202, withdrawn from the top of the scrub column, 10, is then partially cooled and condensed in an overhead condenser heat exchanger, 32, to form a partially condensed (two-phase) stream, 203. The partially condensed stream, 203, is separated in a phase separator, 28, into its liquid and vapor phases to produce a liquid stream, 120, and vapor stream, 207. The liquid stream, 120, is then divided to from the first stream of liquefied first overhead, 125, and further stream of liquefied first overhead, 121, that are then introduced as reflux streams into the scrub column, 10, and de-methanizer column, 12, as previously described in relation to the embodiment shown in Figure 2. The vapor stream, 207, is introduced into the main heat exchanger, 20, where it is further cooled, condensed and subcooled to form the second stream of liquefied first overhead that is taken as the LNG product stream, 205. The overhead condenser heat exchanger, 32, may be a plate and fin heat exchanger, a printed circuit heat exchanger, or any other suitable exchanger.

[0091] In the embodiment shown in Figure 5, the warm mixed refrigerant stream, 309, withdrawn from the bottom of the main heat exchanger, 20, is sent to a compression system (comprising a motor, 36, and associated compressors and inter-and after-coolers) where it is compressed to form a high pressure refrigerant stream, 312. This stream is then phase separated in a separator, 38, to produce a mixed refrigerant vapor (MRV) stream, 302, and a mixed refrigerant liquid (MRL) stream, 301. Both streams, 301 and 302, are sent to the main exchanger to be cooled in separate circuits. The cooled and at least partially condensed MRV stream is withdrawn from the cold end of the cold bundle of the main heat exchanger, expanded (for example by being passed through a J-T valve, as shown), and reintroduced into the shell-side of the main heat exchanger as a cold, low pressure, vaporized/vaporizing refrigerant stream 308 to provide cooling duty to the cold and warm bundles of the main heat exchanger. The cooled MRL stream is withdrawn from the cold end of the warm bundle of the main heat exchanger and is then divided to form two streams. One stream is expanded to a form cold, vaporized/vaporizing low pressure refrigerant stream, 307, that is reintroduced into the shell-side of the main heat exchanger to provide further cooling duty to the warm bundle of the main heat exchanger. The other stream, 320, is expanded (for example by being passed through a J-T valve, as shown) to form cold, vaporized/vaporizing low pressure refrigerant stream, typically at a temperature of a temperature at or between about -60°C to about -120°C, that is passed through overhead condenser heat exchanger 32 to provide the cooling duty for partially condensing the first overhead vapor stream, 202, withdrawn from the top of the scrub column, 10. The warmed refrigerant stream, 350, exiting the overhead condenser heat exchanger, 32, may then be recombined with the warmed refrigerant exiting the warm end of the main heat exchanger as stream 309. Alternatively, if stream 350 is still two-phase, it may be further expanded and sent to the shell-side of the main heat exchanger at an intermediate location to provide additional cooling duty to the warm bundle of the main heat exchanger.

[0092] A benefit of partially condensing the first overhead vapor stream from the scrub column in a separate overhead heat exchanger via heat exchange with refrigerant from the main heat exchanger, rather than in the a warm bundle of the main heat exchanger itself, is that it eliminates multiple circuits and bundles in the main heat exchanger. It also leads to a lower complexity system that is easier to operate. The flow split between streams refrigerant steams 307 and 320 is adjusted based on the overhead temperature of the columns which is in turn determined based on the required purity of the overhead streams from the columns.

[0093] In the embodiment shown in Figure 6, the operation of the refrigeration cycle is similar to that illustrated in Figure 5 and described above. The only difference is that, in the embodiment depicted in Figure 6, the refrigerant stream, 320, supplied to the overhead condenser heat exchanger, 32, is not derived by dividing cooled MRL stream that is withdrawn from the cold end of the warm bundle of the main heat exchanger, but rather by dividing cooled and at least partially condensed MRV stream is withdrawn from the cold end of the cold bundle of the main heat exchanger. The temperature of stream 320, after expansion, is in this case typically at or between about -140°C to -160°C, and is therefore much colder than the equivalent refrigerant stream, 320, in the embodiment shown in Figure 5.

[0094] In addition to the MRL and MRV streams shown in Figures 5-6, additional locations exist from which the refrigerant stream sent to the overhead condenser heat exchanger, 32, may be obtained. These vary with the refrigeration cycle employed. For instance, in the SMR cycle which employs up to four mixed refrigerant streams of different compositions, the refrigerant to generate reflux may be obtained from any of these.

[0095] Referring now to Figure 7, yet another embodiment of the invention is shown, which differs from the embodiment shown in Figure 2 in that the further stream of liquefied first overhead, 121, instead of being introduced into the top of the de-methanizer column, 12, as a reflux stream, is instead used as a refrigerant stream in an overhead condenser heat exchanger in which a portion of the second overhead vapor (i.e. a portion of the de-methanizer column overhead vapor) is condensed, by indirect heat exchange with the further stream of liquefied first overhead, to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column. Thus, although the further stream of liquefied first overhead is not itself used as a reflux stream in the de-methanizer column, in this embodiment the further stream of liquefied first overhead does supply the cooling duty for generating the reflux in the de-methanizer column, and so is still indirectly generating reflux for the de-methanizer column.

[0096] More specifically, and as shown in Figure 7, in this embodiment the stream of first liquefied overhead, 202, withdrawn from the top of the scrub column, 10, is again cooled and partially condensed in the warm bundle 22 of the main heat exchanger, 20, to form a two phase stream, 203, that is then separated into its liquid and vapor phases in separator 28. The liquid phase, 120, is again further divided to form a first stream of liquefied first overhead, 125, and, in this case, two further streams of liquefied first overhead, 121 and 122. The first stream of liquefied first overhead, 125, is, as before, reintroduced into the top of the scrub column, 10, to provide reflux for this column. However, the two further streams of liquefied first overhead, 121 and 125, are in this case used as refrigerant streams to supply cooling duty to a de-methanizer column overhead condenser heat exchanger, 40, and to a de-ethanizer column overhead condenser heat exchanger, 42, respectively.

[0097] In this case, reflux for the de-methanizer column, 12, is, therefore, generated by: withdrawing a stream of de-methanizer column overhead vapor ('second overhead vapor') from the top of the de-methanizer column; partially condensing said stream in the de-methanizer column overhead condenser, 40, by indirect heat exchange with one of the further streams of liquefied first overhead, 121; separating the liquid and vapor phases; returning the liquid phase as to the de-methanizer column as a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the column; and withdrawing the remaining vapor phase as a stream of second overhead vapor, 104 (which stream can, for example and as discussed above, be used as fuel, exported as a gaseous natural gas product, and/or liquefied to provide additional LNG product).

