(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
04 October 2018 (04.10.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/177935 A1

(51) International Patent Classification:
F25J 3/02 (2006.01)

(21) International Application Number:
PCT/EP2018/057464

(22) International Filing Date:
23 March 2018 (23.03.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
17164256.4 31 March 2017 (31.03.2017) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,

(54) Title: NITROGEN RECOVERY APPARATUS AND METHOD OF RECOVERING NITROGEN

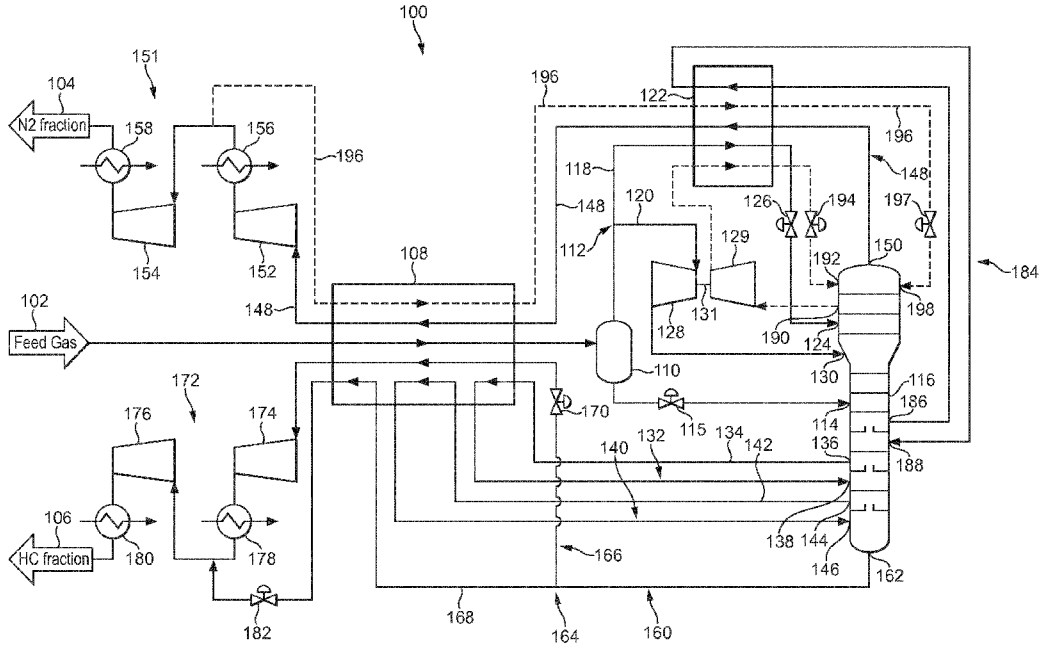

FIG. 1

(57) Abstract: A nitrogen recovery apparatus (100) for recovering nitrogen from natural gas comprises a separator (110) having a liquid fraction port and a vapour fraction port in fluid communication with a split flow arrangement (112), the split flow arrangement (112) having a sub-cooled fluid path (118) and an expanded fluid path (120). A fractionating column (116) has a reflux inlet port (124) in fluid communication with the subcooled fluid path (118) above a middle feed port (130) thereof, the middle feed port (130) being in fluid communication with the expanded fluid path (120). A bottom feed port (114) of the fractionating column (116) is in fluid communication with the liquid fraction port of the separator (110). A side reboiler circuit (132) and a reboiler circuit (140) are operably coupled to the fractionating column (116) below the bottom feed port (114). A bottom hydrocarbon product stream path (160) is in fluid communication with a bottom hydrocarbon port (162) of the fractionating column (116).

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SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

NITROGEN RECOVERY APPARATUS AND METHOD OF RECOVERING NITROGEN

[0001] The present invention relates to a nitrogen recovery apparatus of the type that, for example, comprises a fractionating column for rectifying natural gas. The present invention also relates to a method of recovering nitrogen, the method being of the type that uses a fractionating column.

[0002] In the field of hydrocarbon recovery processing, particularly methane from natural gas extracted from a wellbore, known nitrogen/methane separation systems are operated as nitrogen rejection units with nitrogen treated as a valueless by-product. However, for some applications, valuable hydrocarbons need to be recovered from a nitrogen rich gas whilst keeping the pressure of the nitrogen fraction as high as possible. The hydrocarbon depleted nitrogen fraction is not vented, but reprocessed instead, for example for so-called “Enhanced Oil Recovery” (EOR). Processing of natural gas so as to re-use the nitrogen content of the natural gas can be considered methane recovery rather than nitrogen rejection.

[0003] Some wellbores produce natural gas feeds having a particularly challenging set of content characteristics, for example the feed from a wellbore can have a nitrogen content greater than 30 mol% or even greater than 50 mol%, and the methane content in a recovered nitrogen product fraction can be less than 10 mol% or even less than 3 mol%. Given the valuable nature of the hydrocarbons, it is nevertheless desirable to recover as much of the methane as possible from the recovered nitrogen product fraction. Additionally, the recovered hydrocarbon fraction has to be produced under an elevated pressure, for example greater than 5 bar (500 kPa), such as greater than 10 bar (1000 kPa) without compression. Also, the recovered nitrogen product fraction needs to be produced under elevated pressure, typically greater than 20 bar (2000 kPa) without compression. In order to separate methane from nitrogen in the face of the above set of characteristics, a nitrogen/methane fractionating column has to be operated at a pressure of greater than 20 bar (2000 kPa) and has to be provided with reflux without vaporising liquid

hydrocarbons at a pressure of less than 5 bar (500 kPa). A competitive and economic natural gas processing design is required.

[0004] US patent no. 4,157,904 discloses a so-called "Gas Subcooled Process" (GSP) for refraction of hydrocarbons that employs a separator having a vapour fraction stream separated into two streams, one of which is used to generate refrigeration by work expansion, while the other stream is used to provide reflux for a fractionating column after undergoing at least partial condensation. The process disclosed also employs a side reboiler stream and reboiler stream. However, the process is intended for the separation of methane from heavier hydrocarbons and has specific process parameters that disregard the recovery and re-use of nitrogen.

