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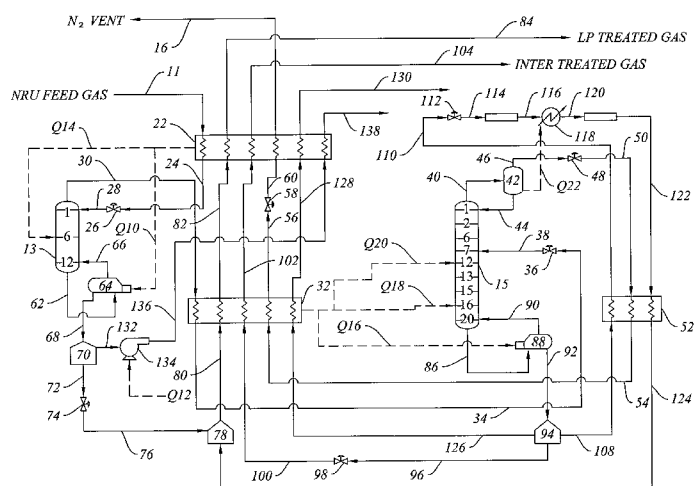


FIG. 3

(57) Abstract: A system and method for removing nitrogen and producing a high pressure methane product stream from natural gas feed streams is disclosed. A system for also producing natural gas liquids in conjunction with nitrogen removal from natural gas feed streams is also disclosed. The system and method of the invention are particularly suitable for use with feed streams in excess of 50 MMSCFD and up to 750 MMSCFD and containing up to 75 ppm carbon dioxide. Typical power requirements for compressing the methane product stream to produce a suitably high pressure stream for sale are reduced according to the system and method of the invention.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**TWO STEP NITROGEN AND METHANE SEPARATION PROCESS****BACKGROUND OF THE INVENTION****1. Field of the Invention**

[0001] This invention relates to a system and method for separating nitrogen from methane and other components from natural gas streams. The invention also relates to a system and method for integrating natural gas liquids (NGL) extraction with nitrogen removal. The system and method of the invention are particularly suitable for use in recovering and processing feed streams typically in excess of 50 MMSCFD.

2. Description of Related Art

[0002] Nitrogen contamination is a frequently encountered problem in the production of natural gas from underground reservoirs. The nitrogen may be naturally occurring or may have been injected into the reservoir as part of an enhanced recovery operation. Transporting pipelines typically do not accept natural gas containing more than 4 mole percent inerts, such as nitrogen. As a result, the natural gas feed stream is generally processed to remove such inerts for sale and transportation of the processed natural gas.

[0003] One method for removing nitrogen from natural gas is to process the nitrogen and methane containing stream through a nitrogen rejection unit or NRU. The NRU may be comprised of two cryogenic fractionating columns, such as that described in U.S. Pat. Nos. 4,451,275 and 4,609,390. These two column systems have the advantage of achieving high nitrogen purity in the nitrogen vent stream, but require

higher capital expenditures for additional plant equipment, including the second column, and may require higher operating expenditures for refrigeration horsepower and for compression horsepower for the resulting methane stream.

[0004] The NRU may also be comprised of a single fractionating column, such as that described in U.S. Pat. Nos. 5,141,544, 5,257,505, and 5,375,422. These single column systems have the advantage of reduced capital expenditures on equipment, including elimination of the second column, and reduced operating expenditures because no external refrigeration equipment is necessary. In addition to capital and operating expenditures, many prior NRU systems have limitations associated with processing NRU feed streams containing high concentrations of carbon dioxide. Nitrogen rejection processes involve cryogenic temperatures, which may result in carbon dioxide freezing in certain stages of the process causing blockage of process flow and process disruption. Carbon dioxide is typically removed by conventional methods from the NRU feed stream, to a maximum of approximately 35 parts per million (ppm) carbon dioxide, to avoid these issues.

SUMMARY OF THE INVENTION

[0005] The system and method disclosed herein facilitate the economically efficient removal of nitrogen from methane in a two step process. The system and method are particularly suitable for NRU feed gas flow rates in excess of 50 MMSCFD and are capable of processing NRU feed gas flow rates of up to around 750 MMSCFD. The system and method are also capable of processing NRU feed gas containing concentrations of carbon dioxide up to approximately 75 ppm for typical nitrogen levels between 20-50%

[0006] According to one embodiment of the invention, a system and method are disclosed for processing an NRU feed gas stream containing primarily nitrogen and methane through two fractionating columns to produce a processed natural gas stream suitable for sale to a transporting pipeline. The first stage column is designed to remove methane and heavier hydrocarbon components from nitrogen, while the second stage column is designed to remove nitrogen from the remaining methane. The overhead stream from the first stage column feeds the second stage column. The NRU feed gas and the first stage overhead stream are not cooled to traditional targeted temperatures of -200 to -245 degrees F. The bottoms streams from the first and second fractionating columns are at varying pressures after further processing and are separately fed to a series of compressors to achieve a processed gas product stream of sufficient pressure for sale, typically at least 615 psia. The higher temperatures in the feeds to the fractionating columns allows the bulk of the methane to be separated from the NRU feed stream while reducing the overall compression required for the process by up to 40% when compared to traditional NRU processes.

[0007] According to another embodiment of the invention, a system and method is disclosed for NGL extraction integrated into the two column NRU process downstream from the first stage column. In traditional nitrogen separation systems, the separation of NGL components is more difficult in streams containing more than 5% nitrogen because nitrogen has a stripping effect, absorbing ethane and heavier components. According to this embodiment of the invention, the bulk methane and heavier components are removed from the nitrogen in the first column, allowing the

bottoms stream containing less than 4% nitrogen, to be further processed for extraction of NGL.

[0008] There are several advantages to the system and method disclosed herein not previously achievable by those of ordinary skill in the art using existing technologies. These advantages include, for example, an ability to process higher flow rate NRU feed streams from around 50 MMSCFD up to around 750 MMSCFD, NRU feed streams containing up to 75 ppm carbon dioxide, reduction in overall compression requirements, and integration of NGL extraction. Although the present system and method has the disadvantage of higher capital costs associated with additional equipment, compared to prior single column NRU processes, the costs of such are sufficiently offset by the savings in operating expenses, such as those from the reduced compression requirements, and the ability to efficiently produce a suitable processed natural gas stream and valuable NGL stream.

[0009] It will be appreciated by those of ordinary skill in the art upon reading this disclosure that references to separation of nitrogen and methane used herein refer to processing NRU feed gas to produce various multi-component product streams containing large amounts of the particular desired component, but not pure streams of any particular component. One of those product streams is a nitrogen vent stream, which is primarily comprised of nitrogen but may have small amounts of other components, such as methane and ethane. Another product stream is a processed gas stream, which is primarily comprised of methane but may have small of other components, such as nitrogen, ethane, and propane. A third product stream, according to one embodiment of the invention, is an NGL product stream, which is primarily comprised of ethane, propane, and butane but may contain amounts of other components, such as hexane and pentane.

[0010] It will also be appreciated by those of ordinary skill in the art upon reading this disclosure that additional processing sections for removing carbon dioxide, water vapor, and possibly other components or contaminants that are present in the NRU feed stream, can also be included in the system and method of the invention, depending upon factors such as, for example, the origin and intended disposition of the product

streams and the amounts of such other gases, impurities or contaminants as are present in the NRU feed stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The system and method of the invention are further described and explained in relation to the following drawings wherein:

FIG. 1 is a simplified process flow diagram illustrating principal processing stages of one embodiment of a system and method for separating nitrogen and methane;

FIG. 2 is a simplified process flow diagram illustrating principal processing stages of another embodiment of a system and method for separating nitrogen and methane including NGL extraction;

FIG. 3 is a more detailed process flow diagram illustrating the nitrogen-methane separation portion of the simplified process flow diagram of FIG. 1;

FIG. 4 is a more detailed process flow diagram illustrating the compression portion of the simplified process flow diagram of FIG. 1;

FIG. 5 is a more detailed process flow diagram illustrating the nitrogen-methane separation portion of the simplified process flow diagram of FIG. 2;

FIG. 6 is a more detailed process flow diagram illustrating the NGL extraction portion of the simplified process flow diagram of FIG. 2; and

FIG. 7 is a more detailed process flow diagram illustrating the compression portion of the simplified process flow diagram of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] Referring to FIG. 1, system 10 comprises processing equipment useful for separating nitrogen from methane according to one embodiment of the invention is depicted. System 10 of the invention includes processing stages 12, 14, and 18 for processing NRU feed gas 11 to produce a nitrogen vent stream 16 and a processed gas stream 20. Processing stage 12 includes a first stage fractionating column, the overhead stream from which serves as the feed for processing stage 14, which includes a second stage fractionating column. The overhead stream from processing stage 14 is a nitrogen vent stream 16. The bottoms streams from processing stages 12 and 14 feed a series of compressors in processing stage 18 to produce processed gas 20 of sufficient pressure and methane composition to be suitable for sale.