[0098] Similarly, in this embodiment reflux for the de-ethanizer column, 14, is, therefore, generated by: withdrawing a stream of de-ethanizer column overhead vapor ('third overhead vapor') from the top of the de-ethanizer column; condensing said stream in the de-ethanizer column overhead condenser, 42, by indirect heat exchange with another of the further streams of liquefied first overhead, 122; returning a portion of the liquefied overhead to the de-ethanizer column as a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the column; and withdrawing the remaining portion of the liquefied overhead as a stream of liquefied third overhead, 106 (which stream can, for example and as discussed above, be sold as an NGL product, used as make-up refrigerant, and/or recombined with the LNG product to adjust the heating value of the latter).

[0099] The warmed streams of first overhead, 126 and 127, exiting the de-methanizer column overhead condenser, 40, and de-ethanizer column overhead condenser, 42, may be put to any suitable or desired use. For example, they may be re-injected into the natural gas feed, and/or used as refrigerant make-up.

[0100] Again, many variations of the arrangement shown in Figure 7 are also possible. For example, instead of obtaining some or all of streams 125, 121 and 122 from phase separator 28 as shown in Figure 7, streams 125, 121 and/or 122 may be obtained from a colder locations of the main heat exchanger, in a similar manner to the first and further streams of liquefied first overhead generated in the embodiments depicted in Figures 3 and 4.

EXAMPLE

[0101] In order to illustrate the operation of the invention, the methods of removing refrigerant from a natural gas liquefaction system as described and depicted in Figures 2 and 3 were simulated using ASPEN Plus software.

[0102] Table 1 below lists the conditions and compositions of the various streams for the simulation of the method depicted in Figure 2, and Table 2 lists the conditions and compositions of the various streams for the simulation of the method depicted in Figure 3. The data in these tables illustrates that utilizing a portion a further stream of liquefied first overhead (generated from cooling, liquefying and dividing the first overhead vapor withdrawn from the scrub column), in order to reflux the de-methanizer column, leads to effective separation of heavy hydrocarbons and NGL components from natural gas. Additionally, these arrangement lead to a reduction in equipment count, as compared to conventional arrangements such as depicted in Figure 1, by eliminating a the de-methanizer column overhead condenser and reflux drum, thereby leading to cost savings and simpler operation.

Table 1

Stream No.	101	125	121	103	104	105	202	203	207
Temperature °C	-34.10	-64.72	-64.72	-35.54	-66.47	30.00	-38.48	-64.72	-64.72
Pressure bara	63.25	55.17	55.17	61.09	26.89	26.95	61.03	55.17	55.17
Flowrate kgmole/ h	45,410	1,376	16	127	65	78	46,658	46,658	45,266
Flowrate kg/h	758,356	31,911	376	6,835	1,082	6,128	783,433	783,433	751,146
Composition Carbon Dioxide Mol%	0.00500	0.00996	0.00996	0.00132	0.00506	0.00000	0.00516	0.00516	0.00501
Nitrogen Mol%	0.494	0.160	0.160	0.096	0.227	0.000	0.485	0.485	0.495
Methane Mol%	96.866	78.358	78.358	40.015	96.771	0.700	96.476	96.476	97.033
Ethane Mol%	1.730	6.403	6.403	4.962	2.400	7.392	1.859	1.859	1.719
Propane Mol%	0.522	5.382	5.382	4.734	0.480	8.410	0.654	0.654	0.508
Isobutane Mol%	0.111	2.827	2.827	3.277	0.063	5.859	0.182	0.182	0.101
Butane Mol%	0.115	3.162	3.162	5.147	0.046	8.982	0.191	0.191	0.100
Isopentane Mol%	0.025	1.269	1.269	2.328	0.005	4.042	0.055	0.055	0.018
Pentane Mol%	0.027	1.535	1.535	3.326	0.004	5.721	0.062	0.062	0.017
Hexane Mol%	0.033	0.852	0.852	10.533	0.000	17.299	0.028	0.028	0.003
Heptane Mol%	0.071	0.027	0.027	25.289	0.000	41.117	0.001	0.001	0.000
Benzene ppm	9.0	143.8	143.8	2,923.7	0.1	4,782.5	5.0	5.0	0.7

Table 2

Stream No.	101	125	121	103	104	105	202	204
Temperature °C	-19.94	-125.48	-126.11	121.11	-61.64	30.00	-68.15	-126.11
Pressure bara	52.13	51.98	43.36	52.24	27.58	27.78	51.98	43.36
Flowrate kgmole/h	30,980	13,441	13	42	20	35	44,391	30,925
Flowrate kg/h	514,824	222,223	213	3,308	343	3,177	733,952	511,303
Composition								
Carbon Dioxide Mol%	0.00500	0.00500	0.00500	0.00586	0.01579	0.00000	0.00500	0.00500
Nitrogen Mol%	0.846	0.847	0.847	0.006	0.569	0.000	0.847	0.847
Methane Mol%	96.979	97.093	97.093	12.451	90.363	0.000	97.093	97.093
Ethane Mol%	1.574	1.571	1.571	3.327	8.038	0.050	1.571	1.571
Propane Mol%	0.312	0.308	0.308	3.010	1.012	3.134	0.308	0.308
Isobutane Mol%	0.060	0.058	0.058	1.634	0.001	1.967	0.058	0.058
Butane Mol%	0.071	0.067	0.067	3.078	0.001	3.691	0.067	0.067
Isopentane Mol%	0.036	0.031	0.031	3.608	0.000	4.310	0.031	0.031
Pentane Mol%	0.024	0.019	0.019	3.567	0.000	4.257	0.019	0.019
Hexane Mol%	0.022	0.000	0.000	15.918	0.000	18.967	0.000	0.000
Heptane Mol%	0.022	0.000	0.000	16.241	0.000	19.352	0.000	0.000
Benzene ppm	113.0	1.0	1.0	83,058.2	0.0	98,966.8	1.0	1.0

[0103] It will be appreciated that the invention is not restricted to the details described above with reference to the preferred embodiments but that numerous modifications and variations can be made without departing from the spirit or scope of the invention as defined in the following claims.