[0005] According to a first aspect of the present invention, there is provided a nitrogen recovery apparatus for recovering nitrogen from natural gas, the apparatus comprising: a separator having a liquid fraction port and a vapour fraction port in fluid communication with a split flow arrangement, the split flow arrangement having a sub-cooled fluid path and an expanded fluid path; a fractionating column having a reflux inlet port in fluid communication with the subcooled fluid path above a middle feed port thereof, the middle feed port being in fluid communication with the expanded fluid path; a bottom feed port of the fractionating column in fluid communication with the liquid fraction port of the separator; a side reboiler circuit operably coupled to the fractionating column below the bottom feed port; a reboiler circuit operably coupled to the fractionating column below the side boiler circuit; and a bottom hydrocarbon product stream path in fluid communication with a bottom hydrocarbon port of the fractionating column.

[0006] The separator may comprise a feed inlet port for receiving partially liquefied natural gas.

[0007] The apparatus may further comprise: a heat exchanger having a natural gas feed inlet port; the heat exchanger may also have an output port; wherein the output port may be in fluid communication with the feed inlet port of the separator.

[0008] The fractionating column may further comprise: an overhead gas stream path arranged to support sub-cooling in the subcooled fluid path.

[0009] The overhead gas stream path may also be in fluid communication with the heat exchanger.

[0010] The apparatus may further comprise: a reflux condenser stream circuit drawn off the fractionating column from below the middle feed; the reflux condenser stream circuit may support cooling in the subcooled fluid path. The reflux condenser stream circuit may be fed by a drawn off from the fractionating column from below the middle feed, The reflux condenser stream circuit being configured to provide cooling in the subcooled fluid path.

[0011] The apparatus may further comprise: a sub-cooler; wherein the sub-cooled fluid path may be arranged to pass through the sub-cooler.

[0012] The sub-cooler may be another heat exchanger.

[0013] The apparatus may further comprise: an expander; wherein the expanded fluid path may be arranged to pass though the expander.

[0014] The expander may be arranged to drive a first compressor.

[0015] The fractionating column may further comprise: a nitrogen product fraction tapping point disposed above the reflux inlet port and operably coupled to a reflux circuit comprising the first compressor; the reflux circuit may return to the fractionating column above the nitrogen product fraction tapping point.

[0016] The apparatus may further comprise the sub-cooler in the reflux circuit.

[0017] The apparatus may further comprise: a nitrogen return compression and cooling arrangement disposed in the overhead gas stream path.

[0018] The nitrogen return compression and cooling arrangement may have an inlet port in fluid communication with another output port of the heat exchanger.

[0019] The expander may be arranged to drive at least part of the nitrogen return compression and cooling arrangement.

[0020] The nitrogen compression and cooling arrangement may comprise a second compressor in fluid communication with a third compressor via an inter-cooler. An aftercooler may be in fluid communication with and downstream of the third compressor.

[0021] The apparatus may further comprise: a reflux path arranged to extend from a partial compression point in the nitrogen return compression and cooling arrangement back to the fractionating column above the reflux inlet port. The reflux path may supply, when in use, another reflux.

[0022] The reflux path may be arranged to pass through the heat exchanger and the sub-cooler.

[0023] The apparatus may further comprise: a hydrocarbon fraction compression and cooling arrangement in fluid communication with the bottom hydrocarbon product stream path.

[0024] The hydrocarbon fraction compression and cooling arrangement may be in fluid communication with the heat exchanger.

[0025] The expander may be arranged to drive at least part of the hydrocarbon fraction compression and cooling arrangement.

[0026] The hydrocarbon fraction compression and cooling arrangement may comprise a fourth compressor in fluid communication with a fifth compressor via an inter-cooler. An aftercooler may be in fluid communication with and downstream of the fifth compressor.

[0027] The bottom hydrocarbon product stream path may comprise another split flow arrangement arranged to provide a first vaporised and superheated fluid path and a second vaporised and superheated fluid path having a first pressure

associated therewith; the second vaporised and superheated fluid path may be further vaporised at a second pressure higher than the first pressure.

[0028] The first vaporised and superheated fluid path may be in fluid communication with an inlet of the hydrocarbon fraction compression and cooling arrangement. The second vaporised and superheated fluid path may be in fluid communication with a partial compression point in the hydrocarbon fraction compression and cooling arrangement.

[0029] The expander may be arranged to drive a generator.

[0030] The first, second, third, fourth and/or fifth compressors may be combined as a train of compressors sharing a common drive shaft.

[0031] The first, second, third, fourth and/or fifth compressors may be driven by at least one of an electric motor, a gas turbine, and/or a steam turbine.

[0032] The fractionating column may comprise a high-pressure fractionating column operably coupled to a low-pressure fractionating column.

[0033] According to a second aspect of the present invention, there is provided a hydrocarbon capture and recovery system comprising: the nitrogen recovery apparatus as set forth above in relation to the first aspect of the invention; and a return fluid path fluidly communicating an output port of the nitrogen return compression and cooling arrangement to a wellbore for returning nitrogen recovered from a natural gas feed and the wellbore under pressure.

[0034] According to a third aspect of the present invention, there is provided a method of recovering nitrogen from natural gas, the method comprising: separating a partially liquefied natural gas feed into a vapour fraction and a liquid fraction; splitting the flow of the vapour fraction to form a first portion and a second portion of vapour fraction; subcooling the first portion of the vapour fraction using an overhead gas stream of a fractionating column to form a reflux stream, the reflux stream being applied to the fractionating column; expanding the second portion of the vapour fraction to form a middle feed to the fractionating column below the reflux stream;

feeding the liquid fraction as a bottom feed to the fractionating column; a side-reboiler circuit feeding the fractionating column below the bottom feed; and a reboiler circuit feeding the fractionating column below the side reboiler circuit.

[0035] It is thus possible to provide an apparatus and method that recovers nitrogen in an efficient manner, thereby increasing the methane recovery rate and achieving the pressure level requirements of all product streams. The amount of product recovered is therefore improved, whilst reducing operating costs. Additionally, the provision of a reflux condenser stream improves heat integration significantly, for example energy requirements for one or more compressors are reduced. The provision of additional reflux circuits also improves methane recovery rates. Furthermore, the provision of the fractionating column as more than one fractionating component facilitates transportation where size restrictions exist.

