(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 796 818 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
29.10.2014 Bulletin 2014/44

(21) Application number: **13164692.9**

(22) Date of filing: **22.04.2013**

(51) Int Cl.:
F25J 1/00 *(2006.01)*
F25J 1/02 *(2006.01)*
F25J 3/02 *(2006.01)*

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(71) Applicant: **Shell Internationale Research Maatschappij B.V.**
2596 HR The Hague (NL)

(72) Inventors:
- **Van Amelsvoort, Jan**
  2288GK Rijswijk (NL)
- **Santos, Alexandre M C R**
  50490 Kuala Lumpur (MY)

(74) Representative: **Matthezing, Robert Maarten et al**
Shell International B.V.
LSI
PO Box 384
2501 CJ The Hague (NL)

(54) **Method and apparatus for producing a liquefied hydrocarbon stream**

(57) A first nitrogen stripper feed stream is fed into a nitrogen stripper column at a stripping pressure. A nitrogen-stripped liquid is drawn from a sump space of the nitrogen stripper column, depressurized to a flash pressure that is lower than the stripping pressure, and fed to an end flash separator. A liquefied hydrocarbon product stream is discharged from the end flash separator, as well as a process vapour. The process vapour is compressed to at least the stripping pressure, and, split in a stripping vapour stream and a fuel gas vapour stream. The stripping vapour stream is fed into the nitrogen stripper column, while the fuel gas vapour stream is passed to a gas turbine. Another fuel gas, having a lower heating value, is obtained from the overhead vapour from the nitrogen stripper column. This other fuel gas is combusted in a combustion device other than a gas turbine.

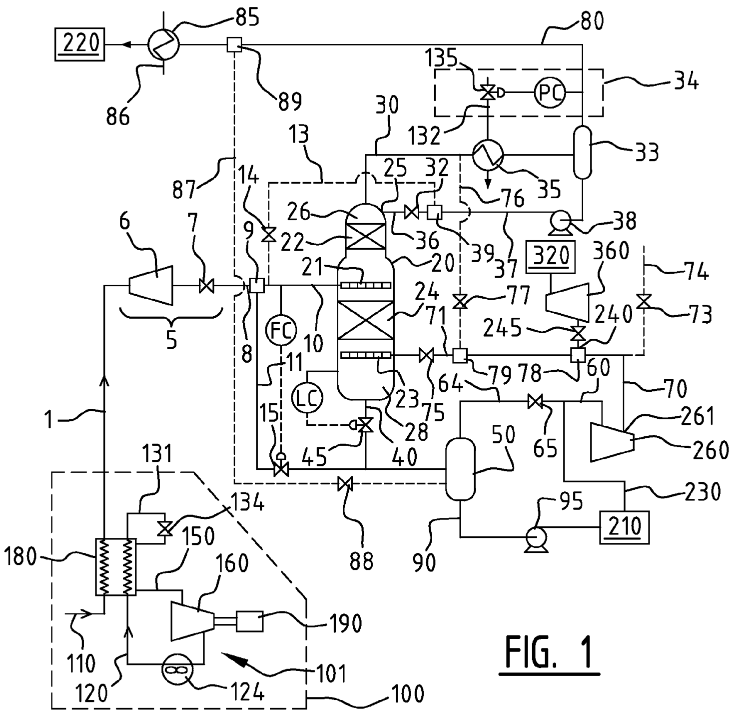

FIG. 1

EP 2 796 818 A1

Description

[0001] The present invention relates to a method and apparatus for producing a liquefied hydrocarbon product stream.

[0002] Liquefied natural gas (LNG) forms an economically important example of such a cryogenic hydrocarbon stream. Natural gas is a useful fuel source, as well as a source of various hydrocarbon compounds. It is often desirable to liquefy natural gas in a liquefied natural gas plant at or near the source of a natural gas stream for a number of reasons. As an example, natural gas can be stored and transported over long distances more readily as a liquid than in gaseous form because it occupies a smaller volume and does not need to be stored at high pressure.

[0003] WO 2011/009832 describes a method wherein a treated liquefied hydrocarbon stream is produced from natural gas, wherein lower boiling point components, such as nitrogen, are separated from a multi-phase hydrocarbon stream, to produce a liquefied natural gas stream with a lower content of such lower boiling point components. The method employs two subsequent gas/liquid separators operating at different pressures. The multi-phase hydrocarbon stream is fed into the first gas/liquid separator at a first pressure. The bottom stream of the first gas/liquid separator is passed to the second gas/liquid separator, which provides vapour at a second pressure that is lower than the first pressure. The vapour is compressed in an overhead stream compressor, and returned to the first gas/liquid separator as a stripping vapour stream. A reflux condenser is envisaged in the first gas/liquid separator to recondense some of the vapours at the top of the first gas/liquid separator.

[0004] Still describing WO 2011/009832, the overhead stream of the first gas/liquid separator is a vapour stream comprising hydrocarbons and at least 30 mol% of nitrogen. This stream is combusted in a low pressure fuel gas consumer in the form of combustion device such as a furnace, boiler, or duel fuel diesel engine. A high pressure fuel stream, suitable for use as a fuel for a gas turbine, is extracted from the hydrocarbon feed stream prior to liquefaction. The high pressure fuel gas stream has a low nitrogen content compared to the low pressure fuel gas stream derived from the first separator overhead stream.

[0005] A drawback of the method and apparatus as described in WO 2011/009832 is that a lot of cooling duty may be required in the reflux condenser to recondense vapours if a high amount of stripping gas is formed in the second gas/liquid separator. This may be the case if there is a high amount of nitrogen in the multi-phase hydrocarbon stream.

[0006] The present invention provides a method of providing a liquefied hydrocarbon product stream, the method comprising:

- providing a cryogenic hydrocarbon composition comprising a nitrogen- and methane-containing liquid phase;
- feeding a first nitrogen stripper feed stream, at a stripping pressure, into a nitrogen stripper column comprising at least one internal stripping section positioned within the nitrogen stripper column, said first nitrogen stripper feed stream comprising at least a first portion of the cryogenic hydrocarbon composition;

- drawing a nitrogen-stripped liquid from a sump space of the nitrogen stripper column below the stripping section;
- producing at least a liquefied hydrocarbon product stream and a process vapour from the nitrogen-stripped liquid, comprising at least depressurizing the nitrogen-stripped liquid to a flash pressure that is lower than the stripping pressure, wherein a flash vapour is generated during said depressurizing of said nitrogen-stripped liquid to said flash pressure, and phase separating the nitrogen-stripped liquid, in an end flash separator, at a flash separation pressure that is equal to or lower than the flash pressure, into the liquefied hydrocarbon product stream and the flash vapour, wherein the process vapour comprises said flash vapour;
- compressing said process vapour to at least the stripping pressure, thereby obtaining a compressed vapour;
- passing a stripping vapour stream into the nitrogen stripper column at a level gravitationally below said stripping section, said stripping vapour stream comprising at least a stripping portion of said compressed vapour;
- discharging a vapour fraction, comprising a discharge fraction of an overhead vapour obtained from an overhead part of the nitrogen stripping column, as off gas, wherein the vapour fraction has a first heating value;
- combusting the vapour fraction in a combustion device other than a gas turbine;
- removing a fuel gas vapour stream from the compressed vapour, said fuel gas vapour stream comprising a fuel gas portion of said compressed vapour, which fuel gas vapour stream has a second heating value that is higher than the first heating value;
- passing the fuel gas vapour stream to a gas turbine whereby the fuel gas vapour stream bypasses the nitrogen stripper column once it has been removed from the compressed vapour;
- combusting the fuel gas vapour stream in the gas turbine.

[0007] In another aspect, the present invention provides an apparatus for providing a liquefied hydrocarbon product stream, the apparatus comprising:

- a cryogenic feed line connected to a source of a cryogenic hydrocarbon composition comprising nitrogen and a methane-containing liquid phase;

- a nitrogen stripper column in fluid communication with the cryogenic feed line, said nitrogen stripper column comprising at least one internal stripping section positioned within the nitrogen stripper column;
- an overhead vapour discharge line communicating with the nitrogen stripper column via an overhead space within the nitrogen stripper column;
- a combustion device other than a gas turbine, fluidly connected with the nitrogen stripper column via at least the overhead vapour discharge line, and arranged to receive a discharge fraction from an overhead vapour carried in the overhead vapour discharge line, and to combust the discharge fraction;
- a nitrogen-stripped liquid discharge line communicating with a sump space within the nitrogen stripper column gravitationally below the stripping section;
- an intermediate depressurizer in the nitrogen-stripped liquid discharge line, fluidly connected to the nitrogen stripper column, arranged to receive a nitrogen-stripped liquid from the sump space of the nitrogen stripper column and to depressurize the nitrogen-stripped liquid, said intermediate depressurizer located on an interface between a stripping pressure side comprising the nitrogen stripper column and a flash pressure side;
- a liquid hydrocarbon product line arranged on the flash pressure side to discharge a liquefied hydrocarbon product stream produced from the nitrogen-stripped liquid;
- a process vapour line arranged on the flash pressure side to receive a process vapour produced from the nitrogen-stripped liquid;
- an end flash separator arranged on the flash pressure side of the interface and in fluid communication with the nitrogen stripper column via the nitrogen-stripped liquid discharge line; and arranged in discharging communication with the liquid hydrocarbon product line and the in discharging communication with the process vapour line;
- a process compressor arranged in the process vapour line arranged to receive the process vapour from the end flash separator, and to compress the process vapour to provide a compressed vapour at a process compressor discharge outlet of the process compressor, said process compressor being on said interface between the stripping pressure side and the flash pressure side;
- a stripping vapour line in fluid communication with the nitrogen stripper column at a level gravitationally below the stripping section and arranged to receive at least a stripping portion of said compressed vapour from the process compressor;
- a fuel gas vapour line fluidly connected with the process compressor discharge outlet via a fuel gas splitter arranged in a path between the process compressor discharge outlet and the stripping vapour line, for removing a fuel gas vapour stream comprising a fuel gas portion of the compressed vapour from the compressed vapour;
- a gas turbine fluidly connected with the fuel gas splitter via a fuel gas line that bypasses the nitrogen stripper column, wherein said gas turbine is arranged to receive and combust the fuel gas portion of the compressed vapour.

[0008] The invention will be further illustrated hereinafter, using examples and with reference to the drawing in which;

Fig. 1 schematically represents a process flow scheme representing a method and apparatus incorporating an embodiment of the invention; and

Fig. 2 schematically represents a process flow scheme representing a method and apparatus incorporating another embodiment of the invention;

Fig. 3 schematically represents a process flow scheme representing a method and apparatus incorporating still another embodiment of the invention; and

Fig. 4 schematically represents a process flow scheme representing a method and apparatus incorporating still another embodiment of the invention.

[0009] In these figures, same reference numbers will be used to refer to same or similar parts. Furthermore, a single reference number will be used to identify a conduit or line as well as the stream conveyed by that line.

[0010] The present description concerns producing a liquefied hydrocarbon product stream. A first nitrogen stripper feed stream comprising at least a first portion of a cryogenic hydrocarbon composition is fed into a nitrogen stripper column at a stripping pressure. The cryogenic hydrocarbon composition contains a nitrogen- and methane-containing liquid phase. A nitrogen-stripped liquid is drawn from a sump space of the nitrogen stripper column, depressurized to a flash pressure that is lower than the stripping pressure, and fed to an end flash separator. A flash vapour is generated during said depressurizing. A liquefied hydrocarbon product stream is discharged from the end flash separator as well as a process vapour comprising said flash vapour. The process vapour is compressed to at least the stripping pressure, and, split in a stripping vapour stream and a fuel gas vapour stream.

[0011] The stripping vapour stream is fed into the nitrogen stripper column, while the fuel gas vapour stream is removed from the compressed vapour and passed to a gas turbine whereby the fuel gas vapour stream bypasses the nitrogen stripper column. This fuel gas vapour stream is identified as high quality fuel gas stream. A low quality fuel gas is obtained from the overhead vapour discharged from the nitrogen stripper column, which low quality fuel gas is combusted in a combustion device other than a gas turbine. Low quality in this context means having a heating value that is lower compared to the heating value of the high quality fuel gas vapour stream, which is combusted in the gas turbine.

[0012] It has been found that the compressed vapour, which according to the prior art process is used as stripping vapour for the nitrogen stripper column, can have a suitable composition and/or heating value for use as fuel gas vapour in a gas turbine. As there is a suitable use for at least some of the compressed vapour, there is an opportunity to reduce the amount of stripping vapour being sent to the nitrogen stripper column. This is advantageous, as it eventually results in less cooling duty being required to recondense excess methane that is not required in the lower value fuel gas which is obtained from the overhead vapour from the nitrogen stripper column.

[0013] The proposed method and apparatus can be advantageously applied for instance if the cryogenic hydrocarbon composition comprises in the range of from 1 mol% to 7 mol% nitrogen. However, most benefit is enjoyed in cases wherein the raw liquefied stream comprises more than 3 mol% of nitrogen, as in such cases a relatively high flow rate of flash vapour is generated, in order to maintain the liquefied hydrocarbon product stream within specification with regard to maximum content of lower boiling constituents, such as nitrogen in commercially tradable liquefied natural gas.

[0014] The cryogenic hydrocarbon composition may be produced by means of a liquefier wherein a hydrocarbon stream is condensed and subcooled into a raw liquefied stream, followed by a pressure reduction system wherein the pressure of the raw liquefied stream is reduced to form the cryogenic hydrocarbon composition. The liquefier may comprise a refrigerant circuit for cycling a refrigerant stream. The refrigerant circuit may comprise a refrigerant compressor coupled to a refrigerant compressor driver, and a cryogenic heat exchanger. The pressure reduction system is suitably arranged downstream of the cryogenic heat exchanger in fluid communication therewith via a rundown line. A refrigerant stream may be cycled in the refrigerant circuit by driving the refrigerant compressor and compressing the refrigerant stream in the refrigerant compressor. The condensing and subcooling of the hydrocarbon stream may involve indirectly heat exchanging the hydrocarbon stream against the refrigerant stream in cryogenic heat exchanger, thereby forming the raw liquefied stream. The raw liquefied stream may then be passed through the pressure reduction system.

[0015] The gas turbine to which the fuel gas vapour stream is passed may be the refrigerant compressor driver, such that this gas turbine drives the refrigerant compressor.