[0013] Referring to FIG. 2, system 210 comprises processing equipment useful for separating nitrogen and methane, as well as extracting NGL, according to another embodiment of the invention is depicted. System 210 of the invention includes processing stages 212, 214, and 218 for processing NRU feed gas 211 to produce a nitrogen vent stream 216 and a processed gas stream 220, similar to system 10. Processing stage 212 includes a first stage fractionating column, the overhead stream from which serves as the feed for processing stage 214, which includes a second stage fractionating column. The overhead stream from processing stage 214 is a nitrogen vent stream 216. The bottoms streams from processing stages 212 and 214 feed a series of compressors in processing stage 218 to produce processed gas 220 of sufficient pressure and methane composition to be suitable for sale. The bottoms stream from processing stage 212 also feeds processing stage 410, which includes an NGL fractionating column, the overhead stream from which serves as additional feed for processing stage 218. The bottoms stream from processing stage 410 is the NGL product stream 412.

[0014] Referring to both FIGS. 1 and 2, the source of NRU feed gas 11 or 211 is not critical to the system and method of the invention; however, natural gas drilling and processing sites with flow rates of 50 MMSCFD or greater are particularly suitable. The NRU feed gas 11 or 211 used as the inlet gas stream for system 10 or 210 will typically contain a substantial amount of nitrogen and methane, as well as other hydrocarbons,

such as ethane and propane, and may contain other components, such as water vapor and carbon dioxide.

[0015] Where present, it is generally preferable for purposes of the present invention to remove as much of the water vapor and other contaminants from the NRU feed gas 11 or 211 as is reasonably possible prior to separating the nitrogen and methane. It may also be desirable to remove excess amounts of carbon dioxide prior to separating the nitrogen and methane; however, the method and system are capable of processing NRU feed streams containing up to around 75 ppm carbon dioxide without encountering the freeze-out problems associated with prior systems and methods. Methods for removing water vapor, carbon dioxide, and other contaminants are generally known to those of ordinary skill in the art and are not described herein.

[0016] System 10 is depicted in greater detail in FIGS. 3 and 4, with processing stages 12 and 14 depicted in FIG. 3 and processing stage 18 depicted in FIG. 4. Referring to FIG. 3, a 250 MMSCFD NRU feed stream 11 containing approximately 25% nitrogen and 70% methane at 115° F and 865 psia passes through heat exchanger 22 from which it emerges as stream 24, having been cooled to -132.5° F. This cooling is the result of heat exchange with other process streams, 60, 82, 102, 128, and 136. Stream 24 passes through expansion valve 26 to produce stream 28 having cooled slightly and having a reduction in pressure of around 250 psia (to 615 psia) before entering as the feed stream for the first stage fractionating column 13. Column 13 operates at approximately -122° F to -147° F and 615 psia, which is at a higher temperature and pressure than targeted values in traditional double-column NRU systems.

[0017] Stream 62 from the bottom of the first stage fractionating column 13 is desirably directed to virtual heat exchanger 64 that receives heat (designated by energy stream Q-10) from heat exchanger 22. Stream 62 is at approximately -123° F and 617 psia and contains approximately 4.6% nitrogen and 85% methane. Vapor stream 66, at approximately -117° F, is returned to the first stage fractionating column 13 as the ascending stripping vapor that strips nitrogen from the hydrocarbon flowing downward through the column. The first stage fractionating column also receives heat (designated by energy stream Q-14) from heat exchanger 22.

[0018] In this example, the NRU feed stream 11 contains no carbon dioxide. However, system 10 is capable of processing NRU feed streams containing up to 75 ppm carbon dioxide. The physical separation characteristics of carbon dioxide are similar to an average of ethane and propane. With these parameters, the carbon dioxide would be separated in the first stage fractionating column 13 into the bottoms stream, along with methane, ethane, propane, and other hydrocarbons. The bottoms stream 62 (and subsequent process streams) of the first stage fractionating column 13 does not feed the second stage fractionating column 15 so the carbon dioxide containing stream does not enter the cryogenic section of the process (processing stage 14). This eliminates freeze-out problems with prior systems and increases the carbon dioxide tolerance of system 10 according to the invention from approximately 35 ppm in prior systems to 75 ppm.

[0019] Overhead stream 30, containing approximately 37% nitrogen and 63% methane at -147.5°F , exits the first stage fractionating column 13. It is not necessary to use a reflux stream in the first stage fractionating column 13 according to the invention. The operating parameters allow sufficient separation of nitrogen, methane, and carbon dioxide without reflux; however, a reflux stream and related equipment could be used with the first stage column of system 10 if desired. Overhead stream 30 then passes through heat exchanger 32 and exits as stream 34 at -215°F . This cooling is the result of heat exchange with other process streams 54, 80, 100, and 126. Stream 34 passes through primary JT valve 36 and exits the valve as stream 38 having the same temperature as stream 34 but having a reduction in pressure of almost half. The primary JT valve is capable of cooling by the well known Joule-Thomson effect, but in post-start up, steady state operation the valve provides less actual thermal cooling, but does provide the necessary pressure reduction for stream 38, which feeds the second stage fractionating column 15 at -215°F and 325 psia.

[0020] Stream 86 from the bottom of the second stage fractionating column 15 is directed to virtual reboiler 88 that receives heat (designated as energy stream Q-16) from heat exchanger 32. Stream 86 is at approximately -169°F and 315 psia and contains approximately 5.4% nitrogen and 94% methane. Vapor stream 90, at approximately -163°F , is returned to the second stage fractionating column 15. The

second stage fractionating column also receives heat from heat exchanger 32, designated by energy streams Q-18 and Q-20.

[0021] Overhead stream 40, containing approximately 98% nitrogen and 1.7% methane at -247°F , internally feeds a reflux condenser depicted by separator 42 and heat exchanger 118 and then exits the second stage fractionating column 15. Internal stream 40 passes through internal condenser 118 and then on to separation chamber 42. Liquid stream 44 exits the separation chamber 42 and to provide reflux to the second stage fractionating column 15. Vapor stream 46 exits condenser 42 containing approximately 99.2% nitrogen and 0.8% methane and passes through expansion valve 48 to drop the pressure and temperature of exiting stream 50 to approximately 30 psia and -306.5°F . Stream 50 then passes through subcooler 52, exiting as stream 54 at approximately -187°F and 25 psia. Stream 54 passes through heat exchanger 32 and exits as stream 56, warmed to -152°F . Valve 58 controls stream 56, but exiting stream 60 is at substantially the same temperature and pressure as stream 56. Valve 58 is strategically placed so as to provide another level of refrigeration and made available in the heat exchanger 22. This valve and the associated Joule-Thomson effect allows for further cooling of the process stream 24. Stream 60 then passes through heat exchanger 22 and exits the system as nitrogen vent stream 16. Vent stream 16 contains approximately 99.2% nitrogen, 0.8% methane and a trace amount of ethane at a temperature and pressure of approximately 105°F and 15 psia. Vent stream 16 may be recycled for supplying enhanced oil and gas recovery efforts.

[0022] There are several methane enriched streams produced in processing stages 12 and 14. One such stream is stream 138, which contains approximately 3% nitrogen, 84% methane, and 8% ethane. Stream 138 is essentially the bottoms stream from the first stage fractionating column 13, after being further processed as described below. Bottoms stream 62 enters virtual heat exchanger 64 to produce vapor stream 66 and liquid stream 68. Liquid stream 68 is split in splitter 70 into streams 72 and 132. Under the parameters of the specific example and operating conditions described herein, splitter 70 is set so that 100% of stream 68 is directed to stream 132. However, under other operating conditions and parameters, some of the flow from stream 68 may be directed to stream 72. Stream 132 is pumped by the first stage bottom pump 134

(powered by energy stream Q-12), with stream 136 exiting pump 134 at approximately 865 psia. Stream 136 then passes through heat exchanger 22 and exits as stream 138. One primary benefit of this design configuration is that all vaporized product in stream 138 can be routed directly to sales gas pipeline without typical sales gas compression. The result is a dramatic reduction in the overall compression requirement as compared to other typical processes.

[0023] The remaining methane enriched streams 84, 104, and 130 are essentially the bottoms stream from the second stage fractionating column 15, after being further processed as described below. Bottoms stream 86 enters reboiler 88 to produce vapor stream 90 and liquid stream 92. Liquid stream 92 is split by splitter 94 into streams 96 (approximately 15% of the flow), 108 (approximately 26% of the flow), and 126 (approximately 59% of the flow). Streams 92, 96, 108, and 126 are all at approximately -163° F and 315 psia. Stream 96 is controlled by valve 98, with stream 100 exiting the valve at -200° F and 125 psia. Stream 100 then passes through heat exchanger 32 to stream 102, then through heat exchanger 22 to stream 104. Stream 104 is approximately 3% nitrogen and 96% methane at 105° F and 116 psia.

[0024] Stream 108 passes through subcooler 52, exiting as stream 110 at approximately -290° F and 310 psia. Stream 110 passes through secondary JT valve 112, with stream 114 exiting the valve. Stream 114 is approximately the same temperature as stream 110, but the pressure has been reduced to approximately 37 psia. Further pressure drop is achieved as stream 114 flows through a vertical (up) length of pipe, becoming stream 116 at 22 psia. Stream 115 passes through heat exchanger 118, supplied with energy stream Q-22 from condenser 42, and exits as stream 120 warmed to -249° F. Stream 120 flows through a vertical (down) length of pipe, becoming stream 122, although there is a negligible change in temperature and pressure between streams 120 and 122 in this example. Stream 122 then passes through subcooler 52, exiting as stream 124 with a slight drop in temperature and pressure. Stream 124 then passes through mixer 78 where it is combined with stream 76 to form stream 80. Stream 72 from splitter 70 is controlled by valve 74, from which stream 76 exits. In this example, no flow is directed to streams 72 or 76, so stream 80 is the same composition as stream 124. Stream 80 then passes through heat

exchanger 32, with stream 82 warmed to -152° F exiting and passing through heat exchanger 22. Stream 84, containing 3% nitrogen and 96% methane at 105° F and 17 psia, exits heat exchanger 22 from stream 82.