[0036] At least one embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[0037] **Figure 1** is a schematic diagram of a nitrogen recovery apparatus constituting an embodiment of the invention; and

[0038] **Figures 2 to 7** are parts of a flow diagram of a method of a method of recovering nitrogen constituting another embodiment of the invention.

[0039] Throughout the following description, identical reference numerals will be used to identify like parts.

[0040] Referring to Figure 1, a nitrogen recovery apparatus 100 comprises a natural gas feed inlet port 102, a nitrogen feedback outlet port 104, and a hydrocarbon outlet port 106. The natural gas feed inlet port 102 is in fluid communication with a first inlet of a first heat exchanger 108. A first outlet of the first heat exchanger 108 is in fluid communication with an inlet of a separator 110, and so a natural gas feed inlet path extends through the first heat exchanger 108. A vapour fraction port of the separator 110 being in fluid communication with a split feed arrangement 112. A liquid fraction port of the separator 110 is in fluid communication with a bottom feed inlet port 114 of a fractionating column 116 via a

first Joule-Thomson device, for example a throttling device, such as a first valve 115.

[0041] The split feed arrangement 112 divides a fluid path originating from the vapour fraction port of the separator 110 into a sub-cooled fluid path 118 and an expanded fluid path 120.

[0042] The sub-cooled fluid path 118 is in fluid communication with a first inlet port of a second heat exchanger 122 constituting a sub-cooler. A first outlet port of the sub-cooler 122 is in fluid communication with a first reflux inlet port 124 of the fractionating column 116 via a second Joule-Thomson device, such as a second valve 126. The sub-cooled fluid path therefore extends through the sub-cooler 122.

[0043] The expanded fluid path 120 is in fluid communication with an inlet port of an expander 128, for example a turboexpander, an outlet port of the expander being in fluid communication with a middle feed inlet port 130 of the fractionating column 116. The expander 128 is therefore in the expanded fluid path 120. In another example, additionally or alternatively, the expander 128 is operably coupled to a first compressor 129 by a drive shaft 131; the application of the first condenser 129 will be described in further detail later herein.

[0044] A side reboiler circuit 132 comprises a side reboiler fluid path 134 coupled at a first end thereof to a side reboiler outlet port 136 of the fractionating column 116 and at a second end thereof to a side reboiler inlet port 138 of the fractionating column 116. The side reboiler outlet port 136 is disposed below the bottom feed inlet port 114 of the fractionating column 116, the side reboiler inlet port 138 being disposed below the side reboiler outlet port 136. The side reboiler fluid path 134 passes through the first heat exchanger 108 via a second inlet port and a second outlet port of the first heat exchanger 108.

[0045] A reboiler circuit 140 comprises a reboiler fluid path 142 coupled at a first end thereof to a reboiler outlet port 144 of the fractionating column 116 and at a second end thereof to a reboiler inlet port 146 of the fractionating column 116. The reboiler outlet port 144 is disposed below the side reboiler inlet port 138 and the

reboiler inlet port 146 is disposed below the reboiler outlet port 144. The reboiler fluid path 142 also passes through the first heat exchanger 108 via a third inlet port and a fourth outlet port of the first heat exchanger 108.

[0046] An overhead gas stream path 148 extends from the fractionating column 116 by way of an overhead gas outlet port 150 of the fractionating column 116 being in fluid communication with a second inlet port of the sub-cooler 122. A second outlet port of the sub-cooler 122 is in fluid communication with a fourth inlet port of the first heat exchanger 108 and the overhead gas stream path 148 passes through the first heat exchanger 108 to a fourth outlet port thereof, the fourth outlet port of the first heat exchanger 108 being in fluid communication with a nitrogen return compression and cooling arrangement 151. The nitrogen return compression and cooling arrangement 151 comprises an inlet port of a second compressor 152 in fluid communication with the fourth outlet port of the first heat exchanger 108. The nitrogen return compression and cooling arrangement 151 also comprises an outlet of the second compressor 152 in fluid communication with an inlet port of a third compressor 154 via a first intermediary heat exchanger, for example a first intercooler 156. An outlet port of the third compressor 154 is in fluid communication with the nitrogen feedback outlet port 104 via a first post-compression heat exchanger, for example a post- or after-cooler 158.

[0047] A bottom hydrocarbon product stream path 160 is fluid communication at one end thereof with a bottom hydrocarbon outlet port 162 of the fractionating column 116. The bottom hydrocarbon product stream path 160 comprises another split feed arrangement 164 providing a first product stream path 166 and a second product stream path 168. The first product stream path 166 is in fluid communication with a fifth inlet port of the first heat exchanger 108 via a third Joule-Thomson device, such as a third valve 170, the first product stream path 166 passing through the first heat exchanger 108 to a fifth outlet port of the first heat exchanger 108. The fifth outlet port of the first heat exchanger 108 is in fluid communication with a hydrocarbon fraction compression and cooling arrangement 172. In this example, the hydrocarbon fraction compression and cooling arrangement 172 comprises a fourth compressor 174 having an inlet port in fluid communication with the fifth outlet

port of the first heat exchanger 108. The hydrocarbon fraction compression and cooling arrangement 172 also comprises a fifth compressor 176, an outlet port of the fourth compressor 174 being in fluid communication with an inlet port of a fifth compressor 176 via a second intermediary heat exchanger, for example a second intercooler 178. An outlet port of the fifth compressor 176 is in fluid communication with the hydrocarbon outlet port 106 via a second post-compression heat exchanger, for example a second post- or after-cooler 180.

[0048] The product stream path 168 also passes through the first heat exchanger 108 by being in fluid communication with a sixth inlet port of the first heat exchanger 108, a sixth outlet port of the first heat exchanger 108 being in fluid communication with a first partial compression point of the hydrocarbon fraction compression and cooling arrangement 172, for example the inlet of the fifth compressor 176, via a fourth Joule-Thomson device, such as a fourth valve 182.