[0016] In preferred embodiments, the cryogenic hydrocarbon composition is split into the first portion that is fed to the nitrogen stripper column as part of the first nitrogen stripper feed stream, and a second portion. The second portion may have the same composition and phase as the first portion, and may be fed into the end flash separator after reducing the pressure of the second portion to the flash pressure. The second portion preferably bypasses the nitrogen stripper column between the stream splitting and the feeding of the second portion into the end flash separator.

[0017] Herewith, the liquid loading of the nitrogen stripper column is reduced compared to when the entire feed of cryogenic hydrocarbon composition is fed into the nitrogen stripper column, while at the same time sufficient liquid can be maintained in the nitrogen stripper column to facilitate effective stripping using the stripping vapour stream. Consequently, the nitrogen stripper column can be sized smaller than in the case of WO 2011/009832 in which the first gas/liquid separator receives all of the multi-phase hydrocarbon stream that is to be treated.

[0018] The split ratio of the cryogenic hydrocarbon composition into the first and second portions may suitably be adjusted whereby maintaining the flow rate of the first portion on a predetermined target flow rate. The split ratio may be defined as the flow rate of the first portion relative to the total flow rata of the first and second portions together.

[0019] Suitably, the nitrogen stripper column further comprises at least one internal rectifying section, which is arranged gravitationally higher than the stripping section within said nitrogen stripper column. A partially condensed intermediate stream may be formed from the overhead vapour obtained from the overhead part of the nitrogen stripping column, whereby the overhead vapour is partially condensed by heat exchanging the overhead vapour against an auxiliary refrigerant stream and thereby passing heat from the overhead vapour to the auxiliary refrigerant stream at a cooling duty. The partially condensed intermediate stream comprises a condensed fraction and a vapour fraction. The overhead part is suitably located above the rectifying section. The condensed fraction may be separated from the vapour fraction, at a separation pressure, and at least a reflux portion of the condensed fraction may be allowed to enter the rectifying section in the nitrogen stripper column from a level above the rectifying section.

[0020] The auxiliary refrigerant stream is suitably formed by a slip stream of the cycled refrigerant stream from the liquefier if a liquefier is provided, or by a slip stream of the liquefied hydrocarbon product stream. An advantage of the latter option is that it can be applied regardless of type of liquefier or other source of the cryogenic hydrocarbon composition, and it can be retrofitted to any pre-existing liquefier or source of the cryogenic hydrocarbon composition. An advantage of using a slip stream of the cycled refrigerant stream is that a separate refrigerant circuit does not have to be provided merely for providing the auxiliary refrigerant stream. Suitably, the slip stream is formed of a part of the cycled refrigerant stream against which the hydrocarbon stream is subcooled. This is generally the refrigerant stream that within the liquefier is adapted to extract heat from the hydrocarbon stream at the lowest temperature range. This makes it the most suitable cycled refrigerant stream that is available in the liquefier for the purpose of partly condensing the vaporous reject stream.

[0021] With the currently proposed solutions, the amount of nitrogen remaining in the produced liquefied hydrocarbon product stream can be kept below a specified maximum nitrogen specification, while rejected vapours generated from the cryogenic hydrocarbon composition in order to achieve the low amount of nitrogen in the produced liquefied hydrocarbon product stream can be used to satisfy two different kinds of fuel gas supplies. The liquefied hydrocarbon product stream can be stored and transported at its cryogenic temperature and approximately atmospheric pressure.

[0022] The vapour fraction, which is discharged and combusted in the combustion device other than the gas turbine, may contain a significant amount of nitrogen, possibly from 50 mol% to 95 mol% of nitrogen. However, this vapour fraction can still be used as low quality fuel gas stream.

[0023] The fuel gas vapour stream that is removed from the compressed vapour may contain less than 30 mol% of nitrogen, so that it can be used to fuel a gas turbine. The fuel gas vapour stream generally contains more than 5 mol%, preferably more than 10 mol% of nitrogen. Herewith it is achieved that the separation efficiency of the nitrogen stripper column does not have to be extremely high whereby some nitrogen is allowed to remain in the nitrogen-stripped liquid. Herewith the nitrogen stripper column can have fewer theoretical stages and use less heating and cooling duty. Furthermore, allowing some nitrogen (up to 30 mol%) to end up in the compressed vapour allows for the optional second portion of the cryogenic hydrocarbon composition (which contains a relatively high amount of nitrogen) to bypass the nitrogen stripper column and be fed directly into the end-flash separator. Herewith the nitrogen stripper column can be kept smaller as well.

[0024] If the nitrogen content in the compressed vapour is still too high for the selected gas turbine, the fuel gas vapour stream that is removed from the compressed vapour may be blended with other fuel gas to bring the fuel on specification. In such cases the invention provides the benefit that the blending requirements are less demanding than if the fuel gas had more than 30 mol% of nitrogen.

[0025] The fuel gas portion of the compressed vapour may have to be subjected to further compression in order to meet a pre-determined gas turbine fuel gas pressure specification.

[0026] Preferably the vapour fraction is used as the low quality fuel gas stream at a fuel gas pressure not higher than the stripping pressure. Herewith, the need of a dedicated low quality fuel gas compressor can be avoided. Moreover, by selecting the stripping pressure at a pressure exceeding the low quality fuel gas pressure, any compression applied to the process vapour has an added associated benefit, such as adding of enthalpy to the process vapour which allows it to be used as stripping vapour.

[0027] The proposed method and apparatus are specifically suitable for application in combination with a liquefier in the form of hydrocarbon liquefier, such as a natural gas liquefier, in order to remove nitrogen from the raw liquefied product that is produced in the hydrocarbon liquefier. It has been found that even when the raw liquefied product - or the cryogenic hydrocarbon composition - contains a fairly high amount of from 3 mol% (or from about 3 mol%) up to 7 mol% (or up to about 7 mol%) of nitrogen, the resulting liquid hydrocarbon product can meet a nitrogen content within a specification of between from 0.5 to 1 mol% nitrogen. A limited amount of the nitrogen from the raw liquefied product - or the cryogenic hydrocarbon composition - ends up in the high quality fuel gas which is combusted in the gas turbine. The remainder of the nitrogen is discharged as part of the vapour fraction in the off gas, together with a non-zero amount of methane.

[0028] Figure 1 illustrates an apparatus comprising an embodiment of the invention. A cryogenic hydrocarbon composition comprising a nitrogen- and methane-containing liquid phase is conveyed in a cryogenic feed line 8. The source of the cryogenic hydrocarbon composition is not a limitation of the invention in its broadest definition, but for the sake of completeness one embodiment is illustrated wherein the cryogenic hydrocarbon composition is sourced from a liquefier 100.

[0029] Such a liquefier 100 would typically be provided upstream of the cryogenic feed line 8. The liquefier 100 may be in fluid communication with the cryogenic feed line 8 via a pressure reduction system 5, which communicates with the liquefier 100 via a rundown line 1. The pressure reduction system 5 is arranged downstream of the cryogenic heat exchanger 180 and arranged to receive and reduce the pressure of a raw liquefied stream from the main cryogenic heat exchanger 180. In the embodiment as shown, the pressure reduction system 5 consists of a dynamic unit, such as an expander turbine 6, and a static unit, such as a Joule Thomson valve 7, but other variants are possible including combinations of one or more static units and/or one or more dynamic units. If an expander turbine is used, it may optionally be drivingly connected to a power generator.

[0030] In the example embodiment shown in Fig. 1, liquefier 100 comprises a refrigerant circuit 101 for cycling a refrigerant. The refrigerant circuit 101 comprises a refrigerant compressor 160 coupled to a refrigerant compressor driver 190 in a mechanical driving engagement. The refrigerant compressor 160 is arranged to compress a spent refrigerant stream 150 and to discharge the refrigerant, in a pressurized condition, into a compressed refrigerant line 120. At least one reject heat exchanger 124 is normally provided in the compressed refrigerant line 120 of the refrigerant circuit 101. The reject heat exchanger 124 is arranged to reject heat from the pressurized refrigerant stream carried in the compressed refrigerant line 120 to the ambient, either to the air or to a body of water such as a lake, a river, or the sea.

[0031] The liquefier 100 typically comprises a refrigerant refrigerator arranged to refrigerate the pressurized refrigerant from the compressed refrigerant line 120 from which heat has been rejected in the reject heat exchanger 124. Herewith a refrigerated refrigerant stream is obtained in a refrigerated refrigerant line 131.

[0032] The liquefier 100 further comprises a cryogenic heat exchanger 180 connected to the refrigerant compressor 160 discharge outlet via the compressed refrigerant line 120. In the embodiment of Figure 1, the cryogenic heat exchanger 180 also fulfils the function of the refrigerant refrigerator discussed in the previous paragraph, but this is not a requirement of the invention. The cryogenic heat exchanger is generally arranged to establish an indirect heat exchanging contact between a hydrocarbon stream 110 and the refrigerant of the refrigerant circuit 101.

[0033] A spent refrigerant line 150 connects the cryogenic heat exchanger 180 with a main suction end of the refrigerant compressor 160. The refrigerated refrigerant line 131 is in fluid communication with the spent refrigerant line 150, via a cold side of the cryogenic heat exchanger 180. The hydrocarbon stream 110 flows through a warm side of the cryogenic heat exchanger 180. The cold side and the warm side are in heat exchanging contact with each other. A main refrigerant control valve 134 is configured in the refrigerated refrigerant line 131.

[0034] The cryogenic heat exchanger 180 receives the refrigerant stream in a depressurized condition from the refrigerated refrigerant line 131 via the main refrigerant control valve 134, and discharges into the refrigerant compressor 160. Thus, the cryogenic heat exchanger 180 forms part of the refrigerant circuit 101.

[0035] The cryogenic heat exchanger 180 may be provided in any suitable form, including a printed circuit type, a plate fin type, optionally in a cold box configuration, or a tube-in-shell type heat exchanger such as a coil wound heat exchanger or a spool wound heat exchanger.

[0036] A specific non-limiting example of the liquefier and its refrigerant circuit based on a tube-in-shell type heat exchanger and including the refrigerant compressor and the cryogenic heat exchanger, is shown in Figures 2 and 3. These figures will be described in detail later below.

[0037] Back to the invention, the cryogenic feed line 8 is in fluid communication with a nitrogen stripper column 20, via a first feed line 10 and a first inlet system 21.

[0038] The nitrogen stripper column 20 comprises an internal stripping section 24 positioned within the nitrogen stripper column 20. An overhead vapour discharge line 30 communicates with the nitrogen stripper column 20 via an overhead space 26 within the nitrogen stripper column 20. A nitrogen-stripped liquid discharge line 40 communicates with the nitrogen stripper column 20 via a sump space 28 within the nitrogen stripper column 20 gravitationally below the stripping section 24.

[0039] The nitrogen stripper column 20 may comprise vapour/liquid contact-enhancing means to enhance component separation and nitrogen rejection. Depending on the tolerable amount of nitrogen in the nitrogen stripped liquid and the amount of nitrogen in the cryogenic feed line 8, between 2 and 8 theoretical stages may typically be needed in total. In one particular embodiment, 4 theoretical stages may be required. Such contact-enhancing means may be provided in the form of trays and/or packing, in the form of either structured or non-structured packing. At least part of the vapour/liquid contact-enhancing means suitably forms part of the internal stripping section 24.

[0040] An intermediate depressurizer 45 is arranged in the nitrogen-stripped liquid discharge line 40, and thereby fluidly connected to the nitrogen stripper column 20. The intermediate depressurizer 45 may be functionally coupled to a level controller LC, which cooperates with the sump space 28 of the nitrogen stripper column 20.

[0041] The intermediate depressurizer 45 is located on an interface between a stripping pressure side comprising the nitrogen stripper column 20, and a flash pressure side. The flash pressure side comprises a liquid hydrocarbon product line 90, arranged to discharge a liquefied hydrocarbon product stream produced from the nitrogen-stripped liquid 40. The flash pressure side also comprises a process vapour line 60, arranged to receive a process vapour produced from the nitrogen-stripped liquid 40.

[0042] If provided, the pressure reduction system 5 as described above is typically located on the stripping pressure side of the interface. In the embodiment as shown, the flash pressure side furthermore comprises a cryogenic storage tank 210 connected to the liquid hydrocarbon product line 90 for storing the liquefied hydrocarbon product stream, an optional boil-off gas supply line 230, and an end flash separator 50.

[0043] Depending on the separation requirements, the end flash separator 50 may be provided in the form of a simple drum which separates vapour from liquid phases in a single equilibrium stage (such as depicted in Fig. 1), or a more sophisticated distillation column. Non-limiting examples of possibilities are disclosed in US Patents 5,421,165; 5,893,274; 6,014,869; 6,105,391; and pre-grant publication US 2008/0066492.

[0044] The end flash separator 50 is configured in fluid communication with the nitrogen stripper column 20 via the intermediate depressurizer 45 and the nitrogen-stripped liquid discharge line 40. The nitrogen-stripped liquid discharge line 40 with the intermediate depressurizer 45 are arranged to receive a nitrogen-stripped liquid from the sump space of the nitrogen stripper column 20 and to discharge this liquid into the end flash separator 50 in a depressurized condition. The end flash separator 50 is in discharging communication with the liquid hydrocarbon product line 90 on one side, and in discharging communication with the process vapour line 60 on the other side.

[0045] For instance, the end flash separator 50 may then be connected to the cryogenic storage tank 210 via the liquid hydrocarbon product line 90. A cryogenic pump 95 may be present in the liquid hydrocarbon product line 90 to assist the transport of the liquid hydrocarbon product to the cryogenic storage tank 210.

[0046] The process vapour line 60, as shown in the embodiment of Fig. 1, may be connected to the end flash separator 50 via a flash vapour line 64 and flash vapour flow control valve 65, as well as to the cryogenic storage tank 210 via the optional boil-off gas supply line 230. An advantage of the latter connection is that it allows for handling of at least part of the boil-off gas from the cryogenic storage tank 210 as part of the process vapour.

[0047] Also configured on the interface between the stripping pressure side and the flash pressure side, is a process compressor 260. The process compressor 260 may be driven by an electric motor or another suitable driver. The process compressor 260 is arranged in the process vapour line 60 to receive the process vapour and to compress the process vapour. A compressed vapour discharge line 70 is fluidly connected with a process compressor discharge outlet 261 of the process compressor 260. Suitably, the process compressor 260 is provided with anti-surge control and a recycle cooler which is used when the process compressor is on recycle and during start-up (not shown in the drawing).