Claims

1. A method of fractionating and liquefying a natural gas feed stream, the method comprising:

(a) introducing the natural gas feed stream into a scrub column in which the natural gas feed stream is separated into a methane-rich vapor fraction collected as a first overhead vapor at the top of the scrub column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a first bottoms liquid at the bottom of the scrub column;

(b) withdrawing a stream of first overhead vapor from the top of the scrub column, and cooling, condensing and dividing said stream to form a first stream of liquefied first overhead, second stream of liquefied first overhead,

and at least one further stream of liquefied first overhead;
(c) returning the first stream of liquefied first overhead to the scrub column as a reflux stream introduced into the top the scrub column, thereby providing reflux for the scrub column;
(d) forming a liquefied natural gas (LNG) product stream from the second stream of liquefied first overhead;
(e) withdrawing a stream of first bottoms liquid from the bottom of the scrub column, and introducing said stream into a de-methanizer column in which the stream of first bottoms liquid is separated into a methane-rich vapor fraction collected as a second overhead vapor at the top of the de-methanizer column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a second bottoms liquid at the bottom of the de-methanizer column; and
(f) providing reflux to the de-methanizer column by:

(1) introducing one of said further streams of liquefied first overhead as a reflux stream into the top of the de-methanizer column; and/or
(2) condensing, by indirect heat exchange with one of said further streams of liquefied first overhead, a portion of the second overhead vapor to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column.

2. The method of Claim 1, wherein step (b) comprises:

withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and partially condensing said stream, separating the resulting liquid and vapor phases, dividing the separated liquid phase to form the first stream of liquefied first overhead and at least one further stream of liquefied first overhead, and further cooling and condensing at least a portion of the separated vapor phase to form the second stream of liquefied first overhead; and/or
withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and partially condensing said stream, separating the resulting liquid and vapor phases, forming the first stream of liquefied first overhead from at least a portion of the separated liquid phase, further cooling and condensing at least a portion of the separated vapor phase, and dividing the resulting further cooled and condensed stream to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead.

3. The method of Claim 1 or 2, wherein:

the second stream of liquefied first overhead is sub-cooled prior to forming the LNG product stream; or
the cooled and condensed stream is sub-cooled prior to being divided to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead, or

wherein the stream of first overhead vapor from the top of the scrub column is cooled and partially condensed in a warm bundle of a coil-wound main heat exchanger, and the at least a portion of the separated vapor phase is further cooled and condensed in a middle and/or cold bundle of the coil-wound main heat exchanger, or
wherein the stream of first overhead vapor from the top of the scrub column is cooled and partially condensed in an overhead condenser heat exchanger, and the at least a portion of the separated vapor phase is further cooled and condensed in a coil-wound main heat exchanger.

4. The method according to any one of the preceding claims, wherein step (b) comprises:

withdrawing the stream of first overhead vapor from the top of the scrub column, cooling and condensing said stream, and dividing the cooled and condensed stream to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead.

5. The method of Claim 4, wherein:

the cooled and condensed stream is sub-cooled prior to being divided to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead; or
the cooled and condensed stream is divided to form the first stream of liquefied first overhead and another liquid stream that is then sub-cooled prior to being divided to form the second stream of liquefied first overhead and at least one further stream of liquefied first overhead; or
the second stream of liquefied first overhead is sub-cooled prior to forming the LNG product stream.

6. The method according to any one of the preceding claims, wherein the first stream of liquefied first overhead, used as a reflux stream in step (c), and the further stream(s) of liquefied first overhead, used in step (f), have a flow ratio of at least about 9:1, or
wherein the first stream of liquefied first overhead, used as a reflux stream in step (c), and the further stream(s) of liquefied first overhead, used in step (f), each have a temperature of or below about -40°C, or
wherein the first overhead vapor and second overhead vapor each comprise at least about 95 mole % methane, and the second bottoms liquid comprises less than about 5 mole % methane.

7. The method according to any one of the preceding claims, wherein the method further comprises: withdrawing a stream of second overhead vapor from the top of the de-methanizer column; cooling and condensing all or a portion of said stream to form additional LNG product; and/or using all or a portion of said stream as a fuel stream; and/or exporting all or a portion of said stream as a gaseous natural gas product stream,
or
wherein the method further comprises withdrawing a stream of second bottoms liquid from the bottom of the de-methanizer column and fractionating the stream of second bottoms liquid to provide one or more natural gas liquids (NGL) streams.

8. The method of Claim 7, wherein the step of fractionating the stream of second bottoms liquid comprises: introducing said stream into a de-ethanizer column in which the stream of second bottoms liquid is separated into ethane-enriched fraction, collected as a third overhead vapor at the top of the de-ethanizer column, and a fraction enriched in hydrocarbons heavier than ethane, collected as a third bottoms liquid at the bottom of the de-ethanizer column.

9. The method of Claim 8, wherein the method further comprises:

withdrawing a stream of third overhead vapor from the top of the de-ethanizer column, and cooling and condensing said stream to form an NGL stream; and/or
withdrawing a stream of third bottoms liquid from the bottom of the de-ethanizer column, and forming one or more NGL streams therefrom, or

wherein the method further comprises providing reflux to the de-ethanizer column by condensing, by indirect heat exchange with a further stream of liquefied first overhead, a portion of the third overhead vapor to form a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the de-ethanizer column, or
wherein the third overhead vapor comprises at least about 95% ethane, and the third bottoms liquid comprises less than about 5 mole % ethane.