[0049] In another embodiment, a reflux condenser circuit 184 is provided that is in fluid communication with a reflux condenser stream outlet port 186 of the fractionating column 116, the reflux condenser stream outlet port 186 being disposed below the bottom feed inlet port 114, but above the side reboiler outlet port 136. In this regard, the reflux condenser stream outlet port 186 is disposed at a level of the fractionating column 116 so as to draw partially vaporised product from underneath trays of the fractionating column 116 fed via the bottom feed inlet port 114. The reflux condenser circuit 184 passes through the sub-cooler 122 via a third inlet port and a third outlet port of the sub-cooler 122, the reflux condenser circuit 184 returning to the fractionating column 116 and is in fluid communication, at the other end thereof, with a reflux condenser stream inlet port 188, which is below the reflux condenser stream outlet port 186 and above the side reboiler outlet port 136.

[0050] In yet another embodiment, additionally or alternatively, a reflux circuit is provided. In this regard, the fractionating column 116 comprises a nitrogen product fraction tapping port 190 in fluid communication with an inlet port of the first compressor 129, an outlet port of the first compressor 129 being in fluid communication with a fourth inlet port of the sub-cooler 122 so that the reflux circuit

passes through the sub-cooler 122. A fourth outlet port of the sub-cooler 122 is in fluid communication with a second reflux inlet port 192 of the fractionating column 116 via a fifth Joule-Thomson device, such as a fifth valve 194.

[0051] In another embodiment, additionally or alternatively, another reflux circuit is formed by feeding back a proportion of partially condensed nitrogen from the nitrogen return compression and cooling arrangement 151. In this regard, a reflux feedback path 196 is in fluid communication with a partial compression point in the nitrogen return compression and cooling arrangement 151, for example the outlet port of the first intercooler 156. The reflux feedback path 196 passes through the first heat exchanger 108, via a seventh inlet port and a seventh outlet port thereof, and the sub-cooler 122, via a fifth inlet port and a fifth outlet port thereof, before returning to the fractionating column 116 via a sixth Joule-Thomson device, such as a sixth valve 197. In this respect, the reflux feedback path 196 is in fluid communication with a third reflux inlet port 198.

[0052] In operation (Figures 2 to 7), natural gas comprising, inter alia, a mixture of nitrogen and hydrocarbons, is supplied (Step 200) to the natural gas feed inlet port 102 from, for example, the wellbore mentioned above. In this example, the gas is at a temperature of between about 10°C and about 65°C, for example about 50°C, and a pressure of between about 3 MPa (30 bar abs) and about 10 MPa (100 bar abs), for example about 6 MPa (60 bar abs). The first heat exchanger 108 partially liquefies (Step 202) the natural gas by virtue of the overhead gas stream path 148 passing through the first heat exchanger 108 to yield a fluid between -130°C and about -100°C in temperature, for example about -117°C, and between about 3.7 MPa (37 bar abs) and about 9.7 MPa (97 bar abs) in pressure, for example 5.7 MPa (57 bar abs). The partially liquefied natural gas then enters (Step 204) the separator 110, the vapour fraction being between about 0.6 mol/mol and about 0.85 mol/mol, for example about 0.74 mol/mol. The liquid fractions leave the separator 110 via the liquid fraction port of the separator 110. In this regard, the liquid fractions exiting the separator 110 pass through the first valve 115 resulting in cooling of the liquid fractions further before entering the fractionating column 116 at a temperature of between about -140°C and about -110°C, for example about -129°C. In this

example, the vapour fraction at this point is between about 0.15 mol/mol and about 0.3 mol/mol, for example about 0.25 mol/mol.

[0053] The vapour fractions exiting the vapour fraction port of the separator 110 are split (Step 206) by the split feed arrangement 112 to form a first vapour fraction of between about 20% and about 50%, for example about 38% of the total vapour exiting the separator 110, which is cooled (Step 208) by the sub-cooler 122 and expanded (Step 210) by the second valve 126 to cause liquefaction of the first vapour fraction before entering (Step 212) the fractionating column 116 at the first reflux inlet port 124. The liquefied first vapour fraction travels down the fractionating column 116 rectifying vapour travelling up the fractionating column 116, thereby removing valuable hydrocarbons from the upwardly travelling vapour. The upwardly travelling vapour originates, at least in part, from a second vapour fraction provided by the split feed arrangement 112 to the expanded vapour path 120. The second vapour fraction comprises between about 50% and about 80%, for example about 62%, of the total vapour exiting the separator 110 and passes through the expander 128 undergoing cooling and partial liquefaction, yielding a distillation reflux that is applied (Step 214) to the fractionating column 116 at the middle feed inlet port 130. At the middle feed inlet port 130, the distillation reflux is between about -150°C and about -120°C, for example about -138°C, in temperature, between about 2 MPa (20 bar abs) and about 3.2 MPa (32 bar abs), for example about 2.6 MPa (26 bar abs), in pressure, and the vapour fraction is between about 0.85 mol/mol and about 0.6 mol/mol, for example about 0.73 mol/mol.

[0054] Liquid from the side reboiler outlet port 136 of the fractionating column 116 is at a temperature of about -130°C and about -110°C, for example about -121°C, and circulates through the side reboiler circuit 132, which passes through the first heat exchanger 108 before returning to the side reboiler inlet port 138 of the fractionating column 116 partially vaporised. In this respect, the partially vaporised fluid returning via the side reboiler inlet port 138 is at a temperature of between about -120°C and about -100°C, for example about -110°C, and comprises a vapour fraction of between about 0.15 mol/mol and about 0.3 mol/mol, for example about 0.24 mol/mol. Similarly, liquid from the reboiler outlet port 144 of the fractionating

column 116 is at a temperature of between about -120°C and about -100°C, for example -109°C and circulates through the reboiler circuit 140, which passes through the first heat exchanger 108 before returning to the reboiler inlet port 146 of the fractionating column 116. At the reboiler inlet port 146, the partially vaporised fluid is at a temperature of between about -115°C and about -95°C, for example about -104°C, and comprises a vapour fraction of between about 0.05 mol/mol and about 0.3 mol/mol, for example about 0.1 mol/mol. The reboiler circuit 140 and the side reboiler circuit 132 serve to reboil the liquid at the bottom of the fractionating column 116 causing vapour to travel up the fractionating column 116. As the function of the reboiler circuit 140 and the side reboiler circuit 132 are known to the skilled person, the reboiler circuit 140 and the side reboiler circuit 132 will not be described in further detail herein for the sake of clarity and conciseness of description.