[0025] Stream 126 passes through heat exchanger 32, with stream 128 warmed slightly exiting and passing through heat exchanger 22. Stream 130, containing 3% nitrogen and 96% methane at 95° F and 307 psia, exits heat exchanger 22 from stream 128. Three of the four methane enriched streams, 84, 104, and 130, are each at different pressures, increasing from the low pressure stream 84 (at 17 psia) to the high pressure stream 130 (at 307 psia). These streams all feed into processing stage 18, where they pass through a series of compressors (described below) to achieve a processed gas stream of sufficient pressure for sale.

[0026] Referring to FIG. 4, stream 84 is compressed by compressor 140 (supplied by energy stream Q-140) emerging as stream 142. Stream 142 is at 285° F and 45 psia, but decreases in temperature (and slightly in pressure) after passing through combination heat exchanger/vessel 144 to emerge as stream 146 at 120° F and 40 psia. Stream 146 is compressed by compressor 148 (supplied by energy stream Q-148) emerging as stream 150 at 320° F and 115 psia. Stream 104 is combined with stream 150, both having substantially equal pressures, and the combined stream passes through the next combination heat exchanger/vessel 152 to emerge as stream 154 at 120° F and 110 psia. Stream 154 is then compressed by compressor 156 (supplied by energy stream Q-156) emerging as stream 158 at 314.5° F and 305 psia. Stream 130 is combined with stream 158, both having substantially equal pressures, and the combined stream passes through the next combination heat exchanger/vessel 160 to emerge as stream 162 at 120° F and 300 psia. Stream 162 is compressed by compressor 164 (supplied by energy stream Q-164) emerging as stream 166. Stream 166 passes through the next vessel 168 to emerge as stream 170 at 120° F and 865 psia. Stream 138 is then mixed with stream 170 in mixer 172, resulting in processed gas stream 20. The processed gas stream 20 is at 111 ° F and 860 psia, containing 3% nitrogen and 90% methane, suitable for sale. As the temperature of the streams passing through vessels 144, 152, 160, and 168 drops, energy streams represented by Q-144, Q-152, Q-160, and Q-168 are created by commercially available heat exchange

cooling equipment and may be used to supply energy to other components of the system 10 or other process systems. The power requirements for successively compressing the streams, represented by Q-140, Q-148, Q-156, and Q-164 (see Table 3 below), are substantially lower than the overall power requirements for traditional NRU systems.

[0027] Acceptable inlet compositions in which this invention may operate satisfactorily are listed in the following Table 1:

TABLE 1
INLET STREAM COMPOSITIONS

Inlet Component	Acceptable Inlet Composition Ranges
Methane	20-90% 20-95%
Ethane and Heavier Components	5-10% 0-20%
Carbon Dioxide	0-75 ppm
Nitrogen	5-80%

[0028] The flow rates, temperatures and pressures of various flow streams referred to in connection with the discussion of the system and method of the invention in relation to FIGS. 3 and 4, for an NRU feed gas flow rate of 250 MMSCFD containing 25% nitrogen and 70% methane and no carbon dioxide, appear in Table 2 below. The values for the energy streams referred to in connection with the discussions of the system and method of the invention in relation to FIGS. 3 and 4 appear in Table 3 below. The values discussed herein and in the tables below are approximate values.

TABLE 2
FLOW STREAM PROPERTIES – Minimum Recompression Case

Stream Reference Numeral	% N₂	% CH₄	Flow Rate (lbmol/h)	Temperature (deg. F)	Pressure (psia)
11	25	70	27450	115	865
16	99.2	0.8	6277	105	15
20	3	90.5	21172	112	860
24	25	70	27450	-132.5	860
28	25	70	27450	-148	615
30	36.6	62.8	17985	-147.5	615

Stream Reference Numeral	% N ₂	% CH ₄	Flow Rate (lbmol/h)	Temperature (deg. F)	Pressure (psia)
34	36.6	62.8	17985	-215	613
38	36.6	62.8	17985	-216	325
40	98.3	1.7	14816	-247	315
44	97.7	2.3	8539	-248	315
46	99.2	0.8	6277	-248	315
50	99.2	0.8	6277	-306.5	30
54	99.2	0.8	6277	-187	25
56	99.2	0.8	6277	-153	21
60	99.2	0.8	6277	-153	20
62	4.6	85.3	13168	-122.9	617
66	8.8	89.6	3704	-117	617
68	3	86.7	9464	-117	617
80	3	96	3000	-250	19
82	3	96	3000	-152.5	18
84	3	96	3000	105	17
86	5.4	93.9	16570	-169	315
90	11.2	88.7	4863	-163	315
92	3	96	11708	-163	315
96	3	96	1750	-163	315
100	3	96	1750	-200	125
102	3	96	1750	-152.5	121
104	3	96	1750	105	116
108	3	96	3000	-163	315
110	3	96	3000	-290	310
114	3	96	3000	-288.5	37
116	3	96	3000	-289	22
120	3	96	3000	-249	20
122	3	96	3000	-249	20
124	3	96	3000	-250	19
126	3	96	6958	-163	315
128	3	96	6958	-160	310
130	3	96	6958	95	307
132	3	83.7	9464	-117	617
136	3	83.7	9464	-112	865
138	3	83.7	9464	105	860
142	3	96	3000	285	45
146	3	96	3000	120	40
150	3	96	3000	321	115
154	3	96	4750	120	110
158	3	96	4750	314.5	305
162	3	96	11708	120	300
166	3	96	11708	326	870

Stream Reference Numeral	% N₂	% CH₄	Flow Rate (lbmol/h)	Temperature (deg. F)	Pressure (psia)
170	3	96	11708	120	865

TABLE 3
ENERGY STREAM REPORT – Minimum Recompression Case

Energy Stream Reference Numeral	Energy Rate (Btu/h)	Power (hp)	From	To
Q-10	6.24E+06	2451	Heat Exchanger 22	Virtual Heat Exchanger 64
Q-12	552334	217	—	Stg 1 Btm Pump 134
Q-14	6E+06	2358	Heat Exchanger 22	Fractionator 13
Q-16	1.2E+07	4718	Heat Exchanger 32	Reboiler 88
Q-18	1E+07	3930	Heat Exchanger 32	Fractionator 15
Q-20	3.75E+06	1474	Heat Exchanger 32	Fractionator 15
Q-22	1.11E+07	4366	Condenser 42	Heat Exchanger 118
Q-140	4.99E+06	1960	--	Compressor 140
Q-144	4.63E+06	1819	Vessel 144	--
Q-148	5.64E+06	2219	--	Compressor 148
Q-152	5.51E+06	2165	Vessel 152	--
Q-156	8.55E+06	3360	--	Compressor 156
Q-160	7.36E+06	2892	Vessel 160	--
Q-164	2.19E+07	8613	--	Compressor

Energy Stream Reference Numeral	Energy Rate (Btu/h)	Power (hp)	From	To
				164
Q-168	2.50E+07	9839	Vessel 168	--

[0029] It will be appreciated by those of ordinary skill in the art that these values are based on the particular parameters and composition of the feed stream in the above example. The values will differ depending on the parameters and composition of the NRU Feed stream 11.

[0030] System 210 is depicted in greater detail in FIGS. 5, 6, and 7, with processing stages 212 and 214 depicted in FIG. 5; processing stage 410 depicted in FIG. 6; and processing stage 218 depicted in FIG. 7. Many of the process steps depicted in FIGS. 5 and 7 are the same as those in FIGS. 3 and 4.

[0031] Referring to FIG. 5, a 250 MMSCFD NRU feed stream 211 containing 25% nitrogen, 70% methane, 3% ethane, 25 ppm of carbon dioxide at 115° F and 865 psia passes through heat exchanger 222 from which it emerges as stream 224, having been cooled to -162.5 F. Stream 224 passes through expansion valve 226 to produce stream 228 having substantially the same temperature but having a reduction in pressure of around 250 psia (to 615 psia) before entering as the feed stream for the first stage fractionating column 213. Column 213 operates at approximately -126° F to -163° F and 615 psia, and causes the nitrogen gas to separate from the methane and flow upwardly through the tower as a vapor.

[0032] Stream 262 from the bottom of the first stage fractionating column 213 is desirably directed to virtual heat exchanger 264 that receives heat (designated by energy stream Q-210) from heat exchanger 222. Stream 262 is at approximately -127° F and 617 psia and contains 5.6% nitrogen and 90% methane. Vapor stream 266, at -119° F, is returned to the first stage fractionating column 213 as the ascending stripping vapor that strips nitrogen from the hydrocarbon flowing downward through the column.