10. A system for fractionating and liquefying a natural gas feed stream, the system comprising:

a scrub column arranged and operable to receive the natural gas feed stream and separate said stream into a methane-rich vapor fraction collected as a first overhead vapor at the top of the scrub column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a first bottoms liquid at the bottom of the scrub column;
a set of conduits, one or more heat exchangers, and optionally one or more separators, arranged and operable to withdraw a stream of first overhead vapor from the top of the scrub column and to cool, condense and divide said stream to form a first stream of liquefied first overhead, second stream of liquefied first overhead, and at least one further stream of liquefied first overhead;
a conduit arranged and operable to return the first stream of liquefied first overhead to the scrub column as a reflux stream introduced into the top the scrub column, thereby providing reflux for the scrub column;
a conduit arranged and operable to withdraw from the system a liquefied natural gas (LNG) product stream formed from the second stream of liquefied first overhead;
a de-methanizer column arranged and operable to receive a stream of first bottoms liquid from the bottom of the scrub column and to separate said stream into a methane-rich vapor fraction collected as a second overhead vapor at the top of the de-methanizer column, and a liquid fraction, enriched in hydrocarbons heavier than methane, collected as a second bottoms liquid at the bottom of the de-methanizer column;
a conduit arranged and operable to withdraw the stream of first bottoms liquid from the bottom of the scrub column and introduce said stream into the de-methanizer column; and
one or both of:

(1) a conduit arranged and operable to introduce one of said further streams of liquefied first overhead as

a reflux stream into the top of the de-methanizer column, thereby providing reflux for the de-methanizer column;
(2) a heat exchanger arranged and operable to condense, by indirect heat exchange with one of said further streams of liquefied first overhead, a portion of the second overhead vapor to form a stream of liquefied second overhead that is reintroduced as a reflux stream into the top the de-methanizer column, thereby providing reflux for the de-methanizer column, and a conduit arranged and operable to introduce said further stream of liquefied first overhead into said heat exchanger.

11. A system according to Claim 10, wherein the set of conduits, one or more heat exchangers, and one or more separators arranged and operable to withdraw, cool, condense and divide the stream of first overhead vapor comprise:

a conduit arranged and operable to withdraw the stream of first overhead vapor from the top of the scrub column;
a heat exchanger or section of a heat exchanger arranged and operable to cool and partially condense said stream;
a separator arranged and operable to separate the resulting liquid and vapor phases;
a set of conduits arranged and operable to divide the separated liquid phase to form the first stream of liquefied first overhead and a further stream of liquefied first overhead; and
a heat exchanger or section of a heat exchanger arranged and operable to receive, further cool and condense at least a portion of the separated vapor phase to form the second stream of liquefied first overhead.

12. A system according to Claims 10 or 11, wherein the system further comprises a heat exchanger or section of a heat exchanger arranged and operable to receive and sub-cool the second stream of liquefied first overhead, or
wherein the section of a heat exchanger arranged and operable to cool and partially condense the stream of first overhead vapor comprises a warm bundle of a coil-wound main heat exchanger, and the section of a heat exchanger arranged and operable to further cool and condense at least a portion of the separated vapor phase comprises a middle and/or cold bundle of the coil-wound main heat exchanger, or
wherein the heat exchanger arranged and operable to cool and partially condense the stream of first overhead vapor comprises an overhead condenser heat exchanger, and the heat exchanger arranged and operable to further cool and condense at least a portion of the separated vapor phase comprises a coil-wound main heat exchanger.

13. A system according to Claims 10 to 12, wherein the set of conduits and one or more heat exchangers arranged and operable to withdraw, cool, condense and divide the stream of first overhead vapor comprise:

a conduit arranged and operable to withdraw the stream of first overhead vapor from the top of the scrub column;
a heat exchanger or section of a heat exchanger arranged and operable to cool and condense said stream; and
a set of conduits arranged and operable to divide the cooled and condensed stream to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead.

14. A system according to Claims 10 to 13, wherein the system further comprises a heat exchanger or section of a heat exchanger arranged and operable to sub-cool the cooled and condensed stream prior to said stream being divided to form the first stream of liquefied first overhead, the second stream of liquefied first overhead, and at least one further stream of liquefied first overhead, or
wherein the system further comprises a heat exchanger or section of a heat exchanger arranged and operable to sub-cool the second stream of liquefied first overhead.

15. A system according to Claims 10 to 14, wherein the system further comprises:

a de-ethanizer column arranged and operable to receive a stream of second bottoms liquid from the bottom of the de-methanizer column and to separate said stream into an ethane-enriched fraction, collected as a third overhead vapor at the top of the de-ethanizer column, and a fraction enriched in hydrocarbons heavier than ethane, collected as a third bottoms liquid at the bottom of the de-ethanizer column; and
a conduit arranged and operable to withdraw the stream of second bottoms liquid from the bottom of the de-methanizer column and introduce said stream into the de-ethanizer column.

16. A system according to Claim 15, wherein the system further comprises:

a conduit arranged and operable to withdraw a stream of third overhead vapor from the top of the de-ethanizer column, and one or more heat exchangers arranged and operable to receive, cool and condense said stream to form an NGL stream; and/or
a conduit arranged and operable to withdraw a stream of third bottoms liquid from the bottom of the de-ethanizer column, for forming one or more NGL streams therefrom, or

wherein the system further comprises a heat exchanger arranged and operable to condense, by indirect heat exchange with a further stream of liquefied first overhead, a portion of the third overhead vapor to form a stream of liquefied third overhead that is reintroduced as a reflux stream into the top the de-ethanizer column, thereby providing reflux for the de-ethanizer column, and a conduit arranged and operable to introduce said further stream of liquefied first overhead into said heat exchanger.