[0055] The vapour travelling up the fractionating column 116 is rectified by the reflux travelling down the fractionating column 116. The vapour exiting the fractionating column 116 via the overhead gas outlet port 150 is largely devoid of hydrocarbons to a required degree of purity and exits at a temperature of between about -160°C and about -140°C, for example about -149°C, and at a pressure of between about 2 MPa (20 bar abs) and about 3.2 MPa (32 bar abs), for example 3.2 MPa (32 bar abs). The vapour from the overhead gas outlet port 150 passes through the sub-cooler 122 and the first heat exchanger 108, thereby supporting cooling by both heat exchanges, before being compressed and cooled by the nitrogen return compression and cooling arrangement 151 and then provided at the nitrogen feedback outlet port 104. The nitrogen present at the nitrogen feedback outlet port 104 can be fed back to the wellbore (not shown), for example under pressure, in order to enhance extraction of natural gas from the wellbore.

[0056] Hydrocarbon fractions in liquid state exit the fractionating column 116 via the bottom hydrocarbon outlet port 162 at a temperature of between about -115°C and about -95°C, for example about -104°C, and a pressure of between about 2 MPa (20 bar abs) and about 3.2 MPa (32 bar abs), for example 2.6 MPa (26 bar abs), and follow the bottom hydrocarbon product stream path 160 before being split so as to follow the first product stream path 166 and the second product stream path

168. In this example, the flow fraction of the first product stream path 166 is between about 10% and about 30%, for example about 17%, of the total liquid in the bottom hydrocarbon product stream path 160, and the flow fraction of the second product steam path 168 is between about 90% and about 70%, for example about 83%, of the total liquid in the bottom hydrocarbon product stream path 160. The liquid fraction following the first product stream path 166 undergoes partial vaporisation and superheating, at a first pressure of between about 500 kPa (5 bar abs) and about 2 MPa (20 bar abs), for example about 1.1 MPa (11 bar abs), in the first heat exchanger 108 before being supplied to the compression and cooling arrangement 172. However, the portion of liquid in the second product stream path 168 is also fully vaporised at an elevated, second, pressure greater than the first pressure, the second pressure being between about 2 MPa (20 bar abs) and about 3.2 MPa (32 bar abs), for example 2.6 MPa (26 bar abs). The fully vaporised and superheated product is applied to the inlet port of the fifth compressor 176, thereby reducing the energy consumption of the fourth compressor 174.

[0057] In another embodiment, employing the reflux condenser circuit 184 described above, a liquid side stream at a temperature of between about -145°C and -125, for example about -135°C, is drawn off (Step 216) from the underneath the reflux condenser stream outlet port 186 and passes through the sub-cooler 122 (Step 218) before returning (220) to the fractionating column 116 via the reflux condenser stream inlet port 188 at a temperature of between about -140°C and about -120°C, for example about -131°C, thereby supporting refrigeration provided by the sub-cooler 122. This therefore improves the energy efficiency when generating reflux through the sub-cooler 122. The fluid returning to the fractionating column 116 via the reflux condenser stream inlet port 188 comprises a vapour fraction of between about 0.05 mol/mol and about 0.2 mol/mol, for example about 0.13 mol/mol.

[0058] In yet another embodiment, vapour, at a temperature of between about -155°C and about -135°C, for example about -145°C, is tapped off (Step 222) the fractionating column 116 at the nitrogen product fraction tapping port 190 and undergoes compression (Step 224) by the first compressor 129, cooling by the sub-

cooler 122 and then further cooling by passage through the fifth valve 194, resulting in the extracted vapour being partially liquefied and providing additional distillation reflux that is introduced (Step 226) into the fractionating column 116 at the second reflux inlet port 192. The additional distillation reflux is at a temperature of between about -160°C and about -145°C, for example -153°C, and comprises a vapour fraction of between about 0 mol/mol and about 0.15 mol/mol, for example about 0.04 mol/mol.

[0059] In another embodiment, employing the reflux feedback path 196, a portion of the overhead gas stream is tapped off from the nitrogen return compression and cooling arrangement 151 at the point of partial compression mentioned above, for example after passage of the overhead gas stream through the first intercooler 156. The reflux feedback path 196 comprises between about 0% and about 50%, for example about 30%, of the total vapour in the overhead gas stream path 148 and the fluid is at a pressure of between about 3.5 MPa (35 bar abs) and about 10 MPa (100 bar abs), for example about 6 MPa (60 bar abs). The tapped portion of the overhead gas stream follows the reflux feedback path 196 so as to become cooled by passing back (Step 228) through the first heat exchanger 108 and the sub-cooler 122 before being cooled further and partially liquefied using the sixth valve 197 and then reintroduced (Step 230) into the fractionating column 116 at the third reflux inlet port 198 as further distillation reflux. The further distillation reflux is at a temperature of between about -160°C and about -145°C, for example about -151°C, and comprises a vapour fraction of between about 0 mol/mol and about 0.2 mol/mol, for example about 0.08 mol/mol.

[0060] The provision of the extra distillation reflux in the above embodiments serves to provide additional rectification so as to improve the purity of the nitrogen leaving the fractionating column 116 via the overhead gas outlet port 150 and so increase the proportion of hydrocarbons that can be recovered. Furthermore, the nitrogen recovered can be employed in a hydrocarbon capture and recovery system employing, for example an EOR technique.

[0061] The skilled person should appreciate that the above-described implementations are merely examples of the various implementations that are conceivable within the scope of the appended claims. Indeed, although in these examples, the expander 128 is employed to drive the first compressor 129, the skilled person should appreciate that the work produced by the expander 128 can be employed to drive some or part of the nitrogen return compression and cooling arrangement 151 and/or the hydrocarbon fraction compression and cooling arrangement 172. Furthermore, the compressors of the nitrogen return compression and cooling arrangement 151 and/or the hydrocarbon fraction compression and cooling arrangement 172 can be arranged in combination, optionally with the first compressor 129, as a train of compressors sharing a common drive shaft driven by the expander 128. Additionally or alternatively, the compressors of the nitrogen return compression and cooling arrangement 151 and/or the hydrocarbon fraction compression and cooling arrangement 172 can, optionally with the first compressor 129, be driven by at least one of an electric motor, a gas turbine and/or a steam turbine. The first compressor 129 does not necessarily have to be driven by the expander 128 and other modes of drive can be employed. Indeed, the expander 128 can be used instead to drive an electrical generator.