[0048] A stripping vapour line 71 is in fluid communication with the nitrogen stripper column 20 via a second inlet system 23 configured at a level gravitationally below the stripping section 24 and preferably above the sump space 28. The stripping vapour line 71 is connected to the compressed vapour discharge line 70 via an optional bypass splitter 79. A stripping vapour valve 75 is provided in the stripping vapour line 71.

[0049] Optionally, an external stripping vapour supply line 74 is provided in fluid communication with the second inlet system 23 of the nitrogen stripper column 20. In one embodiment, as shown in Fig. 1, the optional external stripping vapour supply line 74 connects to the compressed vapour discharge line 70. An external stripping vapour flow control valve 73 is provided in the optional external stripping vapour supply line 74. In one embodiment, the optional external stripping vapour supply line 74 is suitably connected to a hydrocarbon vapour line in, or upstream of, the liquefier 100.

[0050] A combustion device 220 other than a gas turbine is arranged fluidly connected to the nitrogen stripper column 20 via at least the overhead vapour discharge line 30. This combustion device is arranged to receive a discharge fraction from the overhead vapour carried in the overhead vapour discharge line 30, and to combust the discharge fraction as low quality fuel.

[0051] The combustion device 220 may comprise multiple combustion units. It may include, for example, one or more of a furnace, a boiler, an incinerator, a dual fuel diesel engine, or cross-combinations thereof. A boiler and a duel fuel diesel engine may advantageously be coupled to an electric power generator.

[0052] A fuel gas vapour line 240 is fluidly connected with the process compressor discharge outlet 261 via a fuel gas splitter 78 arranged in a path between the process compressor discharge outlet 261 and the stripping vapour line 71. The fuel gas vapour line 240 is intended for removing a fuel gas vapour stream comprising a fuel gas portion of the compressed vapour from the compressed vapour in the compressed vapour discharge line 70. This fuel gas vapour stream is identified as the high quality fuel gas stream. A fuel flow control valve 245 may optionally be arranged in the fuel gas vapour line 240.

[0053] A gas turbine 320 is fluidly connected with the fuel gas splitter 78 via the fuel gas vapour line 240. This gas turbine 320 is arranged to receive and combust the fuel gas portion of the compressed vapour. The fuel gas vapour line 240 bypasses the nitrogen stripper column 20. Optionally, a fuel gas compressor 360 is arranged in the fuel gas vapour line 240 between the fuel gas splitter 78 and the gas turbine 320.

[0054] Suitably, the gas turbine 320 in which the high quality fuel gas vapour is ultimately combusted is the refrigerant compressor driver 190 that is in driving engagement with the refrigerant compressor 160. The gas turbine 320 may drive the refrigerant compressor 160.

[0055] A vapour recycle line 87 is optionally configured to receive at least a vaporous recycle portion of the vapour from the overhead discharge line 30. The vapour recycle line 87 bypasses the nitrogen stripper column 20, and feeds back into at least one of the group consisting of: the liquid hydrocarbon product line 90 and the process vapour line 60. A vapour recycle flow control valve 88 is preferably provided in the vapour recycle line 87. A benefit of the proposed vapour recycle line 87 is that it allows for selectively increasing of the nitrogen content in the liquefied hydrocarbon product stream 90. The vapour recycle line 87 suitably feeds into the end flash separator 50.

[0056] The first feed line 10 may connect the cryogenic feed line 8 with the first inlet system 21 of the nitrogen stripper column 20 via an optional initial stream splitter 9 arranged between the cryogenic feed line 8 and the first feed line 10.

[0057] An optional second feed line 11 is connected, at an upstream side thereof, to the optional initial splitter 9. Via such initial stream splitter 9 and second feed line 11, the cryogenic feed line 8 can be connected to the end-flash separator 50 whereby bypassing the nitrogen stripper column 20, in addition to the connection already described above via first feed line 10 and the nitrogen-stripped liquid discharge line 40 which does not bypass the nitrogen stripper column 20.

[0058] The optional initial splitter 9 is configured to divide the cryogenic hydrocarbon composition that flows through the cryogenic feed line 8 into a first portion, which is passed to the first feed line 10, and a second portion, which is passed to the second feed line 11. A benefit of the second feed line 11 and the initial splitter 9 is that the nitrogen stripper column 20 can be sized smaller than in the case that the cryogenic feed line 8 and the first feed line 10 would be directly connected without a splitter whereby all of the cryogenic hydrocarbon composition is let into the nitrogen stripper column 20 via the first inlet system 21.

[0059] Preferably, the second feed line 11 does not pass through any indirect heat exchanger functional to indirectly exchange heat with any process stream.

[0060] In embodiments using the optional initial splitter 9, a bypass stream flow control valve 15 may advantageously be arranged in the second feed line 11. The bypass stream flow control valve is functionally connected to a flow controller FC provided in the first feed line 10. The flow controller FC is configured to maintain the flow rate of said first portion though the first feed line 10 on a predetermined target flow rate, by controlling a split ratio of the cryogenic hydrocarbon composition flowing through the cryogenic feed line 8 into the first and second portions.

[0061] Optionally, the nitrogen stripper column 20 comprises an internal rectifying section 22 in addition to the internal stripping section 24. The internal rectifying section 22 is positioned within the nitrogen stripper column 20, gravitationally higher than the stripping section 24. The first inlet system 21 is provided gravitationally between the internal rectifying section 22 and the internal stripping section 24. The overhead part 26 is formed by a space within the nitrogen stripper column 20, gravitationally above the rectifying section 22.

[0062] The optional internal rectifying section 22 may comprise vapour/liquid contact-enhancing means similar to the internal stripping section 24, to further enhance component separation and nitrogen rejection.

[0063] Typically, the nitrogen stripper column 20 cooperates with a condenser to provide downward liquid flow through the internal stripping section 24 and/or the optional internal rectifying section 22. For example, in Figure 1 the condenser is provided in the form of an overhead condenser 35 external to the nitrogen stripper column 20, whereas in Figure 2 it is provided in the form of an integrated internal overhead condenser 235, which is internally configured inside the overhead part 26 within the nitrogen stripper column 20.

[0064] Such condenser may be advantageously utilized to recondense at least part of compressed process vapour from the compressed vapour discharge line 70. For instance, in the embodiment of Figure 1, the overhead condenser 35 is arranged in the overhead vapour discharge line 30. Inside the overhead condenser 35 the overhead vapour can pass in indirect heat exchange contact with an auxiliary refrigerant stream 132, whereby heat passes from the overhead vapour to the auxiliary refrigerant stream at a cooling duty. An auxiliary refrigerant stream flow control valve 135 is provided in the auxiliary refrigerant line 132.

[0065] A cooling duty controller 34 may be provided to control the cooling duty, being the rate at which heat passes from the overhead vapour to the auxiliary refrigerant stream. Suitably, the cooling duty controller 34 is configured to control the cooling duty in response to an indicator of heating value of the off gas relative to a demand for heating power. In the embodiment as shown, the cooling duty controller 34 is embodied in the form of a pressure controller PC and the auxiliary refrigerant stream flow control valve 135, which are functionally coupled to each other.

[0066] Still referring to Figure 1, an overhead separator 33 is arranged on a downstream side of the overhead vapour discharge line 30. The overhead vapour discharge line 30 discharges into the overhead separator 33. The overhead separator 33 is arranged to separate any, non-condensed, vapour fraction from any condensed fraction of the overhead vapour. A vapour fraction discharge line 80 is arranged to discharge the vapour fraction.

[0067] Suitably, the combustion device 220 is arranged on a downstream end of the vapour fraction discharge line 80, to receive at least a fuel portion of the vapour fraction in the vapour fraction discharge line 80. Suitably, the configuration of the optional vapour recycle line 87 comprises an optional vapour fraction splitter 89, which may be provided in the vapour fraction line 80, allowing controlled fluid communication between the vapour fraction line 80 and the vapour recycle line 87.

[0068] A cold recovery heat exchanger 85 may be provided in the vapour fraction discharge line 80, to preserve the cold vested in the vapour fraction 80 by heat exchanging against a cold recovery stream 86 prior to feeding the vapour fraction 80 to any combustion device.

[0069] In one embodiment, the cold recovery stream 86 may comprise or consist of a side stream sourced from the hydrocarbon feed stream in the hydrocarbon feed line 110 of the liquefier 100. The resulting cooled side stream may for instance be combined with the cryogenic hydrocarbon composition in the cryogenic feed line 8. Thus, the cold recovery heat exchanging in the cold recovery heat exchanger 85 supplements the production rate of the cryogenic hydrocarbon composition. In another embodiment, the cold recovery stream 86 may comprise or consist of the overhead vapour in the overhead vapour discharge line 30, preferably in the part of the overhead vapour discharge line 30 where through the overhead vapour is passed from the nitrogen stripper column 20 to the overhead condenser 35. Herewith the duty required from the auxiliary refrigerant stream 132 in the overhead condenser 35 would be reduced.

[0070] A reflux system is arranged to allow at least a reflux portion 36 of the condensed fraction into the nitrogen stripper column 20 at a level above the rectifying section 22. In the embodiment of Figure 1, the reflux system comprises a condensed fraction discharge line 37 fluidly connected to a lower part of the overhead separator 33, an optional reflux pump 38 provided in the condensed fraction discharge line 37, and an optional condensed fraction splitter 39. The optional condensed fraction splitter 39 fluidly connects the condensed fraction discharge line 37 with the nitrogen stripper column 20, via a reflux portion line 36 and a reflux inlet system 25, and with an optional liquid recycle line 13. The optional liquid recycle line 13 is in liquid communication with the liquid hydrocarbon product line 90. Liquid communication means that the liquid recycle line 13 is connected to any suitable location from where at least a part of a liquid recycle portion can flow into the liquid hydrocarbon product line 90 while staying in the liquid phase. Thus, the liquid recycle line 13 may for instance be connected directly to one or more selected from the group consisting of: the nitrogen stripper column 20, the cryogenic feed line 8, the first feed line 10, the second feed line 11, the nitrogen-stripped liquid discharge line 40, the end flash separator 50, and the liquid hydrocarbon product line 90. A recycle valve 14 is configured in the optional liquid recycle line 13. An optional reflux flow valve 32 functionally controlled by a reflux flow controller (not shown) may preferably be provided in the reflux portion line 36.

[0071] The liquid recycle line 13 is in liquid communication with the liquid hydrocarbon product line 90, preferably via a recycle path that does not pass through the rectifying section 22 if it is provided. This way the liquid recycle line 13 helps to avoid feeding too much liquid onto the rectifying section 22 and to avoid passing the recycle liquid through the rectifying section 22. This is beneficial to avoid disturbing the equilibrium in the nitrogen stripper column 20.

[0072] The optional bypass splitter 79 is in fluid communication with the overhead vapour discharge line 30, preferably on an upstream side of the overhead condenser 35 if the latter is provided. Hereto an optional vapour bypass line 76 may be provided between the optional bypass splitter 79 and the overhead vapour discharge line 30. A vapour bypass control valve 77 is preferably provided in the vapour bypass line 76. A benefit of such a vapour bypass line 76 is that at times when there is an excess of process vapour, this can be processed together with the off gas in the vapour fraction discharge line 80 without upsetting the material balance in the nitrogen stripper column 20. The vapour bypass line 76 suitably extends along a bypass path between the bypass splitter 79 the overhead vapour discharge line 30 on an upstream side of the overhead condenser 35. The bypass path extends between the bypass splitter 79 and the overhead vapour discharge line 30 and/or the vapour fraction discharge line 80. The bypass path does not pass through the internal stripping section 24 in the nitrogen stripper column 20. This way it can be avoided that the non-stripping portion passes through the internal stripping section 24, which helps to avoid disturbing the equilibrium in the nitrogen stripper column 20.

[0073] The apparatus described above may be used in a method described as follows.

[0074] A cryogenic hydrocarbon composition 8 comprising a nitrogen- and methane-containing liquid phase is provided at an initial pressure and an initial temperature. Providing of the cryogenic hydrocarbon composition 8 may comprise passing a hydrocarbon stream 110 through the liquefier 100. The hydrocarbon stream 110 may be condensed and subcooled in the liquefier 100. The condensing and subcooling of the hydrocarbon stream 110 preferably involves indirectly heat exchanging the hydrocarbon stream 110 against the refrigerant in the liquefier 100. The thus formed subcooled liquefied hydrocarbons stream is referred to as the raw liquefied stream. Thus the raw liquefied stream is formed out of the hydrocarbon stream by condensing and subsequently subcooling the hydrocarbon stream.

[0075] For example, in such a liquefier 100, the hydrocarbon stream 110 comprising a hydrocarbon-containing feed vapour may be heat exchanged, for example in the cryogenic heat exchanger 180, against a main refrigerant stream, thereby liquefying the feed vapour of the feed stream to provide the raw liquefied stream within the rundown line 1. The desired cryogenic hydrocarbon composition 8 may then be obtained from the raw liquefied stream 1. The raw liquefied stream may be discharged in the rundown line 1 from the liquefier 100. The cryogenic hydrocarbon composition 8 may be obtained from the raw liquefied stream, for instance by passing the raw liquefied stream through a pressure reduction step in pressure reduction system 5. In this pressure reduction step, the pressure may be reduced from the liquefaction pressure to the initial pressure of between 2 and 15 bar absolute.

[0076] The cryogenic hydrocarbon composition 8 may be obtained from natural gas or petroleum reservoirs or coal beds. As an alternative the cryogenic hydrocarbon composition 8 may also be obtained from another source, including as an example a synthetic source such as a Fischer-Tropsch process. Preferably the cryogenic hydrocarbon composition 8 comprises at least 50 mol% methane, more preferably at least 80 mol% methane. A preferred initial temperature of lower than -130 °C may be achieved by passing a hydrocarbon stream 110 through a liquefaction system 100. An embodiment of passing the hydrocarbon stream 110 through the liquefaction system 100 will be described in more detail below.