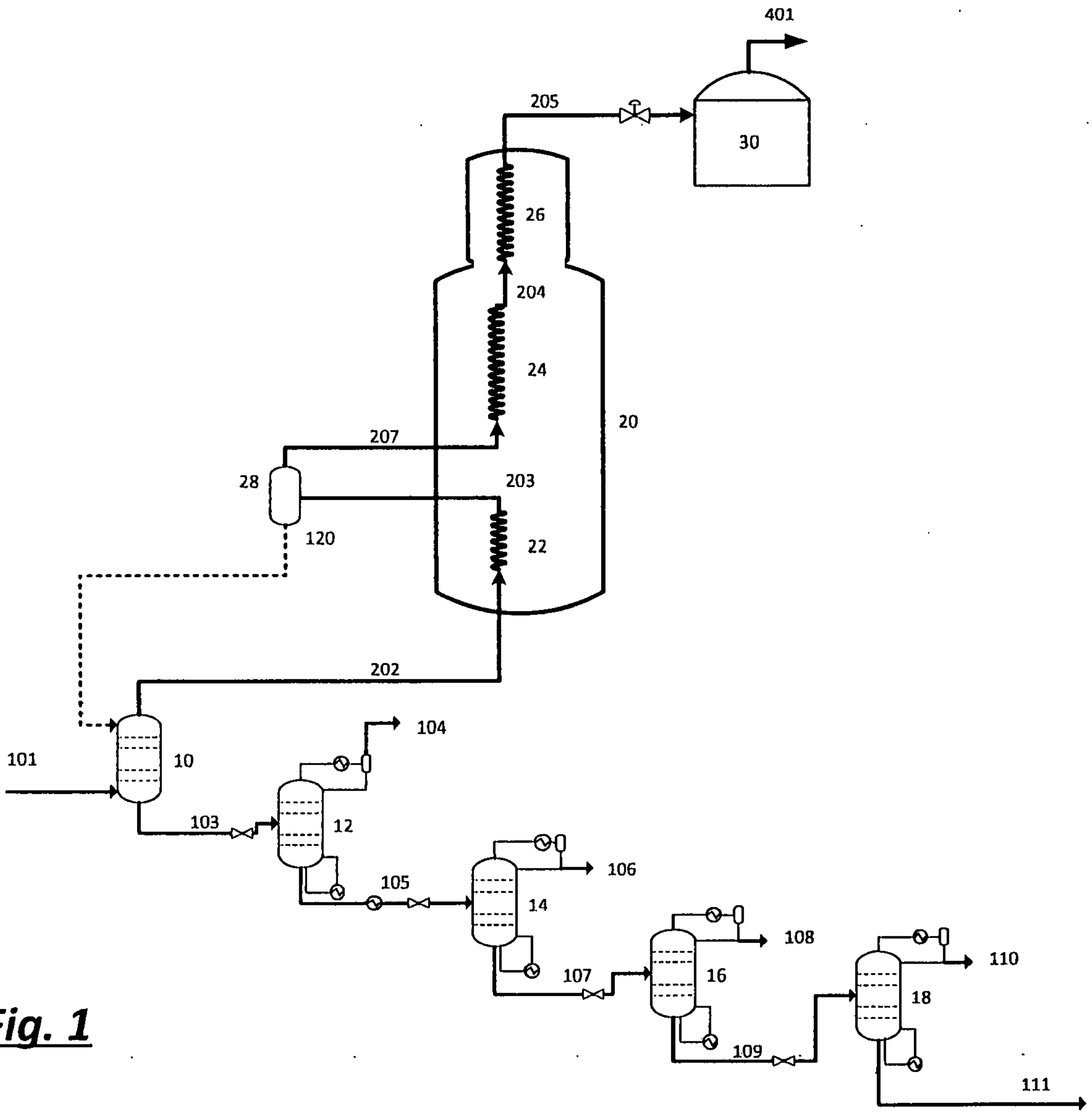
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Fig. 1

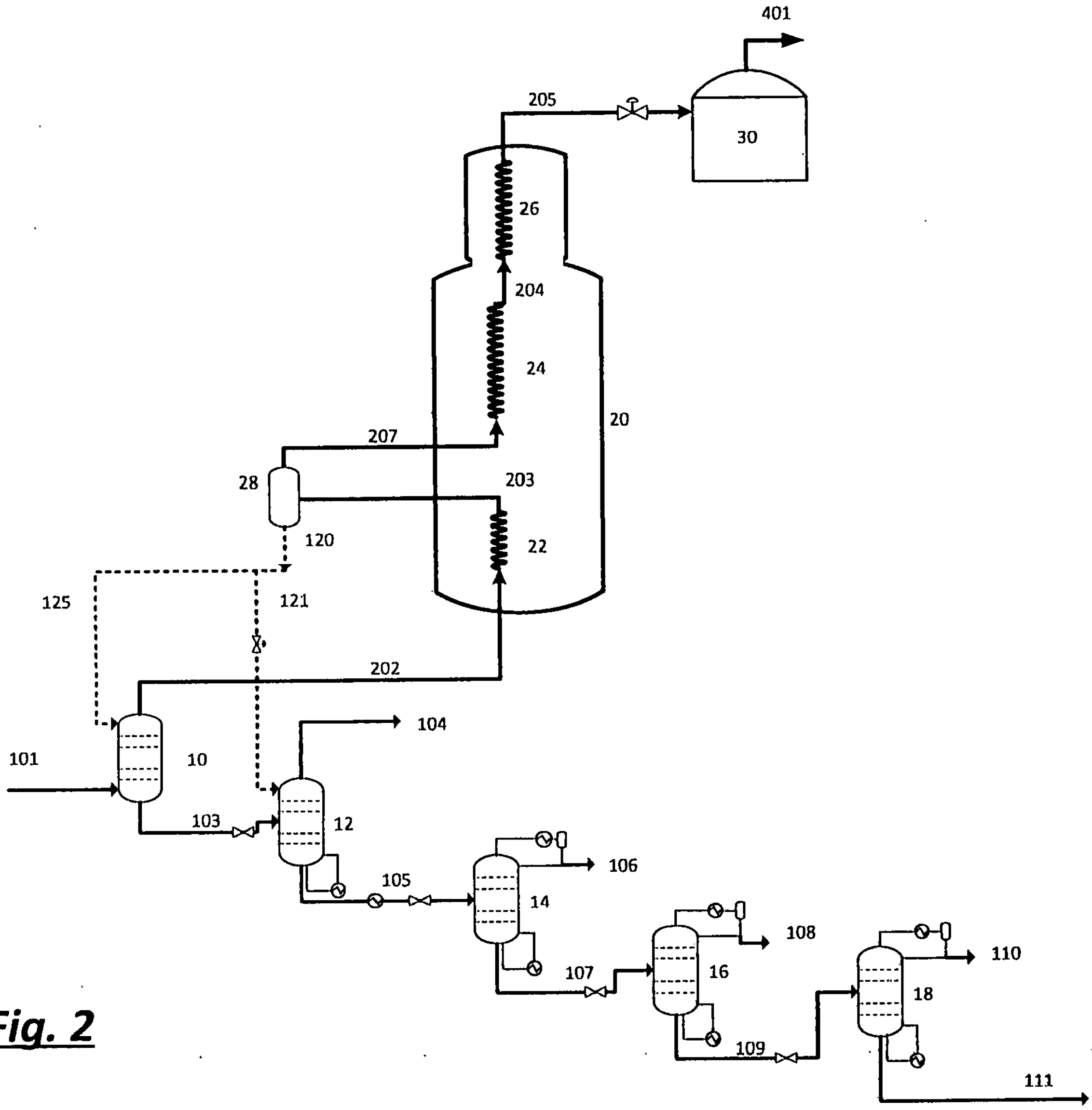
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Fig. 2