[0062] In some embodiments, the fractionating column can be formed from more than one part, for example two parts, such as a first high-pressure fractionating column operably coupled to a second lower-pressure fractionating column.

[0063] Although, in the above examples, a specific number and types of heat exchangers are described, it should be appreciated that heat exchanges can be implemented using any number and type of heat exchangers, depending upon implementation requirements. In the above examples, the number and types of heat exchangers are employed for reasons of efficiency and sometimes implementation convenience.

Claims

1. A nitrogen recovery apparatus (100) for recovering nitrogen from natural gas, the apparatus (100) comprising:

a separator (110) having a liquid fraction port and a vapour fraction port in fluid communication with a split flow arrangement (112), the split flow arrangement (112) having a sub-cooled fluid path (118) and an expanded fluid path (120);

a fractionating column (116) having a reflux inlet port (124) in fluid communication with the subcooled fluid path (118) above a middle feed port (130) thereof, the middle feed port (130) being in fluid communication with the expanded fluid path (120);

a bottom feed port (114) of the fractionating column (116) in fluid communication with the liquid fraction port of the separator (110);

a side reboiler circuit (132) operably coupled to the fractionating column (116) below the bottom feed port (114);

a reboiler circuit (140) operably coupled to the fractionating column (116) below the side boiler circuit (132); and

a bottom hydrocarbon product stream path (160) in fluid communication with a bottom hydrocarbon port (162) of the fractionating column (116).

2. An apparatus as claimed in Claim 1, wherein the separator (110) comprises a feed inlet port for receiving partially liquefied natural gas.

3. An apparatus as claimed in Claim 2, further comprising:

a heat exchanger (108) having a natural gas feed inlet port, the heat exchanger (108) also having an output port; wherein

the output port is in fluid communication with the feed inlet port of the separator (110).

4. An apparatus as claimed in any one of Claims 1 to 3, wherein the fractionating column (116) further comprises:

an overhead gas stream path (148) arranged to support sub-cooling in the subcooled fluid path (118).

5. An apparatus as claimed in Claim 4, when dependent upon Claim 2, wherein the overhead gas stream path (148) is also in fluid communication with the heat exchanger (108).

6. An apparatus as claimed in any one of the preceding claims, further comprising:

a reflux condenser stream circuit (184) which is fed by a drawn off from the fractionating column (116) from below the middle feed (130), the reflux condenser stream circuit (184) being configured to provide cooling in the subcooled fluid path (118).

7. An apparatus as claimed in Claim 3, further comprising:

a sub-cooler (122); wherein

the sub-cooled fluid path (118) is arranged to pass through the sub-cooler (122).

8. An apparatus as claimed in any one of the preceding claims, further comprising:

an expander (128); wherein

the expanded fluid path (120) is arranged to pass though the expander (128).

9. An apparatus as claimed in Claim 8, wherein the expander (128) is arranged to drive a first compressor (129).

10. An apparatus as claimed in Claim 9, wherein the fractionating column further comprises:

a nitrogen product fraction tapping point (190) disposed above the reflux inlet port (124) and operably coupled to a reflux circuit comprising the first compressor

(128), the reflux circuit returning to the fractionating column (116) above the nitrogen product fraction tapping point (190).

11. An apparatus as claimed in Claim 10, when dependent upon Claim 7, further comprising the sub-cooler (122) in the reflux circuit.

12. An apparatus as claimed in Claim 4 or any one of Claims 5, 6, or 8 to 11, when dependent upon Claim 4, further comprising:

a nitrogen return compression and cooling arrangement (151) disposed in the overhead gas stream path (148).

13. An apparatus as claimed in Claim 12, when dependent upon Claim 8, wherein the expander (128) is arranged to drive at least part of the nitrogen return compression and cooling arrangement (151).

14. A hydrocarbon capture and recovery system comprising:

the nitrogen recovery apparatus (100) as claimed in any one of the preceding claims; and

a return fluid path fluidly coupling an output port of a nitrogen return compression and cooling arrangement (151) to a wellbore for returning nitrogen recovered from a natural gas feed and the wellbore under pressure.

15. A method of recovering nitrogen from natural gas, the method comprising:

separating (202) a partially liquefied natural gas feed into a vapour fraction and a liquid fraction;

splitting (206) the flow of the vapour fraction to form a first portion and a second portion of vapour fraction;