[0077] A first nitrogen stripper feed stream 10, obtained from the cryogenic hydrocarbon composition 8, is then fed into the nitrogen stripper column 20 at a stripping pressure, via the first inlet system 21. The first nitrogen stripper feed stream 10 comprises at least a first portion of the cryogenic hydrocarbon composition 8. In preferred embodiments the cryogenic hydrocarbon composition 8 undergoes stream splitting into said first portion and a second portion, but such embodiments will be discussed in more detail herein below.

[0078] The stripping pressure is usually equal to or lower than the initial pressure. The stripping pressure in preferred embodiments is selected in a range of between 2 and 15 bar absolute. Preferably, the stripping pressure is at least 4 bara, because with a somewhat higher stripping pressure the stripping vapour in stripping vapour line 71 can benefit from some additional enthalpy (in the form of heat of compression) that is added to the process stream 60 in the process compressor 260. Preferably, the stripping pressure is at most 8 bara in order to facilitate the separation efficiency in the nitrogen stripper column 20. Moreover, if the stripping pressure is within a range of between 4 and 8 bara, the off gas in the vapour fraction discharge line 80 can readily be used as so-called low pressure fuel stream without a need to further compress.

[0079] An overhead vapour stream 30 is obtained from the overhead part 26 of the nitrogen stripping column 20. A vapour fraction 80 obtained from the overhead vapour stream 30, and comprising a discharge fraction of the overhead vapour 30, is discharged as off gas. Suitably, at least a fuel portion of the vapour fraction 80 is passed to the combustion device 220 where it is combusted. Preferably, the fuel portion is passed into the combustion device 220 at a fuel gas pressure that is not higher than the stripping pressure. The vapour fraction 80 from which the fuel portion is extracted has a first heating value.

[0080] A nitrogen-stripped liquid 40 is drawn from the sump space 28 of the nitrogen stripper column 20. The temperature of the nitrogen-stripped liquid 40 is typically higher than that of the first nitrogen stripper feed stream 10. Typically, it is envisaged that the temperature of the nitrogen-stripped liquid 40 is higher than that of the first nitrogen stripper feed stream 10 and between -140 °C and -80 °C, preferably between -140 °C and -120 °C.

[0081] The nitrogen-stripped liquid 40 is then depressurized, preferably employing the intermediate depressurizer 45, to a flash pressure that is lower than the stripping pressure. At least part of a liquefied hydrocarbon product stream 90 and a process vapour stream 60 are formed from the nitrogen-stripped liquid 40 as a result of the depressurization in the intermediate depressurizer 45.

[0082] The intermediate depressurizer 45 may be controlled by the level controller LC, set to increase the flow rate through the intermediate depressurizer 45 if the level of liquid accumulated in the sump space 28 of the nitrogen stripper column 20 increases above a target level. As a result of the depressurization, the temperature may for instance be lowered to below -160 °C. The liquefied hydrocarbon product stream 90 that is produced hereby can typically be kept at an atmospheric pressure in an open insulated cryogenic storage tank.

[0083] A flash vapour is also generated during the depressurizing of the nitrogen-stripped liquid stream 40. The flash vapour is phase separated from the nitrogen-stripped liquid stream 40 in the end flash separator 50 at a flash separation pressure that is equal to or lower than the flash pressure. The process vapour stream 60 comprises the flash vapour thus separated.

[0084] The process vapour 60 is then compressed to at least the stripping pressure, thereby obtaining a compressed vapour stream 70. A stripping vapour stream 71 is obtained from the compressed vapour stream 70, and passed into the nitrogen stripper column 20 via the second inlet system 23. The stripping vapour stream 71 comprises at least a stripping portion of the compressed vapour 70. This stripping vapour can percolate upward through the stripping section 23 in contacting counter current with liquids percolating downward through the stripping section 23.

[0085] If the external stripping vapour supply line 74 is provided in fluid communication with the second inlet system 23, an external stripping vapour may selectively be fed into the nitrogen stripper column 20 via the second inlet system 23. Herewith major disruption of the nitrogen stripper column 20 may be avoided, for instance, in case the process compressor 260 is not functioning to provide the compressed vapour stream 70 in sufficient amounts.

[0086] The stripping vapour stream 71 is obtained from the compressed vapour stream 70 from which a fuel gas vapour stream 240 has been removed. Thus the stripping vapour stream 71 does not contain a fuel gas portion of the compressed vapour 70 that is removed from the compressed vapour 70 as fuel gas vapour stream 240. This fuel gas vapour stream 240 has a second heating value that is higher than the first heating value. The thus obtained fuel gas vapour stream 240 is passed to a gas turbine 320, whereby the fuel gas vapour stream 240 bypasses the nitrogen stripper column 20 once it has been removed from the compressed vapour 70. The fuel gas vapour stream 240 is combusted in the gas turbine 320.

[0087] The first and second heating values define the amount of heat that can be released by combustion of a mole of the fuel gas. This can be either the so-called "high" heating value as the "low" heating value as long as the same conditions are used for comparing the two heating values. Preferably the "low" heating value is used to compare the two heating values, as this is the closest to the combustion conditions used in the invention. The heating value may be determined using ASTM D3588-98 or DIN 51857 standards applied regardless of the composition of the vapour fraction 80 and/or the compressed vapour 70. As a result of cryogenic distillation in the nitrogen stripper column 20, the first heating value (belonging to the vapour fraction 80) is lower than the second heating value (belonging to the compressed vapour 70).

[0088] Optionally, the fuel gas vapour stream 240 is further compressed, for instance in the optional fuel gas compressor 360, to a second fuel gas pressure that is higher than the pressure of the compressed vapour stream 70.

[0089] As described above, an optional initial stream splitter 9 may be arranged between the cryogenic feed line 8 and the first feed line 10. In such embodiments, when the cryogenic hydrocarbon composition 8 arrives at the initial stream splitter 9 the cryogenic hydrocarbon composition 8 is split in the initial stream splitter 9 into the first portion in the form of the first nitrogen stripper feed stream in the first feed line 10, and the second portion in the form of a bypass feed stream in the second feed line 11. The second portion has the same composition and phase as the first portion. The stream splitting of the cryogenic hydrocarbon composition 8 into the first and second portions is such that the second portion 11 has the same composition and phase as the first portion 10.

[0090] The second portion of the cryogenic hydrocarbon composition 8, in the form of the bypass feed stream 11, is passed to and into the end flash separator 50. Before feeding the second portion into the end flash separator 50, the second portion is subjected to depressurizing to the flash pressure. From the stream splitting in the initial stream splitter

9 to the feeding into the end flash separator 50, the second portion bypasses the nitrogen stripper column 20. The second portion originating from the initial stream splitter 9 is preferably not subject to any functional indirect heat exchange in any single pass from the initial stream splitter 9 to said subsequent feeding. In this context the term "functional indirect heat exchange" is intended to exclude inherent "non-functional" heat exchange and/or *de-minimis* heat exchange between the second portion in second feed line 11 and the ambient surrounding the second feed line 11.

[0091] The split ratio, defined as the flow rate of the second portion relative to the flow rate of the cryogenic hydrocarbon composition in the cryogenic hydrocarbon composition line 8, may be controlled using the bypass stream flow control valve 15. This bypass stream flow control valve 15 may be controlled by the flow controller FC to maintain a predetermined target flow rate of the first nitrogen stripper feed stream 10 into the nitrogen stripper column 20. The flow controller FC will increase the open fraction of the bypass stream flow control valve 15 if there is a surplus flow rate that exceeds the target flow rate, and decrease the open fraction if there is a flow rate deficit compared to the target flow rate.

[0092] As a general guideline, the size of the nitrogen stripper and a design split ratio are determined based on the expected design amount of nitrogen in the feed. If, for instance due to some variation in the feed, a higher content of nitrogen than the design amount, the operation may continue using a lower value for the split ratio than the design split ratio. A higher value would be preferred for lower content of nitrogen in the condensed hydrocarbon composition.

[0093] Depending on the source, the hydrocarbon stream 110 may contain varying amounts of components other than methane and nitrogen, including one or more non-hydrocarbon components other than water, such as CO_2, Hg, H_2S and other sulphur compounds; and one or more hydrocarbons heavier than methane such as in particular ethane, propane and butanes, and, possibly lesser amounts of pentanes and aromatic hydrocarbons. Hydrocarbons with a molecular mass of at least that of propane may herein be referred to as C_3+ hydrocarbons, and hydrocarbons with a molecular mass of at least that of ethane may herein be referred to as C_2+ hydrocarbons.

[0094] If desired, the hydrocarbon stream 110 may have been pre-treated to reduce and/or remove one or more of undesired components such as CO_2 and H_2S, or have undergone other steps such as pre-pressurizing or the like. Such steps are well known to the person skilled in the art, and their mechanisms are not further discussed here. The composition of the hydrocarbon stream 110 thus varies depending upon the type and location of the gas and the applied pre-treatment(s).

[0095] A refrigerant may be cycled in the refrigerant circuit 101 of the liquefier 100. Cycling comprises driving the refrigerant compressor 160, and compressing the refrigerant stream in the refrigerant compressor 160. Particularly, spent refrigerant 150 is compressed in the refrigerant compressor 160, to form a compressed refrigerant 120 out of the spent refrigerant 150. Heat is removed from the compressed refrigerant discharged from the refrigerant compressor 160, via the one or more heat exchangers that are provided in the compressed refrigerant line 120 including the least one reject heat exchanger 124. This results in an at least partially condensed compressed refrigerant. The at least partially condensed compressed refrigerant is then refrigerated by passing it through a heat exchange, for example the cryogenic heat exchanger 180, whereby indirectly heat exchanging the at least partially condensed compressed refrigerant against the main refrigerant stream. As a result, the refrigerant is subcooled and discharged into the refrigerated refrigerant line 131. It may be passed to the cold side of the cryogenic heat exchanger 180 where it is allowed to evaporate by picking up heat from the hydrocarbon stream 110 and/or the at least partially condensed compressed refrigerant stream. The spent refrigerant stream 150 is formed by the evaporated refrigerant being discharged from the cold side of the cryogenic heat exchanger 180.

[0096] Suitably, the gas turbine 320 in which the fuel gas vapour stream 240 is ultimately combusted is the refrigerant compressor driver 190 that is in driving engagement with the refrigerant compressor 160. The gas turbine 320 may drive the refrigerant compressor 160.

[0097] Obtaining of the stripping vapour stream 71 from the compressed vapour stream 70 may further involve splitting the compressed vapour stream 70 into the stripping vapour stream 71 and a vapour bypass portion that does not comprise the stripping portion and that can be selectively injected into the overhead vapour line 30 whereby bypassing at least the stripping section 22 of the nitrogen stripper column 20 or possibly bypassing the entire the nitrogen stripper column 20. The selective injection may be controlled using the vapour bypass control valve 77. Suitably, the vapour bypass control valve 77 is controlled by a pressure controller on the compressed vapour line 70, which is set to increase the open fraction of the vapour bypass control valve 77 in response to an increasing pressure in the compressed vapour line 70. It is envisaged that the flow rate of the vapour bypass portion that is allowed to flow through the vapour bypass line 76 into the overhead vapour stream 30 is particularly high during so-called loading mode at which time usually the amount of boil-off gas is much higher than in is usually the case during so-called holding mode. The vapour bypass control valve 77 may be fully closed during normal operation in holding mode.

[0098] In preferred embodiments, a partially condensed intermediate stream is formed from the overhead vapour 30. This involves indirectly heat exchanging the overhead vapour 30 against the auxiliary refrigerant stream in 132 the auxiliary refrigerant line 132, whereby heat is passed from the overhead vapour 30 to the auxiliary refrigerant stream 132 at a selected cooling duty. The resulting partially condensed intermediate stream comprises a condensed fraction and a vapour fraction. If the nitrogen stripper column 20 is equipped with the optional internal rectifying section 22 as described above, the overhead vapour stream 30 is preferably obtained from an overhead part of the nitrogen stripping column 20 above the rectifying section 22.

[0099] The condensed fraction is separated from the vapour fraction in the overhead separator 33, at a separation pressure that may be lower than the stripping pressure, and preferably lies in a range of between 2 and 15 bar absolute. The vapour fraction is discharged via the vapour fraction discharge line 80. The condensed fraction is discharged from the overhead separator 33 into the reflux system, for instance via the condensed fraction discharge line 37.

[0100] At least a reflux portion 36 of the condensed fraction is allowed into the nitrogen stripper column 20, starting at a level above the rectifying section 22. In the case of the embodiment of Figure 1, the condensed fraction may pass through the optional reflux pump 38 (and/or it may flow under the influence of gravity). The reflux portion is then obtained from the condensed fraction and charged into the nitrogen stripper column 20 via reflux inlet system 25 and reflux portion line 36. In the case of the embodiment of Figures 2 and 3, the condensed fraction is separated inside the overhead part of the nitrogen stripper column 20 and therefore already available above the rectifying section to percolate downward through the rectifying section 22, in contact with vapours rising upward through the rectifying section 22.

[0101] The reflux portion may contain all of the condensed fraction, but optionally, the condensed fraction is split in the optionally provided condensed fraction splitter 39 into a liquid recycle portion which is charged via liquid recycle line 13 into, for instance, the first feed stream 10, and the reflux portion which is charged into the nitrogen stripper column 20 via reflux inlet system 25 and reflux portion line 36. The capability of splitting the condensed fraction into the reflux portion 36 and the liquid recycle portion 13 is beneficial to divert any excess condensed fraction around the rectifying section 22 such as not to upset the operation of the rectifying section 22. The recycle valve 14 may suitably be controlled using a flow controller provided in the condensed fraction discharge line 37 and/or a level controller provided on the overhead separator 33.

[0102] The partially condensing may also involve direct and/or indirect heat exchanging with other streams in other consecutively arranged overhead heat exchangers. For instance, the cold recovery heat exchanger 85 may be such an overhead heat exchanger whereby the partially condensing of the overhead stream further comprises indirect heat exchanging against the vapour fraction 80.

[0103] The optional vapour recycle line 87 may be selectively employed, suitably by selectively opening the vapour recycle control valve 88, to increase the amount of nitrogen that remains in the liquefied hydrocarbon product stream 90. This may be done by drawing a vaporous recycle portion from the vapour fraction, depressurising the vaporous recycle portion to the flash pressure and subsequently injecting the vaporous recycle portion into at least one of: the nitrogen-stripped liquid 40; the liquefied hydrocarbon product stream 90; and the process vapour 60. Suitably, the vaporous recycle portion is injected into the end flash separator 50 such as is illustrated in Figure 1. The remaining part of the vapour fraction 80 that is not passed into the vapour recycle line 87 may form the fuel portion that may be conveyed to the combustion device 220.