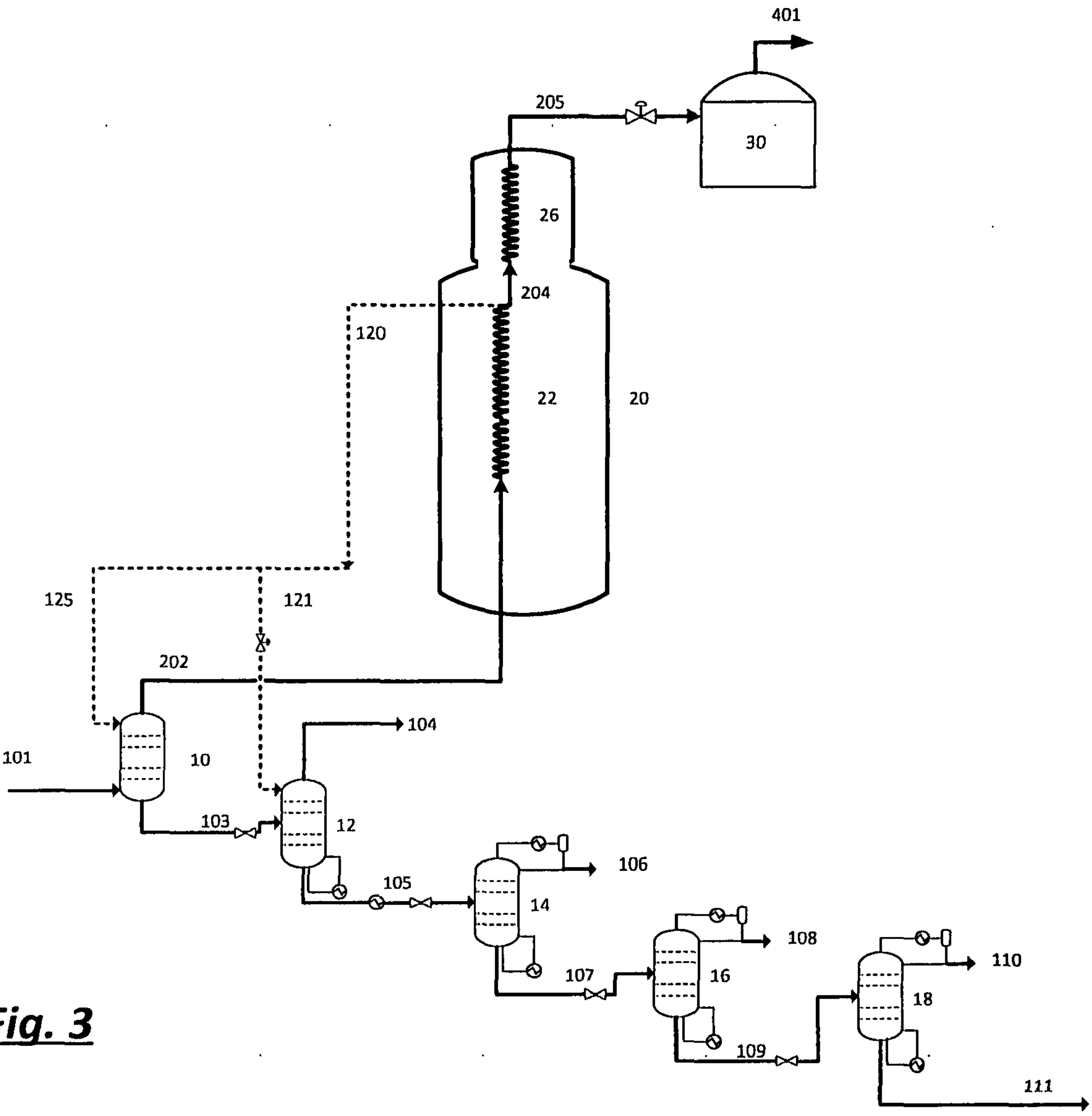
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Fig. 3