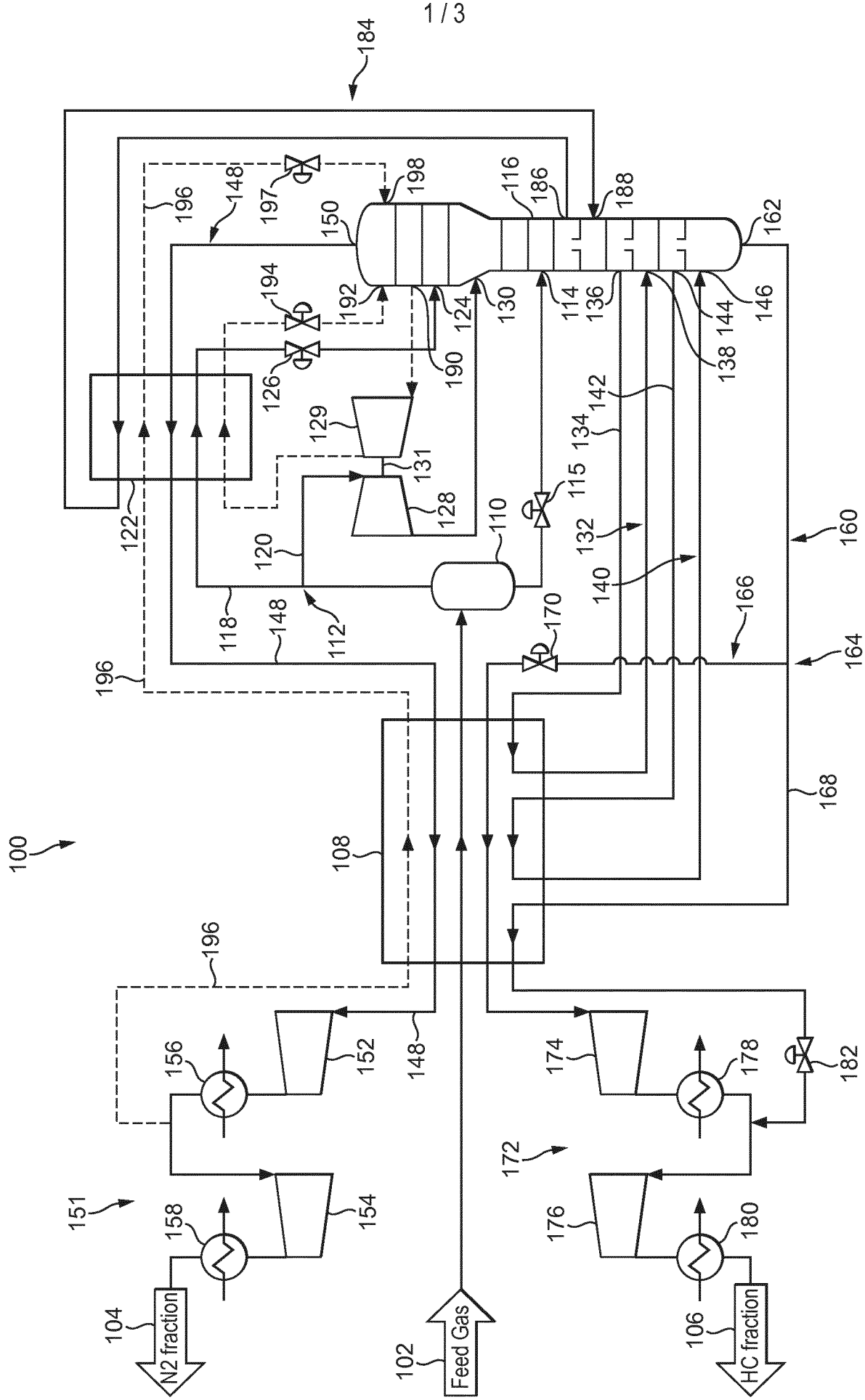
subcooling (208) the first portion of the vapour fraction using an overhead gas stream (148) of a fractionating column (116) to form a reflux stream, the reflux stream being applied to the fractionating column (116);

expanding (210) the second portion of the vapour fraction to form a middle feed to the fractionating column (116) below the reflux stream;

feeding (204) the liquid fraction as a bottom feed to the fractionating column (116);

a side-reboiler circuit (132) feeding the fractionating column (116) below the bottom feed; and

a reboiler circuit (140) feeding the fractionating column (116) below the side reboiler circuit.


184
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120
140
118
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112
166
170
164
196
168
100
108
196
156
152
148
174
178
182
172
151
158
154
176
180
104
N2 fraction
102
Feed Gas
106
HC fraction

FIG. 1

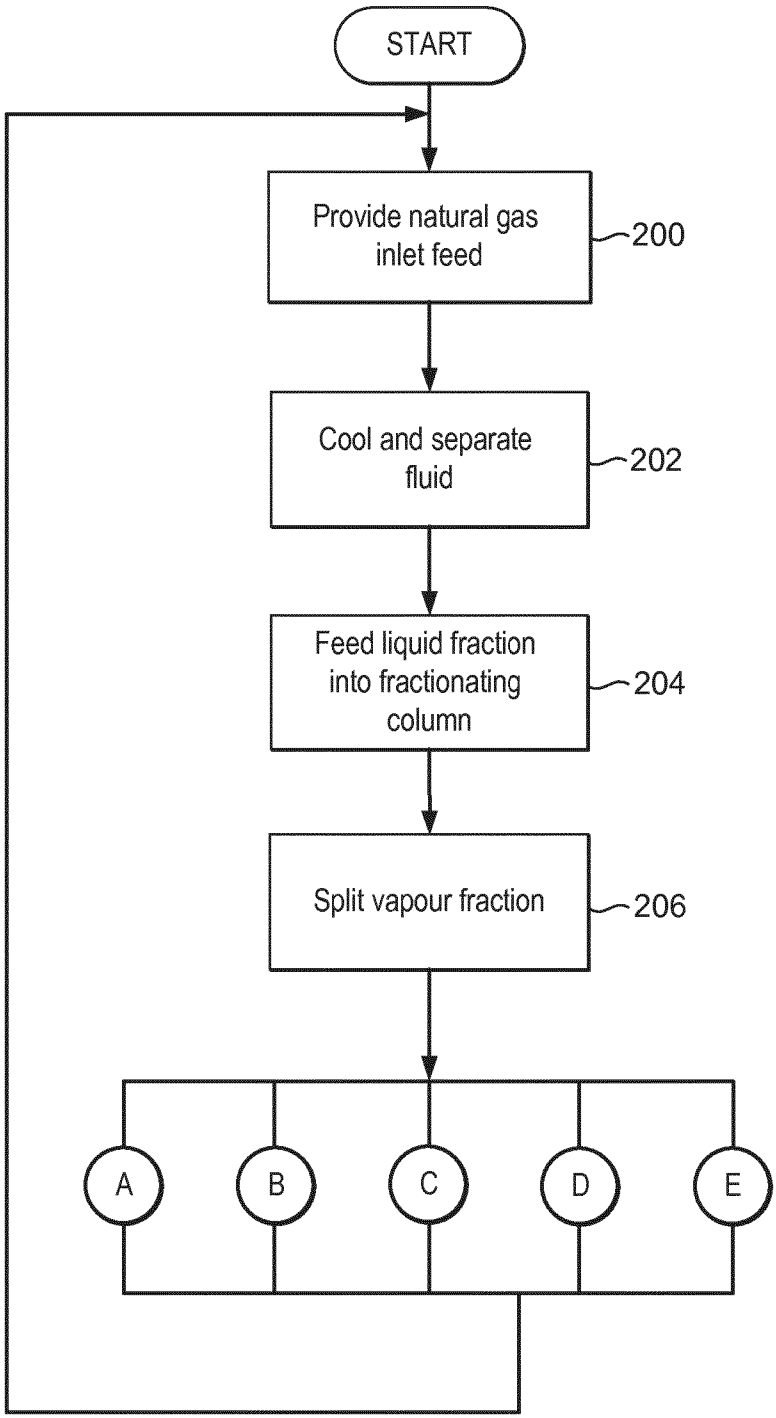
START
Provide natural gas inlet feed
200
Cool and separate fluid
202
Feed liquid fraction into fractionating column
204
Split vapour fraction
206
A
B
C
D
E