[0033] In this example, the NRU feed stream 211 contains 25 ppm carbon dioxide. However, system 210 is capable of processing NRU feed streams containing up to 75 ppm carbon dioxide as previously discussed. The bottoms stream 262 (and subsequent process streams) of the first stage fractionating column 213, which contains 29 ppm, does not feed the second stage fractionating column 215 so the carbon dioxide containing stream does not enter the cryogenic section of the process (processing stage 214). The overhead stream 230 (and subsequent process streams 234 and 238), which contains only 4.9 ppm carbon dioxide, feeds the second stage fractionating column; however, this small amount of carbon dioxide does not create significant freeze-out problems. The carbon dioxide tolerance of system 210 according to the invention is increased from a maximum of around 35 ppm in prior systems to a maximum of around 75 ppm for typical nitrogen levels in the NRU feed stream.

[0034] Overhead stream 230 exits the first stage fractionating column 213 containing approximately 50% nitrogen and 49.6% methane at -164° F. It is not necessary to use a reflux stream in the first stage fractionating column 213 according to the invention. The operating parameters allow sufficient separation of nitrogen, methane, NGL components, and carbon dioxide without reflux; however, a reflux stream and related equipment could be used with the first stage column of system 210 if desired. Overhead stream 230 then passes through heat exchanger 232 and exits as stream 234 at -225° F. Stream 234 passes through primary JT valve 236 and exits the valve as stream 238 having substantially the same temperature as stream 234 but having a pressure reduction of almost half. The primary JT valve is capable of cooling by the well known Joule-Thomson effect, but in post-start up, steady state operation the valve provides less actual thermal cooling, but does provide the necessary pressure reduction for stream 238, which feeds the second stage fractionating column 215 at -225° F and 325 psia. Stream 238 enters fractionating column 215 at an intermediate stage of the column.

[0035] Stream 286 from the bottom of the second stage fractionating column 215 is directed to virtual reboiler 288 that receives heat (designated as energy stream Q-216) from heat exchanger 232. Stream 286 is at -168° F and 315 psia and contains 5% nitrogen and 94% methane. Vapor stream 290, at approximately -164° F, is returned to

the second stage fractionating column 215. The second stage fractionating column also receives heat from heat exchanger 232, designated by energy streams Q-218 and Q-220.

[0036] Overhead stream 240, containing approximately 98% nitrogen and 1.7% methane at -247° F, internally feeds a reflux condenser depicted by separator 242 and heat exchanger 318 and then exits the second stage fractionating column 215. Internal stream 240 passes through internal condenser 318 and then on to separation chamber 242. Liquid stream 244 exits the separation chamber 242 and to provide reflux to the second stage fractionating column 215. Vapor stream 246 exits condenser 242 containing approximately 99.2% nitrogen and 0.8% methane and passes through valve 248 to drop the pressure and temperature of exiting stream 250 to approximately 30 psia and -306.5° F. Stream 250 then passes through subcooler 252, exiting as stream 254 at -258° F and 25 psia. Stream 254 passes through heat exchanger 232 and exits as stream 256, warmed to -172° F. Stream 256 then passes through heat exchanger 222 and exits the system as nitrogen vent stream 216. Vent stream 216 contains approximately 99% nitrogen, 0.8% methane and a trace amount of ethane at a temperature and pressure of approximately 105° F and 16 psia. Vent stream 216 may be recycled for supplying enhanced oil and gas recovery efforts.

[0037] There are several methane enriched streams produced in processing stages 212 and 214. One such stream is stream 338, which contains approximately 3% nitrogen, 88% methane, and 5% ethane, and 4.3 ppm carbon dioxide. Stream 338 is essentially the bottoms stream from the first stage fractionating column 213, after being further processed as described below. Bottoms stream 262 enters virtual heat exchanger 264 to produce vapor stream 266 and liquid stream 268. Liquid stream 268 is split in splitter 270 into streams 272 and 332. Under the parameters of the specific example and operating conditions described herein, splitter 270 is set so that 100% of stream 268 is directed to stream 332. However, under other operating conditions and parameters, some of the flow from stream 268 may be directed to stream 272. Stream 332 at -119° F and 617 psia passes through expansion valve 334 exiting as stream 336 at -154° F and 315 psia. Stream 336 then passes through heat exchanger 222 and exits as stream 338.

[0038] The remaining methane enriched streams 284, 304, and 230 are essentially the bottoms stream from the second stage fractionating column 215, after being further processed as described below. Bottoms stream 286 enters reboiler 288 to produce vapor stream 290 and liquid stream 292. Liquid stream 292 is split by splitter 294 into streams 296 (approximately 42% of the flow), 308 (approximately 37% of the flow), and 326 (approximately 21% of the flow). Streams 292, 296, 308, and 326 are all at -164° F and 315 psia. Stream 296 passes through expansion valve 298, with stream 300 exiting the valve at -200° F and 125 psia. Stream 300 then passes through heat exchanger 232 to stream 302, then through heat exchanger 222 to stream 304. Stream 304 is approximately 3% nitrogen and 96% methane at 107.5° F and 116 psia.

[0039] Stream 308 passes through subcooler 252, exiting as stream 310 at approximately -285° F and 310 psia. Stream 310 passes through secondary JT valve 312, with stream 314 exiting the valve. Stream 314 is approximately the same temperature as stream 310, but the pressure has been reduced to approximately 36 psia. Further pressure drop is achieved as stream 314 flows through a vertical (up) length of pipe, becoming stream 316 at 21 psia. Stream 316 passes through condenser or heat exchanger 318, supplied with energy stream Q-222 from condenser 242, and exits as stream 320 warmed to -252° F. Stream 320 flows through a vertical (down) length of pipe, becoming stream 322, although there is a negligible change in temperature and pressure between streams 320 and 322 in this example. Stream 322 then passes through subcooler 252, exiting as stream 324 warmed to -200° F and with a slight drop pressure. Stream 324 then passes through mixer 278 where it is combined with stream 276 to form stream 280. Stream 272 from splitter 270 is controlled by valve 274, from which stream 276 exits. In this example, no flow is directed to streams 272 or 276, so stream 280 is the same composition as stream 324. However, under other operating conditions and parameters, some of the flow from stream 268 may be directed to stream 272 through splitter 270. Stream 280 then passes through heat exchanger 232, with stream 282 warmed to -169° F exiting and passing through heat exchanger 222. Stream 284, containing 3% nitrogen and 96% methane at 107.5° F and 16 psia, exits heat exchanger 222 from stream 282.

[0040] Stream 326 is mixed with stream 414 (from FIG. 6) in mixer 416 resulting in stream 328. Stream 328 passes through heat exchanger 322, with stream 330 warmed to 109° F and at 307 psia exiting the heat exchanger. Stream 330 contains 3% nitrogen and 94% methane. Three of the four methane enriched streams, 284, 304, and 330, are each at different pressures, increasing from the low pressure stream 284 (at 16 psia) to the high pressure stream 330 (at 307 psia). These streams all feed into processing stage 218 (Fig 7), where they pass through a series of compressors (described below) to achieve a processed gas stream of sufficient pressure for sale.

[0041] Referring to FIG. 6, the NGL extraction processing stage 410 of system 210 is depicted. Stream 338 containing 3% nitrogen, 88% methane, 5% ethane, and 1.9% propane at -115° F and 312 psia feeds NGL fractionating column 411. This fractionating column 411 produces an overhead stream 414, containing 3.2% nitrogen and 94% methane, that is mixed with stream 326 (see FIG. 5) and a bottoms stream 418 primarily containing NGL, such as ethane and propane. Fractionating column 411 is supplied with heat (designated as energy stream Q-214) from heat exchanger 222. Bottoms stream 418 enters virtual reboiler 420 to produce vapor stream 422 and liquid stream 412. The liquid stream 412 is the NGL product stream containing 42.5% ethane, 27% propane, 0.53% methane, 138 ppm carbon dioxide and a trace amount of nitrogen at 90° F and 314 psia. Virtual reboiler is supplied with heat (designated as energy stream Q-212) from heat exchanger 222.

[0042] Referring to FIG. 7, stream 284 is compressed by compressor 340 (supplied by energy stream Q-340) emerging as stream 342. Stream 342 is at 299° F and 45 psia, but decreases in temperature (and slightly in pressure) after passing through combination heat exchanger/vessel 344 to emerge as stream 346 at 120° F and 40 psia. Stream 346 is compressed by compressor 348 (supplied by energy stream Q-348) emerging as stream 350 at 321° F and 115 psia. Stream 304 is combined with stream 350, both having substantially equal pressures, and the combined stream passes through the next combination heat exchanger/vessel 352 to emerge as stream 354 at 120° F and 110 psia. Stream 354 is then compressed by compressor 356 (supplied by energy stream Q-356) emerging as stream 358 at 315° F and 305 psia.

Stream 330 is combined with stream 358, both having substantially equal pressures, and the combined stream passes through the next combination heat exchanger/vessel 360 to emerge as stream 362 at 120° F and 300 psia. Stream 362 is compressed by compressor 364 (supplied by energy stream Q-364) emerging as stream 366. Stream 366 passes through the next vessel 368 to emerge as processed gas stream 220. The processed gas stream 220 is at 120 ° F and 825 psia, containing 3% nitrogen and 94.5% methane, suitable for sale. As the temperature of the streams passing through vessels 344, 352, 360, and 368 drops, energy streams represented by Q-344, Q-352, Q-360, and Q-368 are created by commercially available heat exchange cooling equipment and may be used to supply energy to other components of the system 10 or other process systems. The power requirements for successively compressing the streams, represented by Q-340, Q-348, Q-356, and Q-364 (see Table 7 below), are substantially lower than the overall power requirements for traditional NRU systems.