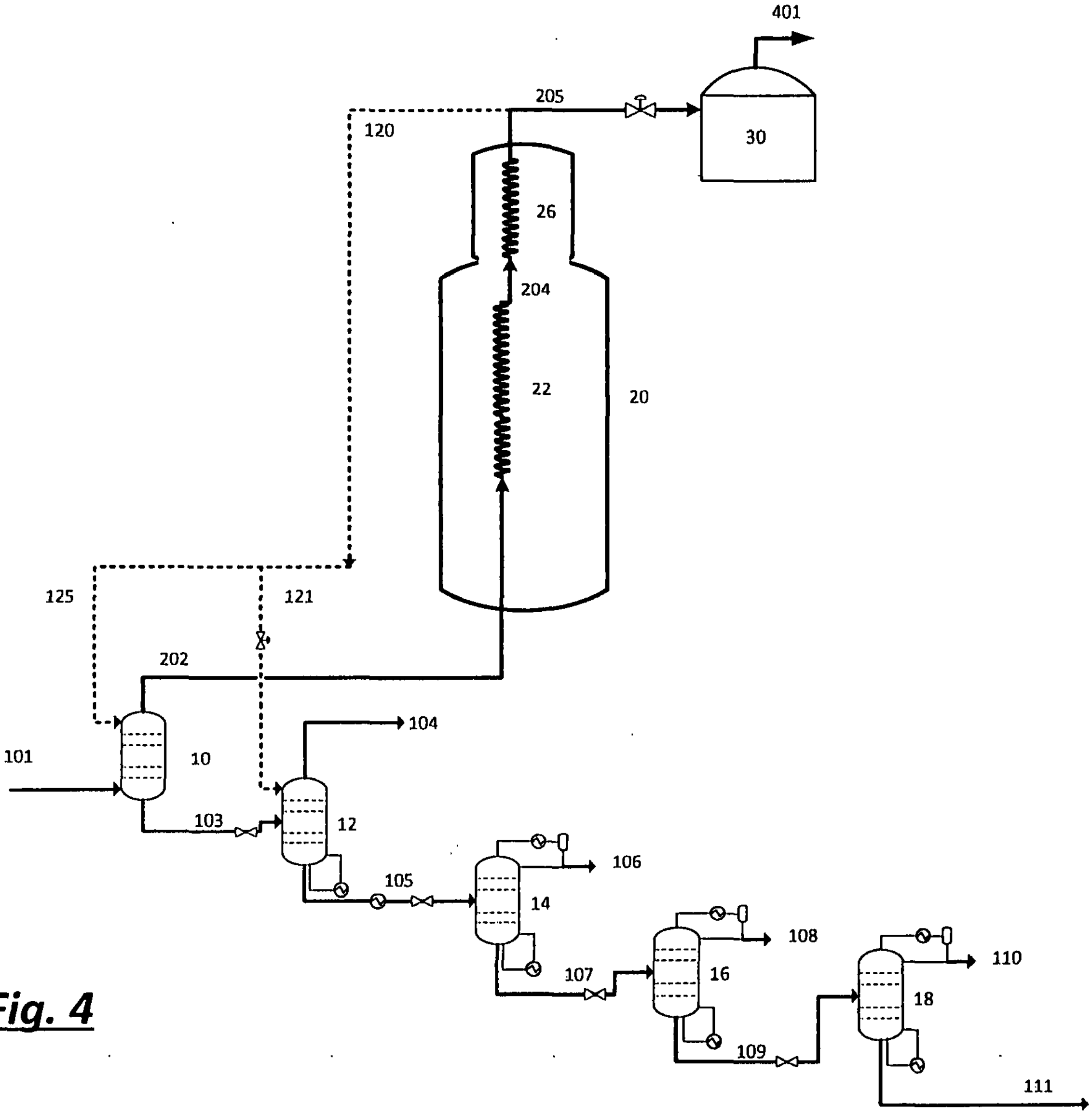

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Fig. 4

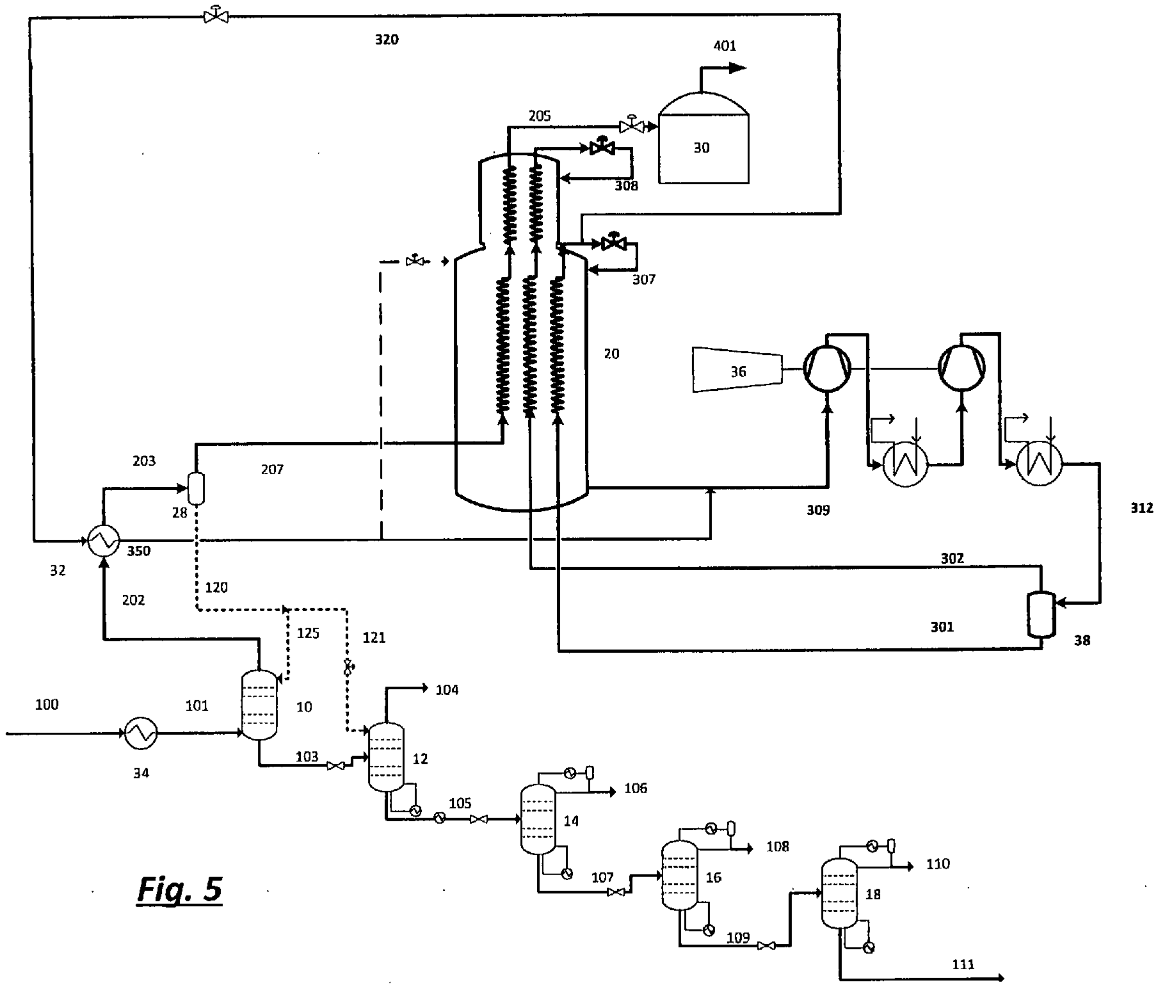
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Fig. 5