FIG. 2

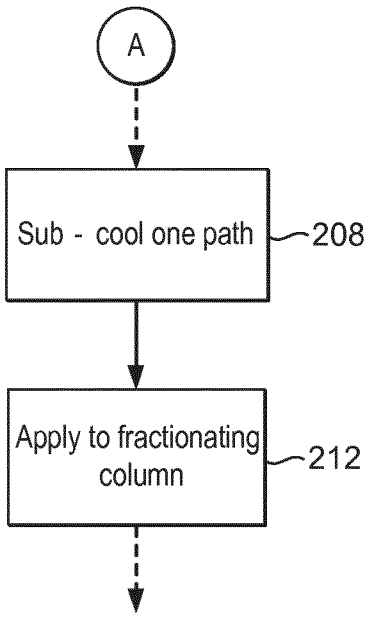

FIG. 3

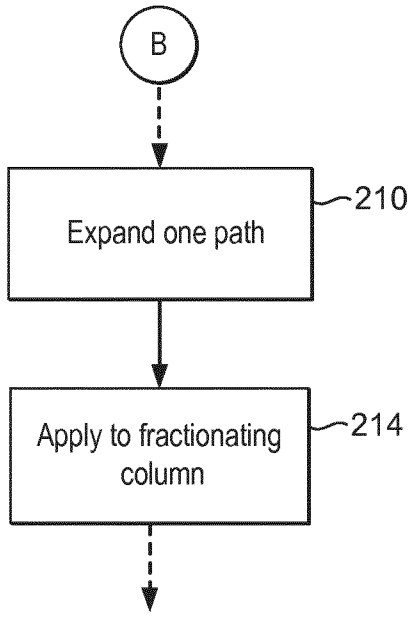

FIG. 4

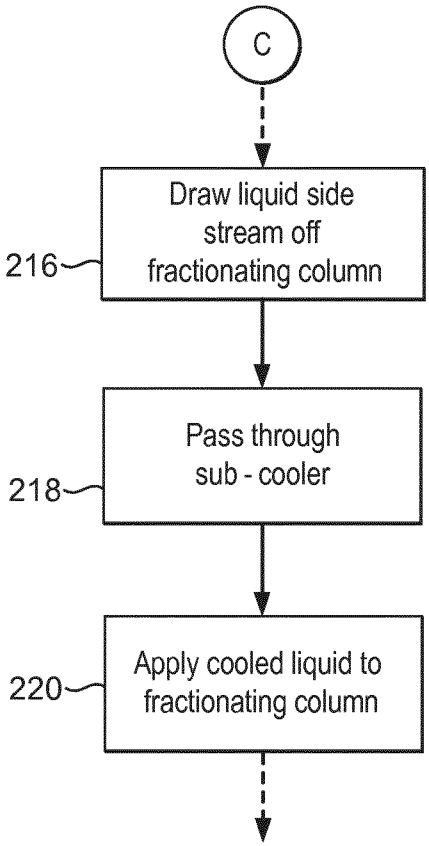

FIG. 5

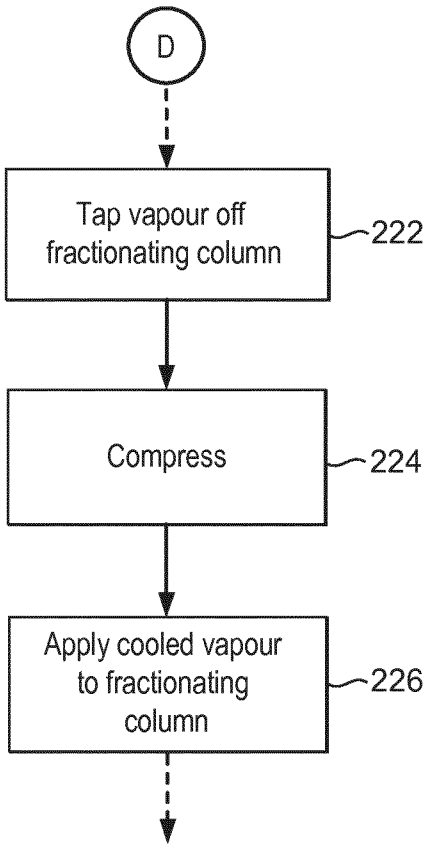

FIG. 6

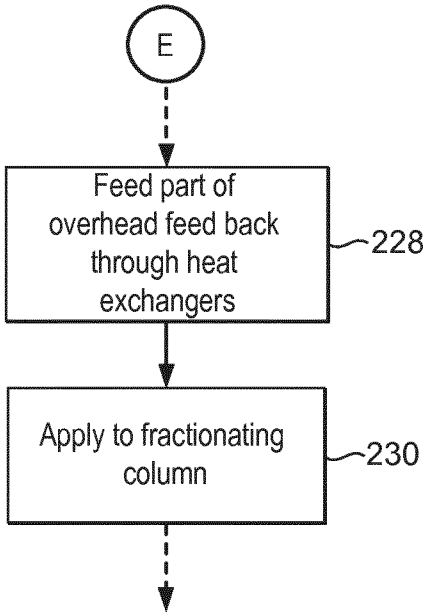

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/057464

A. CLASSIFICATION OF SUBJECT MATTER
INV. F25J3/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	paragraphs [0019], [0020]; figure 2	1-15
Y	DE 38 22 175 A1 (LINDE AG [DE]) 4 January 1990 (1990-01-04) figure	1-15
Y	US 4 504 295 A (DAVIS RUTH A [US] ET AL) 12 March 1985 (1985-03-12) column 6, lines 53-59; figure	1-15

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 June 2018	26/06/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Göritz, Dirk

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	DE 10 2012 017486 A1 (LINDE AG [DE]) 6 March 2014 (2014-03-06) figure	9-13
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Information on patent family members

International application No
PCT/EP2018/057464

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