[0104] The overhead condenser 35 thus allows for recondensation of vaporous methane that has previously formed part of cryogenic hydrocarbon composition 8, to the extent that it is in excess of a target amount of methane in the discharged vapour fraction 80, by adding any such vaporous methane containing stream to the (compressed) process vapour stream. Once forming part of the process vapour 60 or compressed process vapour 70, the vaporous methane can find its way to the heat exchanging with the auxiliary refrigerant 132 by which it is selectively condensed out of the overhead vapour 30 from the nitrogen stripper column 20, while allowing the majority of the nitrogen to be discharged with the off gas. Herewith it becomes possible to remove sufficient nitrogen from the cryogenic hydrocarbon composition 8 to produce a liquefied hydrocarbon product stream 90 within a desired maximum specification of nitrogen content, while as the same time not producing more heating capacity in the off gas than needed.

[0105] Vaporous methane that has previously formed part of cryogenic hydrocarbon composition 8 includes the flash vapour in the flash vapour line 64 from the end flash separator 50. In addition, it may also may include boil-off gas 230, which typically results from adding of heat to the liquefied hydrocarbon product stream 90 whereby a part of the liquefied hydrocarbon product stream 90 evaporates to form the boil-off gas. In order to facilitate transferring of the boil-off gas to the process vapour stream 60, an optional boil-off gas supply line 230 may be employed to connect a vapour space in the cryogenic storage tank 210 with the process vapour line 60. In order to facilitate transferring the flash vapour 64 to the process vapour stream 60, and to further denitrogenate the liquefied hydrocarbon product stream 90, preferably, the nitrogen-stripped liquid after its depressurization is fed into the optional end flash separator where it is phase separated at a flash separation pressure into the liquefied hydrocarbon product stream 90 and the flash vapour 64.

[0106] The proposed solution may facilitate the handling of these vapours. It combines the removal of nitrogen from the cryogenic hydrocarbon composition 8 with recondensation of excess vaporous methane. This forms an elegant solution in situations where little plant fuel is demanded, such as could be the case in a plant driven by gas turbines of the aero derivative type, which are relatively fuel efficient compared to industrial frame type gas turbines.

[0107] The auxiliary refrigerant 132 stream may suitably be formed by a slip stream of the cycled refrigerant stream from the liquefier 100, more preferably by a slip stream of the light refrigerant fraction, as illustrated in Figure 2, or by a slip stream of the liquefied hydrocarbon product stream 90. This latter case is illustrated in Figures 3 and 4. These options may also be applied in the embodiment of Figure 1, and will be illustrated in more detail below.

[0108] It is also possible to employ a separate refrigeration cycle for the purpose of partially condensing the overhead vapour stream 30. Such separate refrigeration cycle may for instance employ a cycled refrigerant fluid containing a large relative amount of nitrogen and/or argon, such as at least 80 mol% of nitrogen and/or argon. However, employing a slip stream from the refrigerant stream that is already being cycled in the liquefier, or a slip stream of the hydrocarbon product stream 90 has as advantage that the amount of additional equipment to be installed is minimal. For instance, no additional auxiliary refrigerant compressor and auxiliary refrigerant condenser would be needed.

[0109] An advantage of employing a slip stream of the hydrocarbon product stream 90 for this purpose is that it can relatively easily be implemented on an already existing plant without the need to interrupt or modify the pre-existing liquefier 100. Moreover, it is the coldest stream readily available in the plant, without the need for providing a dedicated refrigeration cycle, and there is plenty of it.

[0110] The liquefier 100 has so far been depicted very schematically. It can represent any suitable hydrocarbon liquefaction system and/or process, in particular any natural gas liquefaction process producing liquefied natural gas, and the invention is not limited by the specific choice of liquefaction system. Examples of suitable liquefaction systems employ single refrigerant cycle processes (usually single mixed refrigerant - SMR - processes, such as PRICO described in the paper "LNG Production on floating platforms" by K R Johnsen and P Christiansen, presented at Gastech 1998 (Dubai), but also possible is a single component refrigerant such as for instance the BHP-cLNG process also described in the afore-mentioned paper by Johnsen and Christiansen); double refrigerant cycle processes (for instance the much applied Propane-Mixed-Refrigerant process, often abbreviated C3MR, such as described in for instance US Patent 4,404,008, or for instance double mixed refrigerant - DMR - processes of which an example is described in US Patent 6,658,891, or for instance two-cycle processes wherein each refrigerant cycle contains a single component refrigerant); and processes based on three or more compressor trains for three or more refrigeration cycles of which an example is described in US Patent 7,114,351.

[0111] Other examples of suitable liquefaction systems are described in: US Patent 5,832,745 (Shell SMR); US Patent 6,295,833; US Patent 5,657,643 (both are variants of Black and Veatch SMR); US Pat. 6,370,910 (Shell DMR). Another suitable example of DMR is the so-called Axens LIQUEFIN process, such as described in for instance the paper entitled "LIQUEFIN: AN INNOVATIVE PROCESS TO REDUCE LNG COSTS" by P-Y Martin et al, presented at the 22nd World Gas Conference in Tokyo, Japan (2003). Other suitable three-cycle processes include for example US Pat. 6,962,060; WO 2008/020044; US Pat. 7,127,914; DE3521060A1; US Pat. 5,669,234 (commercially known as optimized cascade process); US Pat. 6,253,574 (commercially known as mixed fluid cascade process); US Pat. 6,308,531; US application publication 2008/0141711; Mark J. Roberts et al "Large capacity single train AP-X(TM) Hybrid LNG Process", Gastech 2002, Doha, Qatar (13-16 October 2002). These suggestions are provided to demonstrate wide applicability of the invention, and are not intended to be an exclusive and/or exhaustive list of possibilities. Not all examples listed above employ (aero derivative) gas turbines as primary refrigerant compressor drivers. It will be clear that any drivers other than gas turbines can be replaced for a gas turbine to enjoy the certain preferred benefits of the present invention.

[0112] An example, wherein in the liquefaction system 100 is based on, for instance C3MR or Shell DMR, is briefly illustrated in Figures 2 and 3. In both cases the cryogenic heat exchanger 180 in the liquefaction system 100 is selected to be a coil wound heat exchanger, comprising a warm side comprising all the tubes, including lower and upper hydrocarbon product tube bundles (181 and 182, respectively), lower and upper LMR tube bundles (183 and 184, respectively) and an HMR tube bundle 185. The cold side is formed by the shell side 186 of the cryogenic heat exchanger 180.

[0113] The lower and upper hydrocarbon product tube bundles 181 and 182 fluidly connect the hydrocarbon stream line 110 with the rundown line 1. At least one refrigerated hydrocarbon pre-cooling heat exchanger 115 may be provided in the hydrocarbon stream line 110, upstream of the cryogenic heat exchanger 180.

[0114] The refrigerant provided in the refrigerant circuit 101 will be referred to as "main refrigerant" to distinguish it from other refrigerants that may used in the liquefaction system 100 such as a pre-cooling refrigerant 127 which may provide cooling duty to the refrigerated hydrocarbon pre-cooling heat exchanger 115. The main refrigerant in the present embodiment is a mixed refrigerant.

[0115] The refrigerant circuit 101 comprises a spent refrigerant line 150, connecting the cryogenic heat exchanger 180 (in this case a shell side 186 of the cryogenic heat exchanger 180) with a main suction end of the refrigerant compressor 160, and a compressed refrigerant line 120 connecting the refrigerant compressor 160 discharge outlet with an MR separator 128. One or more heat exchangers are provided in the compressed refrigerant line 120, including in the present example at least one reject heat exchanger 124. The MR separator 128 is in fluid connection with the lower LMR tube bundle 183 via a light refrigerant fraction line 121, and with the HMR tube bundle via a heavy refrigerant fraction line 122.

[0116] The at least one refrigerated hydrocarbon pre-cooling heat exchanger 115 and the at least one refrigerated main refrigerant pre-cooling heat exchanger 125 are refrigerated by the pre-cooling refrigerant (via lines 127 and 126, respectively). The same pre-cooling refrigerant may be shared from the same pre-cooling refrigerant cycle. Moreover, the at least one refrigerated hydrocarbon pre-cooling heat exchanger 115 and the at least one refrigerated main refrigerant pre-cooling heat exchanger 125 may be combined into one pre-cooling heat exchanger unit (not shown). Reference is made to US Pat. 6,370,910 as a non-limiting example.

[0117] The optional external stripping vapour supply line 74 (if provided) may suitably be connected to the hydrocarbon feed line 110, either at a point upstream of the at least one refrigerated hydrocarbon pre-cooling heat exchanger 115, downstream of the at least one refrigerated hydrocarbon pre-cooling heat exchanger 115, or (for instance possible if two or more refrigerated hydrocarbon pre-cooling heat exchangers are provided) between two consecutive refrigerated hydrocarbon pre-cooling heat exchangers, to be sourced with a part of the hydrocarbon feed stream from the hydrocarbon feed line 110.

[0118] At a transition point between the upper (182, 184) and lower (181, 183) tube bundles, the HMR tube bundle 185 is in fluid connection with an HMR line 141. The HMR line 141 is in fluid communication with the shell side 186 of the cryogenic heat exchanger 180 via a first HMR return line 143, in which an HMR control valve 144 is configured. Via the said shell side 186, and in heat exchanging arrangement with each of one of the lower hydrocarbon product tube bundle 181 and the lower LMR tube bundle 183 and the HMR tube bundle 185, first HRM return line 143 is fluidly connected to the spent refrigerant line 150.

[0119] Above the upper tube bundles 182 and 184, near the top of the cryogenic heat exchanger 180, the LMR tube bundle 184 is in fluid connection with the refrigerated refrigerant line 131. A main refrigerant return line 133 establishes fluid communication between the refrigerated refrigerant line 131 and the shell side 186 of the cryogenic heat exchanger 180. A main refrigerant control valve 134 is configured in the main refrigerant return line 133. The main refrigerant return line 133 is in fluid communication with the spent refrigerant line 150, via said shell side 186 and in heat exchanging arrangement with each of one of the upper and lower hydrocarbon product tube bundles 182 and 181, respectively, and each one of the LMR tube bundles 183 and 184, and the HMR tube bundle 185.

[0120] The line-up around the nitrogen stripper column 20 and the end flash separator 50 as shown in Figures 2 and 3 corresponds to the line-up shown in Figure 1. The explanations above made with reference to Figure 1 also apply to Figures 2 and 3. Optional lines including the optional liquid recycle line 13, the optional external stripping vapour supply line 74, the optional vapour bypass line 76 and the optional vapour recycle line 87 may be provided but have not been reproduced in Figures 2 and 3, for purpose of clarity.

[0121] One difference to be noted, however, comparing the embodiments of Figures 2 and 3 with that of Figure 1, is that the overhead condenser 35, the overhead separator 33 and the reflux system of Figure 1 have in Figures 2 and 3 been embodied in the form of an integrated internal overhead condenser 235. Such integrated internal overhead condenser 235 is known in the art. If desired, the optional liquid recycle line 13 can be provided in the case of Figures 2 and 3 as well, for instance by providing the optional condensed fraction splitter 39 in the form of a partial liquid draw off tray (not shown) gravitationally between the integrated internal overhead condenser 235 and the rectifying section 22. Internal or external overhead condensers and reflux systems can be used interchangeably.

[0122] Figure 2 illustrates one possible source of the auxiliary refrigerant which has briefly been mentioned above, and that is the slip stream of the cycled refrigerant stream from the liquefier 100. There are many variations possible to obtain and return such a slip stream. As example, in Figure 2 the refrigerated refrigerant line 131 is split into the auxiliary refrigerant feed line 132 and the main refrigerant return line 133. The auxiliary refrigerant return line 138, on an upstream end thereof, fluidly connects with the auxiliary refrigerant feed line 132 via the condenser (which in Figure 2 is embodied in the form of the integrated internal overhead condenser 235 but it could also be the external overhead condenser 35). In the embodiment of Figure 2, the auxiliary refrigerant return line 138, on a downstream end thereof, ultimately connects with the spent refrigerant line 150 via the first HMR return line 143.

[0123] The refrigerant is cycled in the refrigerant circuit 101, whereby spent refrigerant 150 is compressed in the refrigerant compressor 160 to form a compressed refrigerant 120 out of the spent refrigerant 150. Heat is removed from the compressed refrigerant discharged from the refrigerant compressor 160, via the one or more heat exchangers that are provided in the compressed refrigerant line 120 including the least one reject heat exchanger 124. This results in a partially condensed compressed refrigerant, which is phase separated in the MR separator 128 into a light refrigerant fraction 121 consisting of the vaporous constituents of the partially condensed compressed refrigerant, and a heavy refrigerant fraction 122 consisting of the liquid constituents of the partially condensed compressed refrigerant.

[0124] The light refrigerant fraction 121 is passed via successively the lower LMR bundle 183 and the upper LMR bundle 184 through the cryogenic heat exchanger 180, while the heavy refrigerant fraction 122 is passed via the HMR bundle 185 through the cryogenic heat exchanger 180 to the transition point. While passing through these respective tube bundles, the respective light- and heavy refrigerant fractions are cooled against the light and heavy refrigerant fractions that are evaporating in the shell side 186 again producing spent refrigerant 150 which completes the cycle. Simultaneously, the hydrocarbon stream 110 passes through the cryogenic heat exchanger 180 via successively the lower hydrocarbon bundle 181 and the upper hydrocarbon bundle 182 and is being liquefied evaporating heavy refrigerant fraction and sub-cooled against the evaporating light refrigerant fraction.

[0125] In a preferred embodiment, the auxiliary refrigerant stream is formed by a slip stream of the main refrigerant stream, more specifically by a slip stream of the light refrigerant fraction. This latter case is illustrated in Figure 2. Such a slip stream may conveniently be passed back into the main refrigerant circuit via the shell side 186 of the cryogenic heat exchanger 180, where it may still assist in withdrawing heat from the stream in the upper and/or lower tube bundles.