[0043] Acceptable inlet compositions in which this invention may operate satisfactorily are listed in the following Table 4:

TABLE 4
INLET STREAM COMPOSITIONS - NGL Recovery

Inlet Component	Acceptable Inlet Composition Ranges
Methane	20-90% 20-95%
Ethane and Heavier Components	5-10% 0-20%
Carbon Dioxide	0-75 ppm
Nitrogen	5-80%

[0044] The flow rates, temperatures and pressures of various flow streams referred to in connection with the discussion of the system and method of the invention in relation to FIGS. 5, 6, and 7, for an NRU feed gas flow rate of 250 MMSCFD containing 25% nitrogen, 70% methane, 3% ethane, and 25 ppm carbon dioxide, appear in Tables 5 and 6 below. The values for the energy streams referred to in connection with the discussions of the system and method of the invention in relation to FIGS. 5, 6, and 7 appear in Table 7 below. The values discussed herein and in the tables below are approximate values.

TABLE 5
FLOW STREAM PROPERTIES – NGL Recovery

Stream Reference Numeral	% N ₂	% CH ₄	Flow Rate (lbmol/h)	Temperature (deg. F)	Pressure (psia)
211	25	70	27450	115	865
216	99.2	0.8	6277	105	16
220	3	94.5	20277	120	825
224	25	70	27450	-162.5	860
228	25	70	27450	-164	615
230	50	49.6	12837	-164	615
234	50	49.6	12837	-225	613
238	50	49.6	12837	-226	325
240	98.4	1.6	12754	-247	315
244	97.7	2.3	6477	-248	315
246	99.2	0.8	6277	-248	315
250	99.2	0.8	6277	-306.5	30
254	99.2	0.8	6277	-258	25
256	99.2	0.8	6277	-172.5	21
262	5.6	89.6	31962	-127	617
266	7.7	91	17350	-119	617
268	3	87.9	14613	-119	617
280	3	96.4	2400	-200	18.3
282	3	96.4	2400	-169	17
284	3	96.4	2400	107.5	16
286	5.1	94.4	8862	-168	315
290	11.1	88.8	2302	-164	315
292	3	96.4	6560	-164	315
296	3	96.4	2750	-164	315
300	3	96.4	2750	-200	125
302	3	96.4	2750	-169	121
304	3	96.4	2750	107.5	116
308	3	96.4	2400	-164	315
310	3	96.4	2400	-285	310
314	3	96.4	2400	-284	36
316	3	96.4	2400	-284	21
320	3	96.4	2400	-252	19
322	3	96.4	2400	-252	19
324	3	96.4	2400	-200	18
326	3	96.4	1410	-164	315
328	3.2	93.8	15127	-134	312
330	3.2	93.8	15127	109.5	307

Stream Reference Numeral	% N ₂	% CH ₄	Flow Rate (lbmol/h)	Temperature (deg. F)	Pressure (psia)
332	3	87.9	14613	-119	617
336	3	87.9	14613	-154	315
338	3	87.9	14613	-115	312
342	3	96.4	2400	298.5	45
346	3	96.4	2400	120	40
350	3	96.4	2400	321	115
354	3	96.4	5150	120	110
358	3	96.4	5150	315	305
362	3.1	94.5	20277	120	300
366	3.1	94.5	20277	315	830
414	3.2	93.6	13717	-115	312

TABLE 6
FLOW STREAM PROPERTIES – NGL Recovery

Stream Reference Numeral	% N ₂	% CH ₄	% C ₂ H ₆	% C ₃ H ₈	Flow Rate (lbmol/h)	Temp. (deg. F)	Pressure (psia)
338	3	87.9	5.4	1.9	14613	-115	312
412	trace	.53	42.5	26.8	895	90	314
414	3.2	93.6	2.95	0.23	13717	-115	312
418	trace	1.15	48.5	24.9	1118.8	74.3	314
422	trace	3.6	72.8	17.5	223.5	90	314

TABLE 7
ENERGY STREAM REPORT – NGL Recovery

Energy Stream Reference Numeral	Energy Rate (Btu/h)	Power (hp)	From	To
Q-210	2.54E+07	9980	Heat Exchanger 222	Virt. Reboiler 264
Q-212	1.43E+06	563	Heat Exchanger 222	Virt. Reboiler 420
Q-214	5E+06	1965	Heat Exchanger 222	Fractionator 411

Q-216	5.67E+06	2229	Heat Exchanger 222	Virt. Reboiler 288
Q-218	1.1E+07	4323	Heat Exchanger 232	Fractionator 215
Q-220	4E+06	1572	Heat Exchanger 232	Fractionator 215
Q-222	8.43E+06	3311	Condenser 242	Heat Exchanger 318
Q-340	4.25E+06	1669	--	Compressor 340
Q-344	4.01E+06	1577	Vessel 344	--
Q-348	4.52E+06	1775	--	Compressor 348
Q-352	4.29E+06	1685	Vessel 352	--
Q-356	9.27E+06	3644	--	Compressor 356
Q-360	8.21E+06	3228	Vessel 360	--
Q-364	3.59E+07	14114	--	Compressor 364
Q-368	4.11E+07	16142.5	Vessel 368	--

[0045] Other alterations and modifications of the invention will likewise become apparent to those of ordinary skill in the art upon reading this specification in view of the accompanying drawings, and it is intended that the scope of the invention disclosed herein be limited only by the broadest interpretation of the appended claims to which the inventor is legally entitled.

[0046] I claim:

1. A system for removing nitrogen and for producing a high pressure methane product stream from a feed stream comprising nitrogen, methane, and other components, the system comprising:

a first fractionating column wherein the feed stream is separated into a first overhead stream and a first bottoms stream;

a second fractionating column wherein the first overhead stream is separated into a second overhead stream and a second bottoms stream;

a splitter for dividing the second bottoms stream into a high pressure stream, an intermediate pressure stream, and a low pressure stream;

a first heat exchanger for cooling the feed stream prior to the first fractionating column through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream, high pressure stream, and at least a portion of the first bottoms stream;

a second heat exchanger for cooling the first overhead stream prior to the second fractionating column through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream and the high pressure stream;

a series of compressors for successively compressing the low pressure stream, then a first combined stream comprising the compressed low pressure stream and the intermediate stream, and then a second combined stream comprising the first combined stream and high pressure stream;

and a mixer for mixing second combined stream with at least a portion of the first bottoms stream to produce a high pressure methane product stream.

2. The system of claim 1 wherein the feed stream is cooled to between - - 140° F and -175°F, depending on inlet gas compositions, prior to entering the first fractionating column.

3. The system of claim 2 further comprising a Joule-Thomson valve for reducing the pressure of and further cooling the feed stream after the first heat exchanger and prior to entering the first fractionating column.

4. The system of claim 3 wherein the pressure of the feed stream is between 500 psia and 650 psia when it enters the first fractionating column.

5. The system of claim 1, further comprising a series of vessels between each of the series of compressors to allow for cooling of the streams being compressed.

6. The system of claim 1, further comprising a pump for pumping at least a portion of the first bottoms stream at a pressure substantially equal to that of the combined low pressure, intermediate pressure, and high pressure streams after passing through the series of compressors.

7. The system of claim 6 further comprising a second splitter for dividing the first bottoms stream into a first and second portions prior to the pump, wherein the first portion of the first bottoms stream is directed to the pump.

8. The system of claim 7 further comprising a second mixer for mixing the low pressure stream with a second portion of the first bottoms stream prior to the second heat exchanger, with the combined stream continuing through the system as the low pressure stream.

9. The system of claim 1, further comprising a Joule-Thomson valve for reducing the pressure of the first overhead stream prior to entering the second fractionating column.

10. The system of claim 9 wherein the pressure of the first overhead stream is between 200 psia and 400 psia when it enters the second fractionating column.

11. The system of claim 9, further comprising a second Joule-Thomson valve for reducing the pressure of the low pressure stream and a third Joule-Thomson valve for reducing the pressure of the intermediate pressure stream, both prior to the second heat exchanger.

12. The system of claim 11, further comprising a third heat exchanger for cooling the low pressure stream prior to the second Joule-Thomson valve in heat exchange with the second overhead stream.

13. The system of claim 1 wherein no reflux stream from the first overhead stream is recycled to the first fractionating column.

14. The system of claim 13 further comprising a condenser for recycling a reflux stream from the second overhead stream into the second fractionating column.

15. The system of claim 1 wherein the methane product stream is comprised of at least 90% methane and wherein the second overhead stream is comprised of at least 90% nitrogen.

16. The system of claim 15 wherein the second fractionation tower overhead stream may be recycled for enhanced oil and gas recovery operations.

17. The system of claim 15 wherein the feed stream is between 50 and 750 MMSCFD.

18. The system of claim 17 wherein the feed stream comprises up to 75 ppm carbon dioxide.

19. The system of claim 18 wherein the carbon dioxide is stripped from the feed stream in the first fractionating column and exits the first fractionating column as part of the bottoms product stream.