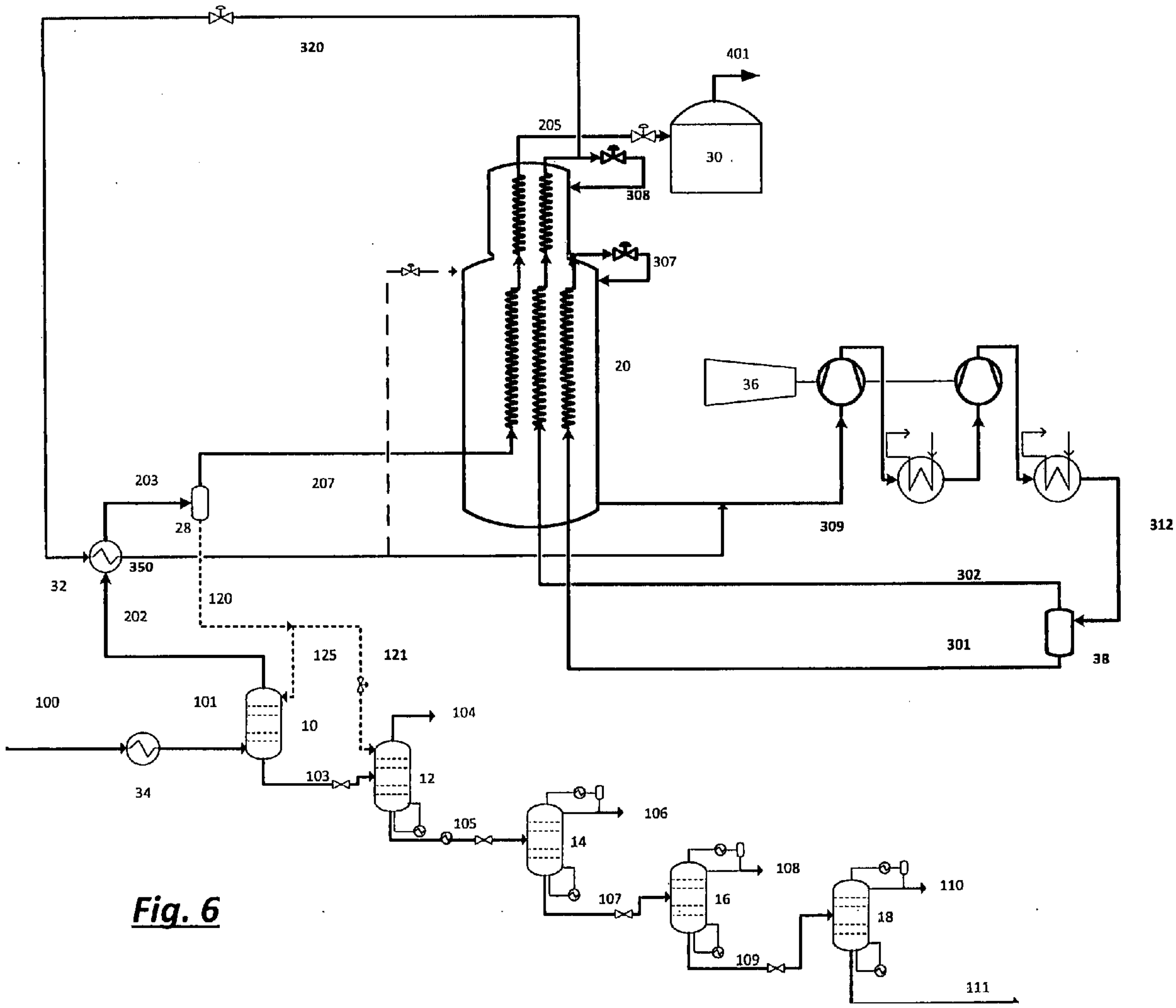
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Fig. 6

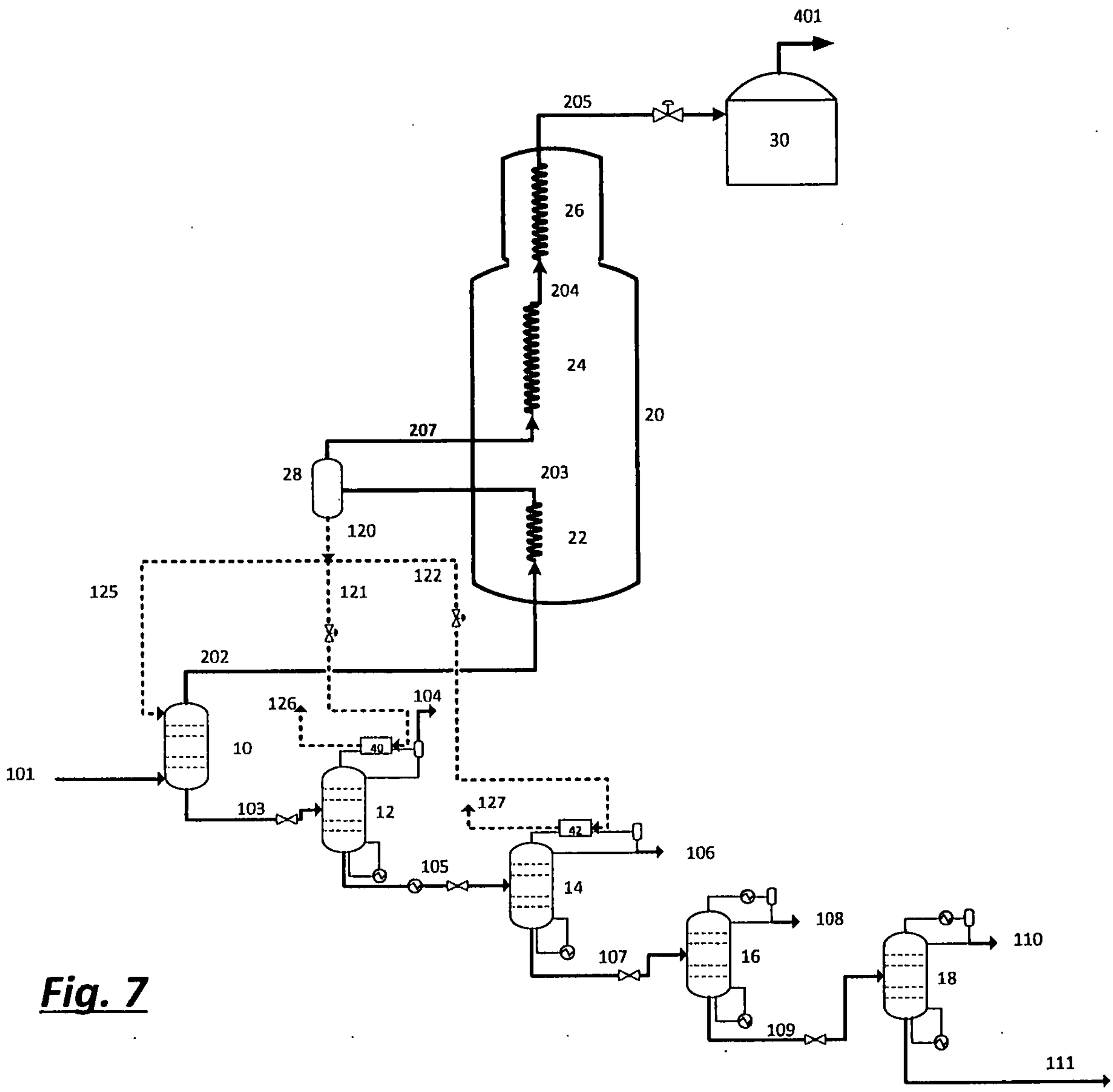
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Fig. 7

REFERENCES CITED IN THE DESCRIPTION

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