[0126] In one example, a contemplated composition of the auxiliary refrigerant contains between 25 mol% and 40 mol% of nitrogen; between 30 mol% and 60 mol% of methane and up to 30 mol% of C_2 (ethane and/or ethylene), whereby the auxiliary refrigerant contains at least 95% of these constituents and/or the total of nitrogen and methane is at least 65 mol%. A composition within these ranges is may be readily available from the main refrigerant circuit if a mixed refrigerant is employed for sub-cooling of the liquefied hydrocarbon stream.

[0127] Employing a slip stream from the main refrigerant stream has as advantage that the amount of additional equipment to be installed is minimal. For instance, no additional auxiliary refrigerant compressor and auxiliary refrigerant condenser would be needed, which would be the case if a separate independent auxiliary refrigerant cycle would be proposed.

[0128] Figures 3 and 4 illustrate another possible source of the auxiliary refrigerant, which has briefly been mentioned above, and that is the slip stream of the liquefied hydrocarbon product stream 90. There are many variations possible to obtain and return such a slip stream. As example, in Figures 3 and 4 the liquefied hydrocarbon product line 90 is split into the auxiliary refrigerant feed line 132 and a main product line 91. The auxiliary refrigerant return line 138, on an upstream end thereof, fluidly connects with the auxiliary refrigerant feed line 132 via the condenser (which in Figure 3 is embodied in the form of the integrated internal overhead condenser 235 but it could also be the external overhead condenser 35 such as illustrated in Figure 4). In the embodiment of Figures 3 and 4, the auxiliary refrigerant return line 138, on a downstream end thereof, ultimately connects with the end-flash separator 50. The end-flash separator 50 is this way suitably used to handle any components from the auxiliary refrigerant stream that may have evaporated upon heat exchanging in the condenser. A separate cryogenic pump 96 may optionally be provided in the auxiliary refrigerant feed line 132.

[0129] Material and heat balance calculations have been performed using Pro2 simulation software, to demonstrate the feasibility of the proposed methods and apparatuses. Table 1 shows results for an embodiment based on Figure 4, assuming cold recovery stream 86 consists of a side stream of natural gas sourced from the hydrocarbon feed stream in the hydrocarbon feed line 110 of the liquefier 100. It has the same composition as the raw liquefied stream 1. The first nitrogen stripper feed stream in the first feed line 10 consists of the cold recovery stream 86 and the part from the cryogenic hydrocarbon composition 8 coming from the initial stream splitter 9. It is further assumed that vapour bypass control valve 77, vapour recycle control valve 88, recycle valve 14, and external stripping vapour flow control valve 73 are closed and in no-flow condition.

[0130] The composition of the liquefied hydrocarbon inventory as stored in the cryogenic storage tank 210 is 0.80 mol.% nitrogen; 98.78 mol.% methane and 0.43 mol.% C_2+, whereby C_2+ indicates all hydrocarbons having a mass corresponding to that of ethane, and upward. The liquefied hydrocarbon stream being passed through the main product line 91 to the cryogenic storage tank 210 has slightly more nitrogen than the liquefied hydrocarbon inventory as stored in the cryogenic storage tank 210.

Table 1

Stream Nr.	1	8	10	30	37	64	70	80	86	90	132	138	230	240
Pressure (bara)	74.8	7.31	7.31	6.20	6.00	1.05	6.50	6.00	89.0	1.05	2.50	2.00	1.00	6.50
Temperature (°C)	-158	-159	-159	-145	-153	-163	-65	-154	-140	-164	-164	-153	-159	-65
Flow rate (kg/s)	199	199	72.1	12.4	3.86	28.2	31.4	8.53	2.57	182	17.6	17.6	3.20	13.9
Nitrogen (mol.%)	3.93	3.93	3.93	48.6	14.3	20.7	20.4	70.0	3.93	0.98	0.98	0.98	17.3	20.4
Methane (mol.%)	95.7	95.7	95.7	51.4	85.7	79.3	79.6	30.0	95.7	98.6	98.6	98.6	82.7	79.6
C_2+ (mol.%)	0.39	0.39	0.39	0.00	0.00	0.00	0.00	0.00	0.39	0.42	0.42	0.42	0.00	0.00

[0131] As calculated in the present example, a low quality fuel gas is discharged from the cold recovery heat exchanger 85 at a pressure of 5.5 bara and a temperature of 12 °C. The fuel gas vapour stream 240, which can ultimately serve as high quality fuel gas, is drawn from the compressed stream 70 at a pressure of 6.5 bara and a temperature of -65 °C. Some cold is there to be recovered, but the amount to be recovered may not be worth the additional equipment and operational complexity.

[0132] It follows from the calculation above that about 10 % of the liquefied hydrocarbon product stream 90 would be needed as the auxiliary refrigerant stream 132 to cool the condenser with sufficient cooling duty. Generally, between 3 and 24 % of the liquefied hydrocarbon product stream 90 may be needed as the auxiliary refrigerant stream 132.

[0133] Regardless of which embodiment is being used, the heating value of the vapour fraction 80 being discharged is suitably regulated by adjusting the cooling duty in the overhead condenser 35 (which is optionally embodied in the form of the integrated internal overhead condenser 235). This may be done by the cooling duty controller 34. By adjusting the cooling duty at which heat is passed from the overhead vapour to the auxiliary refrigerant stream, the relative amount of methane in the off gas can be regulated. As a result, the heating value of the discharged vapour fraction can be regulated to match with a specific demand of heating power. This renders the off gas suitable for use as fuel gas stream, even in circumstances where the demand for heating value is variable.

[0134] In the context of the present description, cooling duty reflects the rate at which heat is exchanged in the condenser, which can be expressed in units of power (e.g. Watt or MWatt). The cooling duty is related to the flow rate of the auxiliary refrigerant being subjected to the heat exchanging against the overhead vapour.

[0135] When the vapour fraction 80 is passed to and consumed by the combustion device 220 as fuel, the heating value may be regulated to match with an actual demand of heating power by the combustion device 220.

[0136] The heating value being regulated may be selected in accordance with the appropriate circumstances of the intended use of the off gas as fuel gas. For many applications, the heating value being regulated may be proportional to the low heating value (LHV; sometimes referred to as net calorific value) as defined herein above. The concept of LHV broadly speaking assumes the latent heat of vaporization of water in the reaction products is not recovered.

[0137] However, for the purpose of regulating the heating value in the context of the present disclosure, the actual heating value of the vapour fraction being discharged does not need to be determined on an absolute basis. Generally it is sufficient to regulate the heating value relative to an actual demand for heating power, with the aim to minimize any shortage and excess of heating power being delivered.

[0138] Preferably, the cooling duty is automatically adjusted in response to a signal that is causally related to the heating value being regulated. In embodiments wherein the vapour fraction is passed to one or more selective consumers of methane, such as for instance the combustion device 220 shown in the figures, the controlling can be done in response to the demanded heating power, whereby the partial flow rate of methane is controlled to achieve a heating value that matches the demand. Suitably, the auxiliary refrigerant stream flow control valve 135 may be controlled by the pressure controller PC to maintain a predetermined target flow rate of auxiliary refrigerant stream 132 through the overhead condenser 35. The actual pressure in the vapour fraction discharge line 80 is causally related to the heating value that is being regulated. The pressure controller PC will be set to decrease the open fraction of the auxiliary refrigerant stream flow control valve 135 when the pressure drops below a pre-determined target level, which is indicative of a higher consumption rate of methane than supply rate in the vapour fraction 80. Conversely, the pressure controller PC will be set to increase the open fraction of the auxiliary refrigerant stream flow control valve 135 when the pressure exceeds the pre-determined target level.

[0139] In some embodiments, the target amount of nitrogen dissolved in the liquefied hydrocarbon product stream 90 is between 0.5 and 1 mol%, preferably as close to 1.0 mol% as possible yet not exceeding 1.1 mol%. The vapour recycle flow control valve 88 regulates the amount of the vapour fraction stream 80 that is fed back into, for instance, the end flash separator 50 while bypassing the nitrogen stripper column 20. Herewith the amount of nitrogen in the liquefied hydrocarbon product stream 90 can be influenced. To further assist in meeting the target nitrogen content, the vapour recycle flow control valve 88 may be controlled in response to a signal from a quality measurement instrument QMI that is optionally provided in the liquid hydrocarbon product line 90.

[0140] In any of the examples and embodiments described above, the raw liquefied stream and/or the cryogenic hydrocarbon composition may comprise in the range of from 1 mol% to 7 mol% nitrogen and more than 81 mol% of methane. Preferably, the raw liquefied stream and/or the cryogenic hydrocarbon composition may comprise in the range of from 3 mol% to 7 mol% nitrogen and more than 85 mol% of methane. The temperature of the raw liquefied stream in the rundown line 1 may be anywhere between -165 °C and -120 °C. Preferably, the initial pressure of the cryogenic hydrocarbon composition is between 2 and 15 bar absolute (bara), and preferably the initial temperature is lower than -130 °C.

[0141] The hydrocarbon stream 110 and/or the cryogenic hydrocarbon composition 8 in any of the examples disclosed herein may be obtained from natural gas or petroleum reservoirs or coal beds. As an alternative hydrocarbon stream 110 and/or the cryogenic hydrocarbon composition 8 may also be obtained from another source, including as an example a synthetic source such as a Fischer-Tropsch process. Preferably the hydrocarbon stream 110 and/or the cryogenic hydrocarbon composition comprises at least 50 mol% methane, more preferably at least 80 mol% methane. The resulting liquid hydrocarbon product conveyed in the liquid hydrocarbon product line 90 and/or stored in the cryogenic storage tank 210 is preferably liquefied natural gas (LNG).

[0142] Compressors forming part of the hydrocarbon liquefaction process in the liquefier 100, particularly any refrigerant compressor including refrigerant compressor 160, may be driven by any type of suitable compressor driver 190, including any selected from the group consisting of gas turbine; steam turbine; and electric motor; and inter combinations thereof. This generally applies also to refrigerant compressor driver 190.

[0143] The gas turbine may be selected from the group of so-called industrial gas turbines, or the group of so-called aero derivative gas turbines. The group of aero derivative gas turbines includes: Rolls Royce Trent 60, RB211, or 6761, and General Electric LMS100™, LM6000, LM5000 and LM2500, and variants of any of these (e.g. LM2500+).

[0144] Typically, the second fuel gas pressure is selected in a range between 15 and 75 bara, more preferably in a range of between 45 and 75 bara. The usual prescribed fuel gas pressure for most conventional types of industrial gas turbines is between around 15 and around 25 bara, on average. However, the latest generation of industrial gas turbine requires relatively high pressure fuel gas, such as in the range of from 35 to 45 bara. The range of between 45 and 75 bara is recommended to meet fuel gas pressure requirements of typical aero derivative gas turbines.

[0145] In any of the examples above, the vapour fraction 80 is envisaged to contain in the range of from 50 mol% to 95 mol% of nitrogen, preferably in the range of from 60 mol% to 95 mol% of nitrogen or in the range of from 50 mol% to 90 mol% of nitrogen, preferably in the range of from 60 mol% to 90 mol% of nitrogen, most preferably from 60 mol% to 80 mol% of nitrogen. To achieve a content of nitrogen of between 60 mol% and 80 mol%, such as about 70 mol%, sufficient methane must be recondensed from the compressed vapour stream 70. This may for instance be done using a pressure of the compressed vapour stream 70 of between 4 and 8 bara, and achieving a temperature of the partially condensed intermediate stream of in the range of from -150 °C to -135 °C.

[0146] The flash pressure may suitably be in a range of between 1 and 2 bar absolute. Preferably, the flash pressure lies in a range of between from 1.0 and 1.4 bara. With a somewhat higher differential between the flash pressure and the stripping pressure, the stripping vapour in stripping vapour line 71 can benefit from some additional heat of compression that is added to the process stream 60 in the process compressor 260.

[0147] The flash separation pressure suitably also lies in the range of from 1 to 2 bar absolute, and it is preferably equal to or lower than the flash pressure. Preferably, the flash separation pressure is in the range of between 1 and 1.2 bara. In one embodiment the flash separation pressure is envisaged to be about 1.05 bara.

[0148] The person skilled in the art will understand that the present invention can be carried out in many various ways without departing from the scope of the appended claims.

Claims

1. Method of providing a liquefied hydrocarbon product stream, the method comprising:

- providing a cryogenic hydrocarbon composition comprising a nitrogen- and methane-containing liquid phase;
- feeding a first nitrogen stripper feed stream, at a stripping pressure, into a nitrogen stripper column comprising at least one internal stripping section positioned within the nitrogen stripper column, said first nitrogen stripper feed stream comprising at least a first portion of the cryogenic hydrocarbon composition;
- drawing a nitrogen-stripped liquid from a sump space of the nitrogen stripper column below the stripping section;
- producing at least a liquefied hydrocarbon product stream and a process vapour from the nitrogen-stripped liquid, comprising at least depressurizing the nitrogen-stripped liquid to a flash pressure that is lower than the stripping pressure, wherein a flash vapour is generated during said depressurizing of said nitrogen-stripped liquid to said flash pressure, and phase separating the nitrogen-stripped liquid, in an end flash separator, at a flash separation pressure that is equal to or lower than the flash pressure, into the liquefied hydrocarbon product stream and the flash vapour, wherein the process vapour comprises said flash vapour;
- compressing said process vapour to at least the stripping pressure, thereby obtaining a compressed vapour;
- passing a stripping vapour stream into the nitrogen stripper column at a level gravitationally below said stripping section, said stripping vapour stream comprising at least a stripping portion of said compressed vapour;
- discharging a vapour fraction, comprising a discharge fraction of an overhead vapour obtained from an overhead part of the nitrogen stripping column, as off gas, wherein the vapour fraction has a first heating value;
- combusting the vapour fraction in a combustion device other than a gas turbine;
- removing a fuel gas vapour stream from the compressed vapour, said fuel gas vapour stream comprising a fuel gas portion of said compressed vapour, which fuel gas vapour stream has a second heating value that is higher than the first heating value;
- passing the fuel gas vapour stream to a gas turbine whereby the fuel gas vapour stream bypasses the nitrogen stripper column once it has been removed from the compressed vapour;
- combusting the fuel gas vapour stream in the gas turbine.