20. The system of claim 1 wherein at least a first portion of the energy released from the first heat exchanger is supplied to an intermediate stage of the first fractionating column.

21. The system of claim 20 wherein at least a second portion of the energy released from the first heat exchanger is supplied to reboil fluid at the bottom of the first fractionating column to provide a recycled vapor stream back to the first fractionating column and wherein the first bottoms stream is a liquid stream.

22. The system of claim 1 wherein at least a first portion of the energy released from the second heat exchanger is supplied to an intermediate stage of the second fractionating column.

23. The system of claim 22 wherein at least a second portion of the energy released from the second heat exchanger is supplied to a bottom stage of the second fractionating column.

24. The system of claim 23 further comprising a reboiler for the second stage fractionating column, wherein a liquid stream and a vapor stream exit the reboiler;
wherein the second bottoms stream is the liquid stream; and
wherein the vapor stream is recycled back to the second fractionating column.

25. The system of claim 24 wherein at least a third portion of the energy released from the second heat exchanger is supplied to the reboiler.

26. A method for removing nitrogen and for producing a high pressure methane product stream, the method comprising:

- providing a feed stream comprising nitrogen and methane;
- separating the feed stream into a first overhead stream and a first bottoms stream in a first fractionating column;
- separating the first overhead stream into a second overhead stream and a second bottoms stream in a second fractionating column;
- dividing the second bottoms stream into a high pressure stream, an intermediate pressure stream, and a low pressure stream;
- cooling the feed stream prior to separating through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream, high pressure stream, and at least a portion of the first bottoms stream;
- cooling the first overhead stream prior to separating through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream and the high pressure stream;
- successively compressing the low pressure stream, then a first combined stream comprising the compressed low pressure stream and the intermediate stream, and then a second combined stream comprising the first combined stream and high pressure stream;
- and mixing the second combined stream with at least a portion of the first bottoms stream to produce a high pressure methane product stream.

27. The method of claim 26 wherein the feed stream is cooled to between – 130 ° F and –175 °F prior to entering the first fractionating column.

28. The method of claim 27 further comprising expanding the feed stream after the first heat exchanger and prior to entering the first fractionating column through a first Joule-Thomson valve.

29. The method of claim 28 wherein the pressure of the feed stream is between 500 psia and 650 psia when it enters the first fractionating column.

30. The method of claim 26, further comprising expanding the first overhead stream through a Joule-Thomson valve prior to entering the second fractionating column.

31. The method of claim 30 wherein the pressure of the first overhead stream is between 200 psia and 400 psia when it enters the second fractionating column.

32. The method of claim 30, further comprising reducing the pressure of the low pressure stream and the intermediate pressure stream through a second and third Joule-Thomson valves, both prior to heat exchange with the first overhead stream.

33. The method of claim 26 wherein the first overhead stream is not condensed prior to cooling and no reflux stream is recycled to the first fractionating column.

34. The method of claim 33 further comprising recycling a reflux stream from the second overhead stream into the second fractionating column.

35. The method of claim 26 wherein the methane product stream is comprised of at least 90% methane and wherein the second overhead stream is comprised of at least 90% nitrogen.

36. The method of claim 35 further comprising recycling the second overhead stream for enhanced oil and gas recovery operations.

37. The method of claim 35 wherein the feed stream is between 50 and 750 MMSCFD.

38. The method of claim 37 wherein the feed stream comprises up to 75 ppm carbon dioxide.

39. The method of claim 38 wherein the first bottoms stream comprises substantially all of the carbon dioxide from the feed stream and the first overhead stream is substantially free of carbon dioxide.

40. The method of claim 26 further comprising supplying at least a first portion of the energy released from cooling the feed stream to an intermediate stage of the first fractionating column.

41. The method of claim 40 further comprising supplying at least a second portion of the energy released from cooling the feed stream to the bottom of the first fractionating column;

reboiling fluid at the bottom of the first fractionating column to produce a vapor stream and a liquid stream;

recycling the vapor stream back to the first fractionating column; and

wherein the first bottoms stream is the liquid stream.

42. The method of claim 26 further comprising supplying at least a first portion of the energy released from cooling the first overhead stream to an intermediate stage of the second fractionating column.

43. The method of claim 42 further comprising supplying at least a second portion of the energy released from cooling the first overhead stream to a bottom stage of the second fractionating column.

44. The method of claim 43 further comprising reboiling a bottom stream from the second fractionating column to produce a vapor stream and a liquid stream, wherein the second bottoms stream is the liquid stream; and

recycling the vapor stream back to the second fractionating column.

45. The method of claim 44 further comprising supplying at least a third portion of the energy released from cooling the first overhead stream to reboil the bottom stream from the second fractionating column.

46. A method for removing nitrogen and for producing a high pressure methane product stream, the method comprising:

- providing a feed stream comprising nitrogen and methane;
- separating the feed stream into a first overhead stream and a first bottoms stream in a first fractionating column;
- separating the first overhead stream into a second overhead stream and a second bottoms stream in a second fractionating column;
- dividing the second bottoms stream into a first split stream, a second split stream, and a high pressure stream;
- cooling the first split stream through heat exchange with the second overhead stream;
- reducing the pressure of the cooled first split stream by passing through a first expansion valve to form a low pressure stream;
- reducing the pressure of the second split stream by passing through a second expansion valve to form an intermediate pressure stream;
- cooling the feed stream prior to entering the first fractionating column through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream, high pressure stream, and at least a portion of the first bottoms stream;
- cooling the first overhead stream prior to entering the second fractionating column through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream and the high pressure stream;
- compressing the low pressure stream to a pressure substantially equal to that of the intermediate pressure stream and combining the two streams to form a first compressed stream;
- compressing the first compressed stream to a pressure substantially equal to that of the high pressure stream and combining the two streams to form a second compressed stream;
- compressing the second compressed stream to a pressure substantially equal to that of the at least a portion of the first bottoms stream to form a third compressed stream; and

mixing the third compressed stream with at least a portion of the first bottoms stream to produce a high pressure methane product stream.

47. The method of claim 46 wherein the feed stream is cooled to between – 130 ° F and 175 °F prior to entering the first fractionating column.

48. The method of claim 47 wherein the pressure of the feed stream is between 500 psia and 650 psia when it enters the first fractionating column.

49. The method of claim 48 wherein the feed stream comprises up to 75 ppm carbon dioxide.

50. The method of claim 49 wherein the first bottoms stream comprises substantially all of the carbon dioxide from the feed stream and the first overhead stream is substantially free of carbon dioxide.

51. The method of claim 48 wherein the first overhead stream is not condensed prior to cooling and no reflux stream is recycled to the first fractionating column.

52. The method of claim 47 further comprising supplying at least a portion of the energy released from cooling the feed stream to the first fractionating column and supplying at least a portion of the energy released from cooling the first overhead stream to the second fractionating column.

53. A system for removing nitrogen and for producing a natural gas liquids stream and a high pressure methane product stream from a feed stream comprising nitrogen, methane, ethane, propane and other components, the system comprising:

- a first fractionating column wherein the feed stream is separated into a first overhead stream and a first bottoms stream;

- a second fractionating column wherein the first overhead stream is separated into a second overhead stream and a second bottoms stream;

- a third fractionating column wherein at least a portion of the first bottoms stream is separated into a third overhead stream and a natural gas liquids product stream;

- a splitter for dividing the second bottoms stream into a low pressure stream, an intermediate pressure stream, and a third split stream;

- a mixer for mixing the third overhead stream and the third split stream to form a high pressure stream;

- a first heat exchanger for cooling the feed stream prior to the entering the first fractionating column, wherein the cooling is by heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream, high pressure stream, and at least a portion of the first bottoms stream prior to entering the third fractionating column;

- a second heat exchanger for cooling the first overhead stream prior to entering the second fractionating column, wherein the cooling is by heat exchange with the second overhead stream, low pressure stream, and intermediate pressure stream;

- a series of compressors for successively compressing the low pressure stream, then a first combined stream comprising the compressed low pressure stream and the intermediate stream, and then a second combined stream comprising the first combined stream and high pressure stream to produce a high pressure methane product stream.

54. The system of claim 53 wherein the feed stream is cooled to between – 130 ° F and – 175 ° F prior to entering the first fractionating column.

55. The system of claim 54 further comprising a first Joule-Thomson valve for reducing the pressure of the feed stream after the first heat exchanger and prior to entering the first fractionating column.

56. The system of claim 55 wherein the pressure of the feed stream is between 500 psia and 650 psia when it enters the first fractionating column.

57. The system of claim 53, further comprising a series of vessels between each of the series of compressors to allow for cooling of the streams being compressed.

58. The system of claim 55, further comprising a second Joule-Thomson valve for reducing the pressure of and cooling at least a portion of the first bottoms stream prior to entering the first heat exchanger.

59. The system of claim 58 further comprising a second splitter for dividing the first bottoms stream into a first and second portions prior to the second Joule-Thomson valve, wherein the first portion of the first bottoms stream is directed to the valve.

60. The system of claim 59 further comprising a second mixer for mixing the low pressure stream with a second portion of the first bottoms stream prior to the second heat exchanger, with the combined stream continuing through the system as the low pressure stream.

61. The system of claim 53, further comprising a Joule-Thomson valve for reducing the pressure of the first overhead stream prior to entering the second fractionating column.

62. The system of claim 61 wherein the pressure of the first overhead stream is between 200 psia and 400 psia when it enters the second fractionating column.

63. The system of claim 61, further comprising a second Joule-Thomson valve for reducing the pressure of and cooling the low pressure stream and a third Joule-Thomson valve for reducing the pressure of and cooling the intermediate pressure stream, both prior to the second heat exchanger.

64. The system of claim 63, further comprising a third heat exchanger prior to the second Joule-Thomson valve for cooling the low pressure stream in heat exchange with the second overhead stream.

65. The system of claim 53 wherein no reflux stream from the first overhead stream is recycled to the first fractionating column.

66. The system of claim 65 further comprising a condenser for recycling a reflux stream from the second overhead stream into the second fractionating column.

67. The system of claim 53 wherein the methane product stream is comprised of at least 90% methane, the second overhead stream is comprised of at least 90% nitrogen, and the natural gas liquid product stream is comprised of at least 30% ethane and less than 5% methane.

68. The system of claim 65 wherein the second overhead stream is recycled for enhanced oil and gas recovery operations.

69. The system of claim 65 wherein the feed stream is between 50 and 750 MMSCFD.

70. The system of claim 67 wherein the feed stream comprises up to 75 ppm carbon dioxide.

71. The system of claim 68 wherein the carbon dioxide is stripped from the feed stream in the first fractionating column and exits the first fractionating column as part of the bottoms stream.

72. The system of claim 53 wherein a first portion of the energy released from the first heat exchanger is supplied to an intermediate stage of the third fractionating column; and

a second portion of the energy released from the first heat exchanger is supplied to reboil fluid at the bottom of the third fractionating column to produce a liquid stream and a vapor stream;

the vapor stream is recycled back to the third fractionating column; and
wherein the natural gas liquids product stream is the liquid stream.

73. The system of claim 70 wherein a third portion of the energy released from the first heat exchanger is supplied to reboil fluid at the bottom of the first fractionating column to produce a liquid stream and a vapor stream;

the vapor stream is recycled back to the first fractionating column; and
wherein the first bottoms stream is the liquid stream.

74. The system of claim 53 wherein at least a first portion of the energy released from the second heat exchanger is supplied to an intermediate stage of the second fractionating column.

75. The system of claim 72 wherein at least a second portion of the energy released from the second heat exchanger is supplied to a bottom stage of the second fractionating column.

76. The system of claim 73 further comprising a reboiler for the second stage fractionating column to produce a liquid stream and a vapor stream;

wherein the second bottoms stream is the liquid stream; and
wherein the vapor stream is recycled back to the second fractionating column.

77. The system of claim 74 wherein at least a third portion of the energy released from the second heat exchanger is supplied to the reboiler.

78. A method for removing nitrogen and for producing a high pressure methane product stream and a natural gas liquids stream, the method comprising:

- providing a feed stream comprising nitrogen, methane, ethane, and propane;
- separating the feed stream into a first overhead stream and a first bottoms stream in a first fractionating column;
- separating the first overhead stream into a second overhead stream and a second bottoms stream in a second fractionating column;
- separating at least a portion of the first bottoms stream into a third overhead stream and a natural gas liquids product stream in a third fractionating column;
- dividing the second bottoms stream into a first split stream, a second split stream, and a third split stream;
- cooling the first split stream through heat exchange with the second overhead stream;
- reducing the pressure of the cooled first split stream by passing through a first expansion valve to form a low pressure stream;
- reducing the pressure of the second split stream by passing through a second expansion valve to form an intermediate pressure stream;
- mixing the third split stream and the third overhead stream to form a high pressure stream;
- cooling the feed stream prior to entering the first fractionating column through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream, high pressure stream, and at least a portion of the first bottoms stream prior to entering the third fractionating column;
- cooling the first overhead stream prior to entering the second fractionating column through heat exchange with the second overhead stream, low pressure stream, and intermediate pressure stream;
- compressing the low pressure stream to a pressure substantially equal to that of the intermediate pressure stream and combining the two streams to form a first compressed stream;

compressing the first compressed stream to a pressure substantially equal to that of the high pressure stream and combining the two streams to form a second compressed stream;

compressing the second compressed stream to produce a high pressure methane product stream.

79. The method of claim 76 wherein the feed stream is cooled to between -130°F and -175°F prior to entering the first fractionating column.

80. The method of claim 77 wherein the pressure of the feed stream is between 500 psia and 650 psia when it enters the first fractionating column.

81. The method of claim 78 wherein the feed stream comprises up to 75 ppm carbon dioxide.

82. The method of claim 79 wherein the first bottoms stream comprises substantially all of the carbon dioxide from the feed stream and the first overhead stream is substantially free of carbon dioxide.

83. The method of claim 78 wherein the first overhead stream is not condensed prior to cooling and no reflux stream is recycled to the first fractionating column.

84. The method of claim 77 further comprising supplying at least a portion of the energy released from cooling the feed stream to the first fractionating column and supplying at least a portion of the energy released from cooling the first overhead stream to the second fractionating column.

85. The method of claim 82 further comprising supplying at least a second portion of the energy released from cooling the feed stream to the third fractionating column.

86. A method for removing nitrogen and for producing a high pressure methane product stream and a natural gas liquids product stream, the method comprising:

- providing a feed stream comprising nitrogen, methane, ethane, and propane;
- separating the feed stream into a first overhead stream and a first bottoms stream in a first fractionating column;
- separating the first overhead stream into a second overhead stream and a second bottoms stream in a second fractionating column;
- separating the first bottoms stream into a third overhead stream and a natural gas liquids product stream in a third fractionating column;
- dividing the second bottoms stream into a high pressure stream, an intermediate pressure stream, and a low pressure stream;
- mixing the high pressure stream and the third overhead stream to form a mixed high pressure stream;
- cooling the feed stream prior to separation through heat exchange with the second overhead stream, low pressure stream, intermediate pressure stream, mixed high pressure stream, and at least a portion of the first bottoms stream;
- cooling the first overhead stream prior to separation through heat exchange with the second overhead stream, low pressure stream, and intermediate pressure stream;
- successively compressing the low pressure stream, then a first combined stream comprising the compressed low pressure stream and the intermediate stream, and then a second combined stream comprising the first combined stream and mixed high pressure stream to produce a high pressure methane product stream.

87. The method of claim 84 wherein the feed stream is cooled to between -130 ° F and -175 °F prior to entering the first fractionating column.

88. The method of claim 85 further comprising reducing the pressure of the feed stream after the first heat exchanger and prior to entering the first fractionating column through a first Joule-Thomson valve.

89. The method of claim 86 wherein the pressure of the feed stream is between 500 psia and 650 psia when it enters the first fractionating column.

90. The method of claim 84, further comprising reducing the pressure of the first overhead stream through a Joule-Thomson valve prior to entering the second fractionating column.

91. The method of claim 88 wherein the pressure of the first overhead stream is between 200 psia and 400 psia when it enters the second fractionating column.

92. The method of claim 88, further comprising reducing the pressure of the low pressure stream and the intermediate pressure stream through a second and third Joule-Thomson valve, both prior to heat exchange with the first overhead stream.

93. The method of claim 84 wherein the first overhead stream is not condensed prior to cooling and no reflux stream is recycled to the first fractionating column.

94. The method of claim 91 further comprising recycling a reflux stream from the second overhead stream into the second fractionating column.

95. The method of claim 84 wherein the methane product stream is comprised of at least 90% methane, the second overhead stream is comprised of at least 90% nitrogen, and the natural gas liquid product stream is comprised of at least 30% ethane and less than 5% methane.

96. The method of claim 93 further comprising recycling the second overhead stream for enhanced oil and gas recovery operations.

97. The method of claim 93 wherein the feed stream is between 50 and 750 MMSCFD.

98. The method of claim 95 wherein the feed stream comprises up to 75 ppm carbon dioxide.

99. The method of claim 96 wherein the first bottoms stream comprises substantially all of the carbon dioxide from the feed stream and the first overhead stream is substantially free of carbon dioxide.

100. The method of claim 84 further comprising supplying at least a first portion of the energy released from cooling the feed stream to the bottom of the first fractionating column;

reboiling fluid at the bottom of the first fractionating column to produce a liquid stream and a vapor stream;

recycling the vapor stream back to the first fractionating column; and

wherein the first bottoms stream is the liquid stream.

101. The method of claim 84 further comprising supplying at least a first portion of the energy released from cooling the first overhead stream to an intermediate stage of the second fractionating column.

102. The method of claim 99 further comprising supplying at least a second portion of the energy released from cooling the first overhead stream to a bottom stage of the second fractionating column.

103. The method of claim 100 further comprising supplying at least a third portion of the energy released from cooling the first overhead stream to reboil a bottom stream from the second fractionating column;

reboiling the bottom stream from the second fractionating column to produce a first vapor stream and a first liquid stream, wherein the second bottoms stream is the first liquid stream; and

recycling the first vapor stream back to the second fractionating column.