2. The method of claim 1, further comprising:

- cycling a refrigerant stream in a liquefier comprising driving a refrigerant compressor and compressing said refrigerant stream in the refrigerant compressor;
- condensing and subcooling a hydrocarbon stream comprising indirectly heat exchanging said hydrocarbon stream against the refrigerant stream in the liquefier, thereby forming a raw liquefied stream; and

- passing the raw liquefied stream through a pressure reduction step thereby providing the cryogenic hydrocarbon composition comprising the nitrogen and methane-containing liquid phase.

3. The method of claim 2, wherein said gas turbine drives said refrigerant compressor.

4. The method of claim 2 or claim 3, wherein said gas turbine is selected from the group consisting of aero derivative gas turbines.

5. The method of any one of the preceding claims, further comprising

- stream splitting of the cryogenic hydrocarbon composition into said first portion and a second portion having the same composition and phase as the first portion;
- depressurizing the second portion to said flash pressure;
- feeding the second portion into the end flash separator subsequently to said depressurizing of said second portion to said flash pressure;

wherein from said stream splitting to said feeding of the second portion the second portion bypasses the nitrogen stripper column.

6. The method according to claim 5, further comprising a step of:

- adjusting a split ratio of the cryogenic hydrocarbon composition into said first portion and said second portion, defined as a flow rate of said first portion relative to the total flow rate of the first and second portions together, thereby maintaining the flow rate of said first portion on a predetermined target flow rate.

7. The method of any one of the preceding claims, wherein the fuel gas vapour stream is further compressed in a fuel gas compressor to a second fuel gas pressure of higher than the pressure of the compressed vapour, and preferably between 15 and 75 bara, more preferably to a second fuel gas pressure of between 45 and 75 bara.

8. The method according to any one of the preceding claims, further comprising feeding the vapour fraction into said combustion device at a fuel gas pressure not higher than the stripping pressure.

9. The method according to any one of the preceding claims, wherein the stripping pressure is in a range of between 2 and 15 bar absolute and/or wherein the flash pressure is between from 1 and 2 bar absolute.

10. The method according to any one of the preceding claims, wherein the vapour fraction comprises between from 50 mol% to 95 mol% of nitrogen.

11. The method according to any one of the preceding claims, wherein the nitrogen stripper column further comprises at least one internal rectifying section gravitationally higher than said stripping section within said nitrogen stripper column; said method further comprising:

- forming a partially condensed intermediate stream from the overhead vapour obtained from the overhead part of the nitrogen stripping column which is located above the rectifying section, said partially condensed intermediate stream comprising a condensed fraction and a vapour fraction, said forming comprising partially condensing the overhead vapour by heat exchanging the overhead vapour against an auxiliary refrigerant stream and thereby passing heat from the overhead vapour to the auxiliary refrigerant stream at a cooling duty;
- separating the condensed fraction from the vapour fraction, at a separation pressure;
- allowing at least a reflux portion of the condensed fraction to enter the rectifying section in the nitrogen stripper column from a level above the rectifying section.

12. The method according to any one of the preceding claims, further comprising selectively injecting a vapour bypass portion of said compressed vapour, which vapour bypass portion does not comprise the stripping portion and does not comprise the fuel gas portion, into the overhead vapour whereby bypassing at least the stripping section of the nitrogen stripper column.

13. The method according to claim 11 or 12, wherein the auxiliary refrigerant stream is formed by a slip stream of the cycled refrigerant stream from the liquefier, or by a slip stream of the liquefied hydrocarbon product stream.

14. The method according to any one of the preceding claims, further comprising:

- drawing a vaporous recycle portion from the vapour fraction;
- depressurising said vaporous recycle portion to the flash pressure;
- injecting the vaporous recycle portion into at least one of the group consisting of: the nitrogen-stripped liquid, the liquefied hydrocarbon product stream, and the process vapour.

15. An apparatus for providing a liquefied hydrocarbon product stream, the apparatus comprising:

- a cryogenic feed line connected to a source of a cryogenic hydrocarbon composition comprising nitrogen and a methane-containing liquid phase;
- a nitrogen stripper column in fluid communication with the cryogenic feed line, said nitrogen stripper column comprising at least one internal stripping section positioned within the nitrogen stripper column;
- an overhead vapour discharge line communicating with the nitrogen stripper column via an overhead space within the nitrogen stripper column;
- a combustion device other than a gas turbine, fluidly connected with the nitrogen stripper column via at least the overhead vapour discharge line, and arranged to receive a discharge fraction from an overhead vapour carried in the overhead vapour discharge line, and to combust the discharge fraction;
- a nitrogen-stripped liquid discharge line communicating with a sump space within the nitrogen stripper column gravitationally below the stripping section;
- an intermediate depressurizer in the nitrogen-stripped liquid discharge line, fluidly connected to the nitrogen stripper column, arranged to receive a nitrogen-stripped liquid from the sump space of the nitrogen stripper column and to depressurize the nitrogen-stripped liquid, said intermediate depressurizer located on an interface between a stripping pressure side comprising the nitrogen stripper column and a flash pressure side;
- a liquid hydrocarbon product line arranged on the flash pressure side to discharge a liquefied hydrocarbon product stream produced from the nitrogen-stripped liquid;
- a process vapour line arranged on the flash pressure side to receive a process vapour produced from the nitrogen-stripped liquid;
- an end flash separator arranged on the flash pressure side of the interface and in fluid communication with the nitrogen stripper column via the nitrogen-stripped liquid discharge line; and arranged in discharging communication with the liquid hydrocarbon product line and the in discharging communication with the process vapour line;
- a process compressor arranged in the process vapour line arranged to receive the process vapour from the end flash separator, and to compress the process vapour to provide a compressed vapour at a process compressor discharge outlet of the process compressor, said process compressor being on said interface between the stripping pressure side and the flash pressure side;
- a stripping vapour line in fluid communication with the nitrogen stripper column at a level gravitationally below the stripping section and arranged to receive at least a stripping portion of said compressed vapour from the process compressor;
- a fuel gas vapour line fluidly connected with the process compressor discharge outlet via a fuel gas splitter arranged in a path between the process compressor discharge outlet and the stripping vapour line, for removing a fuel gas vapour stream comprising a fuel gas portion of the compressed vapour from the compressed vapour;
- a gas turbine fluidly connected with the fuel gas splitter via a fuel gas line that bypasses the nitrogen stripper column, wherein said gas turbine is arranged to receive and combust the fuel gas portion of the compressed vapour.

16. The apparatus of claim 15, further comprising:

- a liquefier comprising a refrigerant circuit for cycling a refrigerant stream, said refrigerant circuit comprising a refrigerant compressor coupled to a refrigerant compressor driver, arranged to compress the refrigerant stream, and a cryogenic heat exchanger arranged to establish an indirect heat exchanging contact between a hydrocarbon stream and the refrigerant stream of the refrigerant circuit, whereby a raw liquefied stream is formed out of the hydrocarbon stream comprising a subcooled hydrocarbon stream;
- a pressure reduction system arranged downstream of the cryogenic heat exchanger in fluid communication therewith to receive the raw liquefied stream and to reduce its pressure, said pressure reduction system located on the stripping pressure side of the interface;
- a rundown line fluidly connecting the pressure reduction system with the cryogenic heat exchanger to establish fluid communication for the raw liquefied stream to pass from the cryogenic heat exchanger to the pressure

reduction system, wherein the rundown line is fluidly connected to the cryogenic feed line via the pressure reduction system.

17. The apparatus of claim 16, wherein said gas turbine forms said refrigerant compressor driver.

18. The apparatus of any one of claims 15 to 17, further comprising:

- an initial stream splitter at a downstream end of the cryogenic feed line, arranged to split the cryogenic hydrocarbon composition into a first portion and a second portion having the same composition and phase as the first portion;
- a first feed line for conveying the first portion from the initial stream splitter to the nitrogen stripper column;
- a second feed line for conveying the second portion from the initial stream splitter to the end flash separator, wherein the second feed line bypasses the nitrogen stripper column.

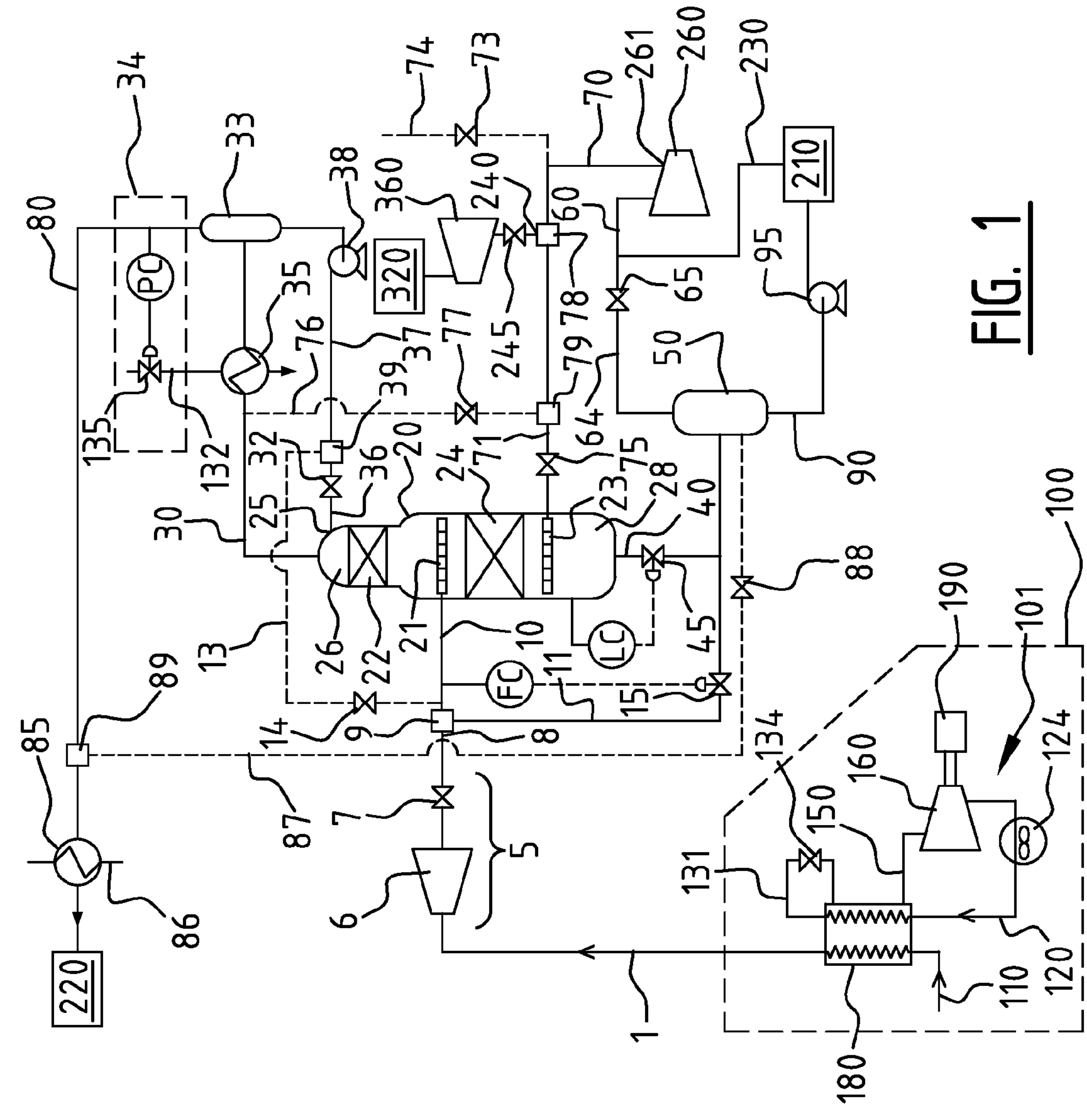
PC
FC
LC
210
220
320
1
5
6
7
8
9
10
11
13
14
15
20
21
22
23
24
25
26
28
30
32
33
34
35
36
37
38
39
40
45
50
60
64
65
70
71
73
74
75
76
77
78
79
80
85
86
87
88
89
90
95
100
101
110
120
124
131
132
134
135
150
160
180
190
230
240
245
260
261
360

FIG. 1

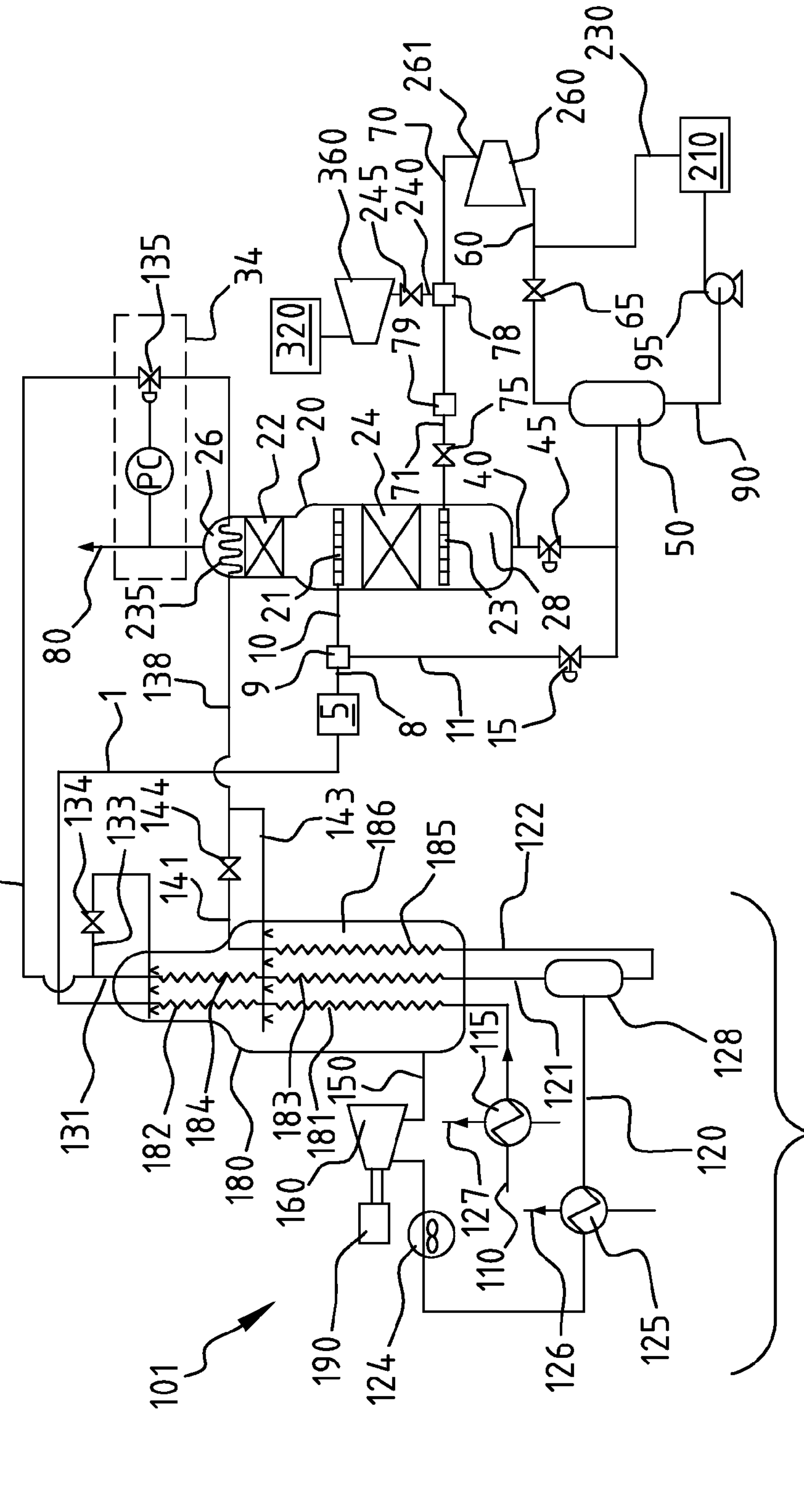
101
190
124
126
125
160
180
184
182
131
181
183
150
110
127
115
121
120
128
100
122
185
186
141
143
144
133
134
132
1
138
8
5
9
10
11
15
21
235
80
26
PC
22
20
24
23
28
45
40
71
75
79
78
65
95
90
50
60
245
240
360
320
70
261
260
230
210
34
135

FIG. 2

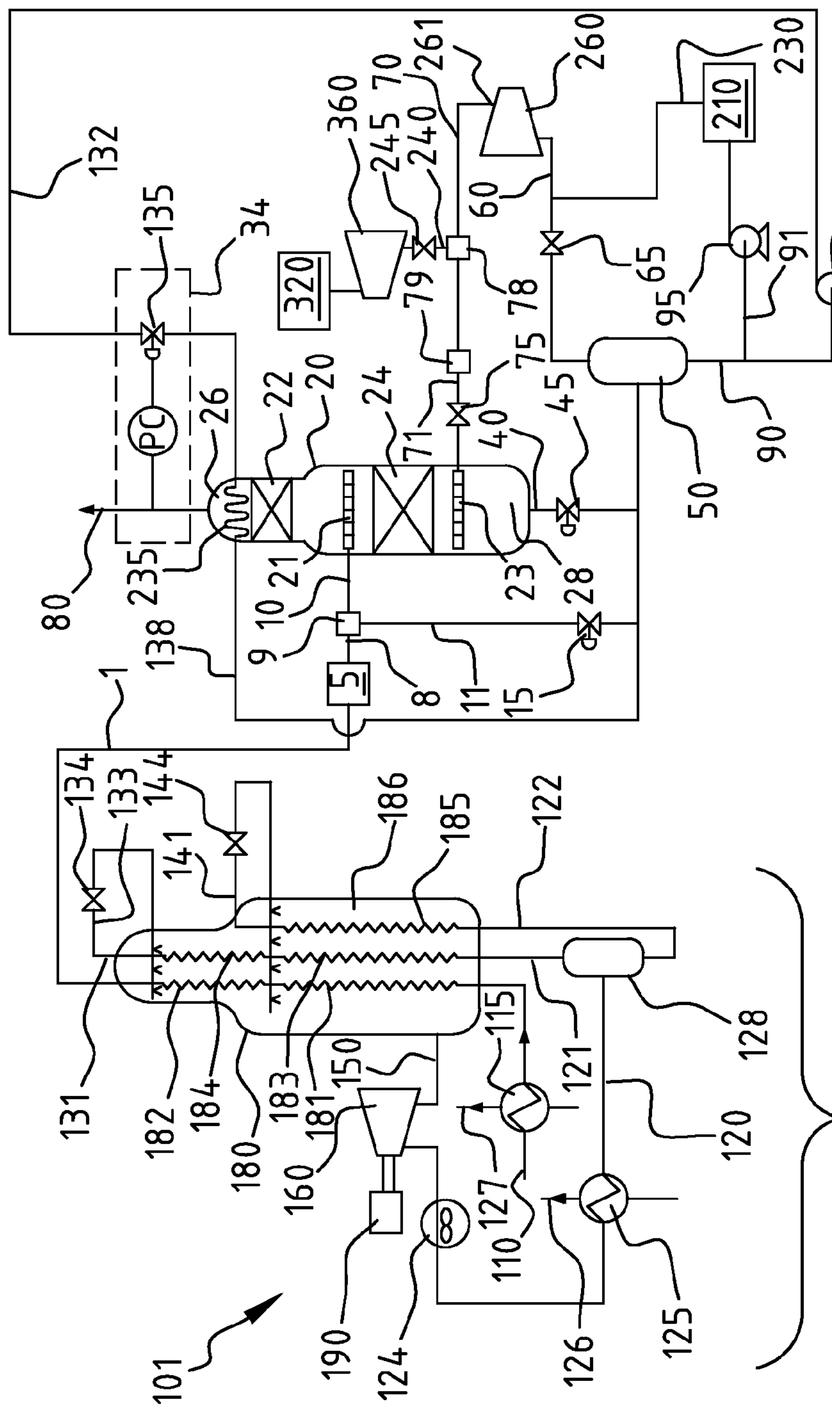
132
135
34
PC
26
22
20
24
360
245
240
70
261
260
230
210
60
65
320
79
78
75
71
40
45
50
90
91
95
96
80
235
21
10
9
138
8
11
15
23
28
5
1
134
133
144
141
186
185
122
131
182
184
180
183
181
150
115
121
128
120
100
160
127
110
126
125
190
124
101

FIG. 3

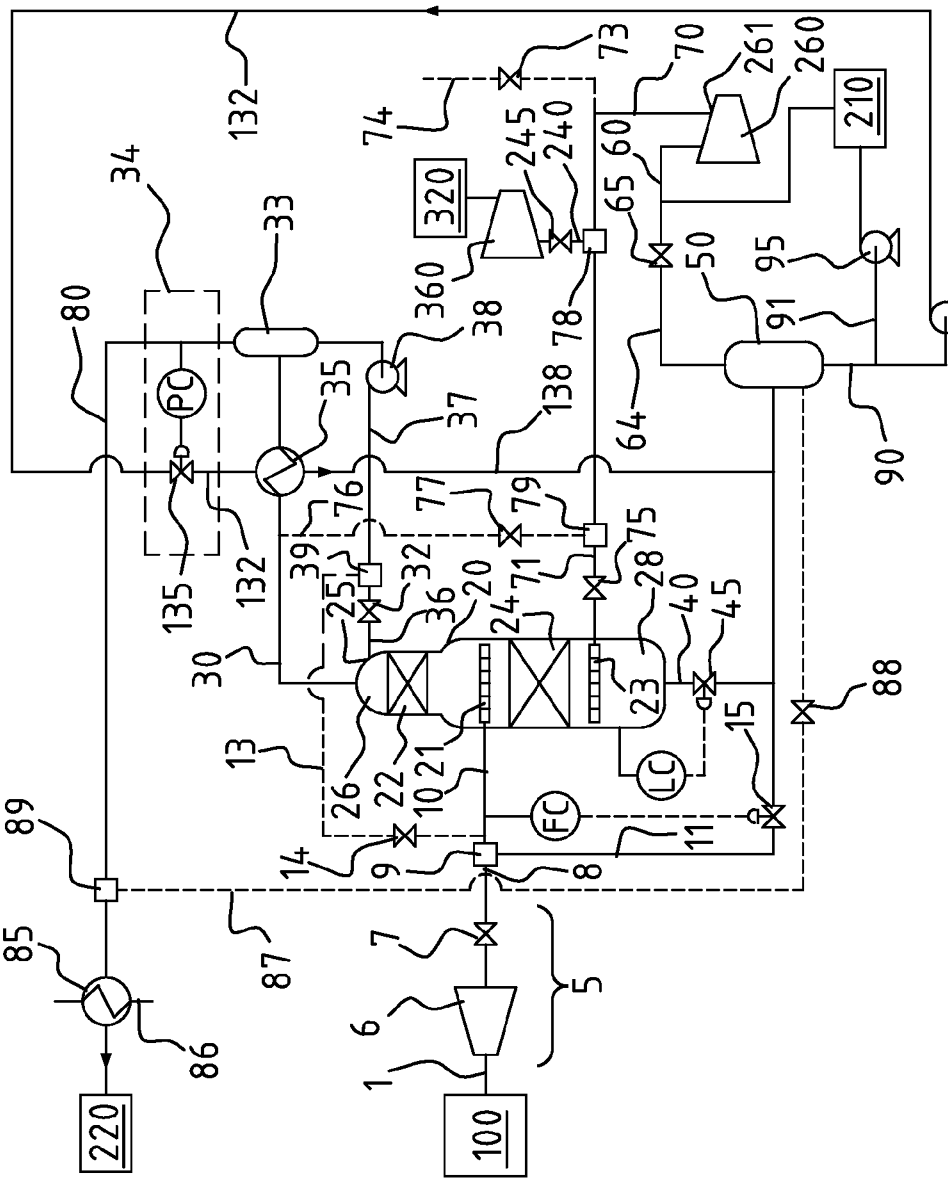
100
220
320
210
PC
FC
LC
1
5
6
7
8
9
10
11
13
14
15
20
21
22
23
24
25
26
28
30
32
33
34
35
36
37
38
39
40
45
50
60
64
65
70
71
73
74
75
76
77
78
79
80
85
86
87
88
89
90
91
95
96
132
135
138
240
245
260
261
360

FIG. 4

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 13 16 4692

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y,D	US 2012/167617 A1 (ANGHEL ALEXANDRA TEODORA [NL] ET AL) 5 July 2012 (2012-07-05) * paragraphs [0042], [0047], [0048], [0058], [0063]; figure 2 *	1-18	INV. F25J1/00 F25J1/02 F25J3/02
Y	US 2011/239701 A1 (KAART SANDER [NL] ET AL) 6 October 2011 (2011-10-06) * paragraphs [0048], [0063], [0064], [0078] *	1-18	
Y	US 3 348 384 A (ALEXANDER HARMENS) 24 October 1967 (1967-10-24) * column 4, lines 13-41; figure * * column 3, lines 3-20 *	1-18	
Y	US 2012/285196 A1 (FIINN ADRIAN JOSEPH [GB] ET AL) 15 November 2012 (2012-11-15) * figure 3 *	13	
Y	US 2005/198999 A1 (GASKIN THOMAS K [US]) 15 September 2005 (2005-09-15) * paragraphs [0003], [0004], [0025], [0028], [0030], [0038]; figure 7 *	1,7-10, 15	TECHNICAL FIELDS SEARCHED (IPC) F25J
Y	US 4 746 342 A (DELONG BRADLEY W [US] ET AL) 24 May 1988 (1988-05-24) * column 6, lines 31-35 * * column 6, line 64 - column 7, line 21 *	1,7-10, 15	

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	2 December 2013	Göritz, Dirk

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 16 4692

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

02-12-2013

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012167617 A1	05-07-2012	AU 2010275307 A1	19-01-2012
		CA 2767369 A1	27-01-2011
		CN 102782430 A	14-11-2012
		EP 2457046 A2	30-05-2012
		JP 2013503314 A	31-01-2013
		KR 20120040700 A	27-04-2012
		RU 2012106137 A	27-08-2013
		US 2012167617 A1	05-07-2012
		WO 2011009832 A2	27-01-2011
US 2011239701 A1	06-10-2011	AU 2009319191 A1	03-06-2010
		CA 2741970 A1	03-06-2010
		CN 102713479 A	03-10-2012
		EP 2342517 A2	13-07-2011
		JP 2012514050 A	21-06-2012
		US 2011239701 A1	06-10-2011
		WO 2010060735 A2	03-06-2010
US 3348384 A	24-10-1967	DE 1501714 A1	23-10-1969
		GB 1069331 A	17-05-1967
		NL 6602096 A	22-08-1966
		US 3348384 A	24-10-1967
US 2012285196 A1	15-11-2012	AU 2010322827 A1	21-06-2012
		EP 2507567 A2	10-10-2012
		GB 2462555 A	17-02-2010
		US 2012285196 A1	15-11-2012
		WO 2011064605 A2	03-06-2011
US 2005198999 A1	15-09-2005	AU 2005224612 A1	29-09-2005
		CA 2557871 A1	29-09-2005
		CN 101389913 A	18-03-2009
		EP 1738122 A1	03-01-2007
		RU 2366872 C2	10-09-2009
		US 2005198999 A1	15-09-2005
		WO 2005090887 A1	29-09-2005
US 4746342 A	24-05-1988	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2011009832 A **[0003] [0004] [0005] [0017]**
- US 5421165 A **[0043]**
- US 5893274 A **[0043]**
- US 6014869 A **[0043]**
- US 6105391 A **[0043]**
- US 20080066492 A **[0043]**
- US 4404008 A **[0110]**
- US 6658891 B **[0110]**
- US 7114351 B **[0110]**
- US 5832745 A **[0111]**
- US 6295833 B **[0111]**
- US 5657643 A **[0111]**
- US 6370910 B **[0111] [0116]**
- US 6962060 B **[0111]**
- WO 2008020044 A **[0111]**
- US 7127914 B **[0111]**
- DE 3521060 A1 **[0111]**
- US 5669234 A **[0111]**
- US 6253574 B **[0111]**
- US 6308531 B **[0111]**
- US 20080141711 A **[0111]**

Non-patent literature cited in the description

- **P-Y MARTIN et al.** LIQUEFIN: AN INNOVATIVE PROCESS TO REDUCE LNG COSTS. *22nd World Gas Conference in Tokyo,* 2003 **[0111]**
- **MARK J. ROBERTS et al.** Large capacity single train AP-X(TM) Hybrid LNG Process. *Gastech 2002,* 13 October 2002 **[0111]**