104. The method of claim 101 further comprising supplying a second portion of the energy released from cooling the feed stream to an intermediate stage of the third fractionating column;

supplying a third portion of the energy released from cooling the feed stream to reboil a bottom stream from the third fractionating column;

reboiling the bottom stream from the third fractionating column to produce a second vapor stream and a second liquid stream, wherein the natural gas liquids product stream is the second liquid stream; and

recycling the second vapor stream back to the third fractionating column.

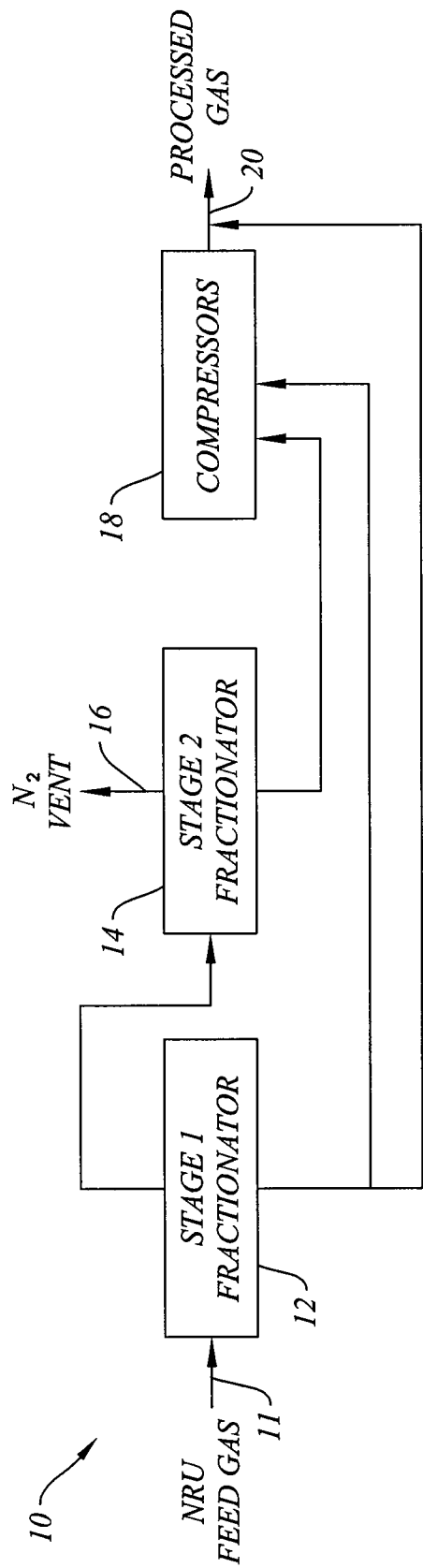


FIG. 1

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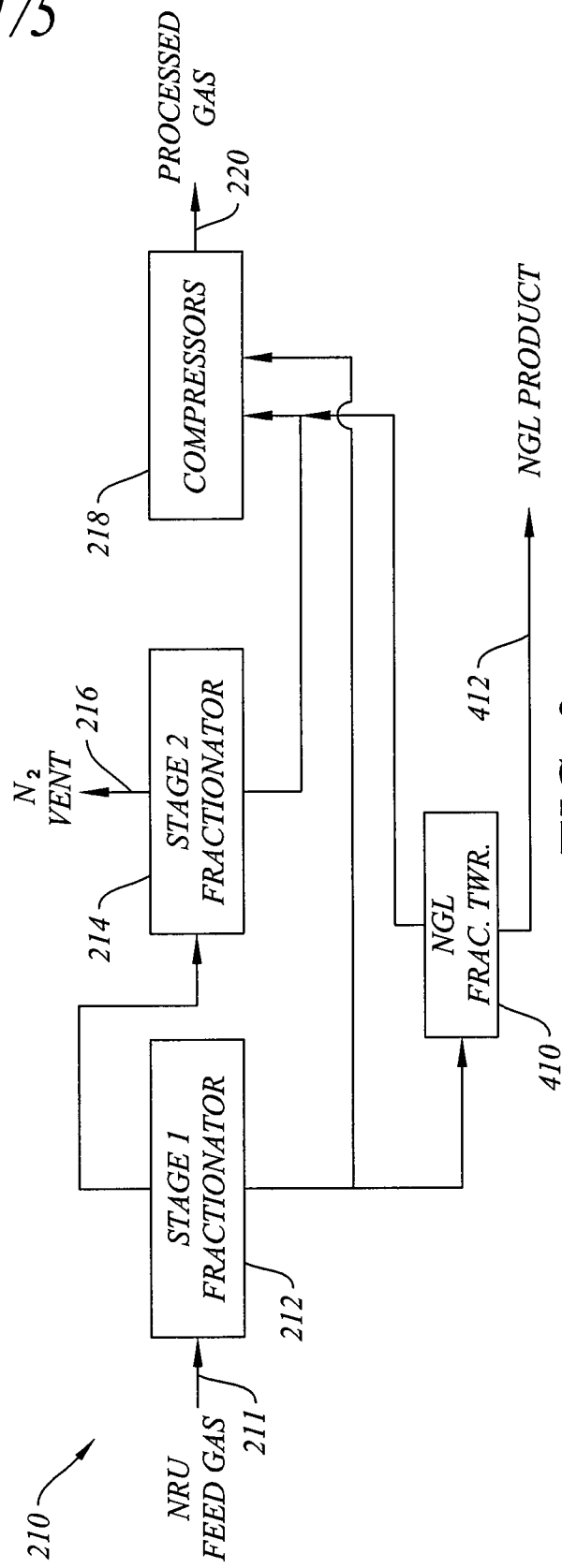


FIG. 2

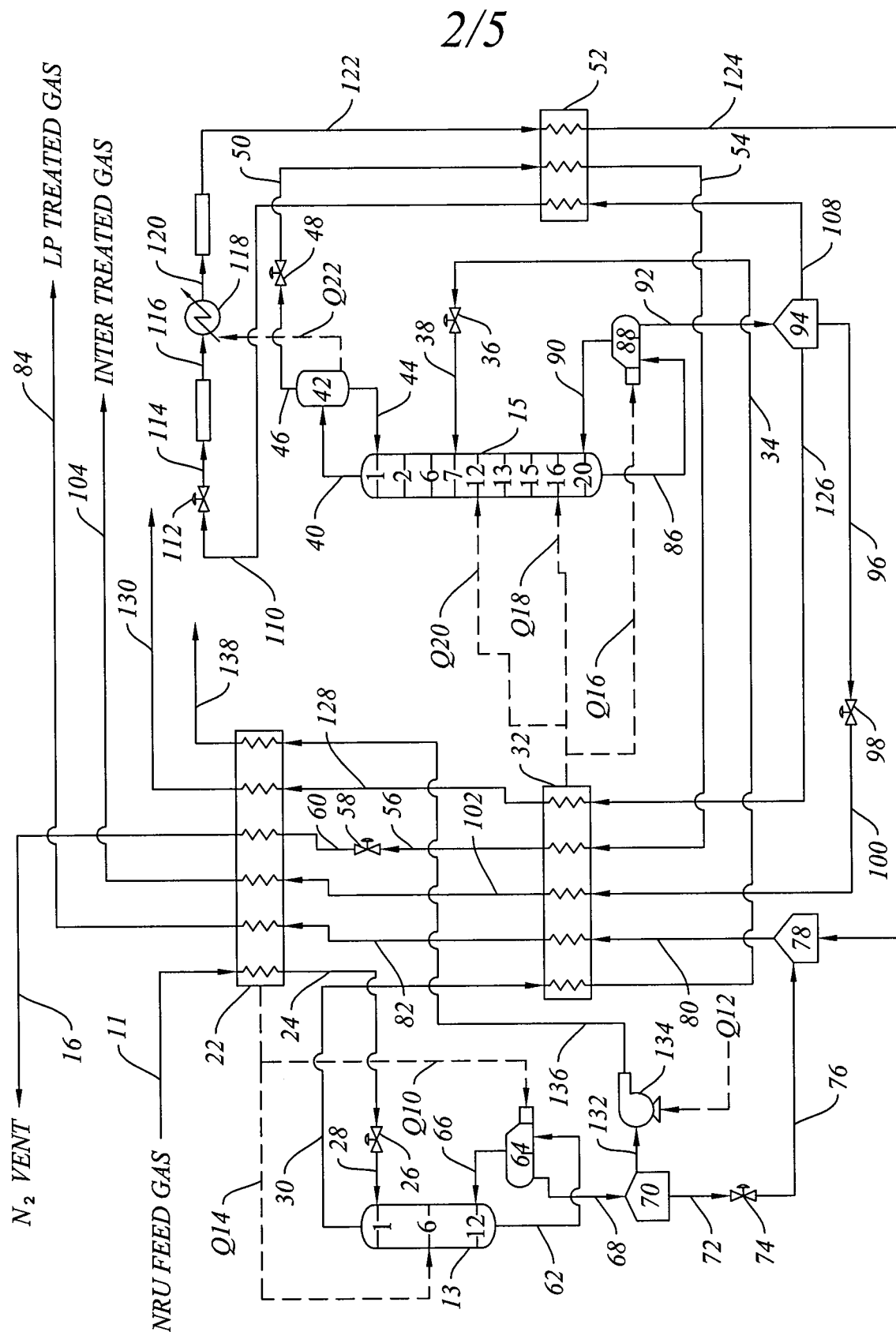


FIG. 3

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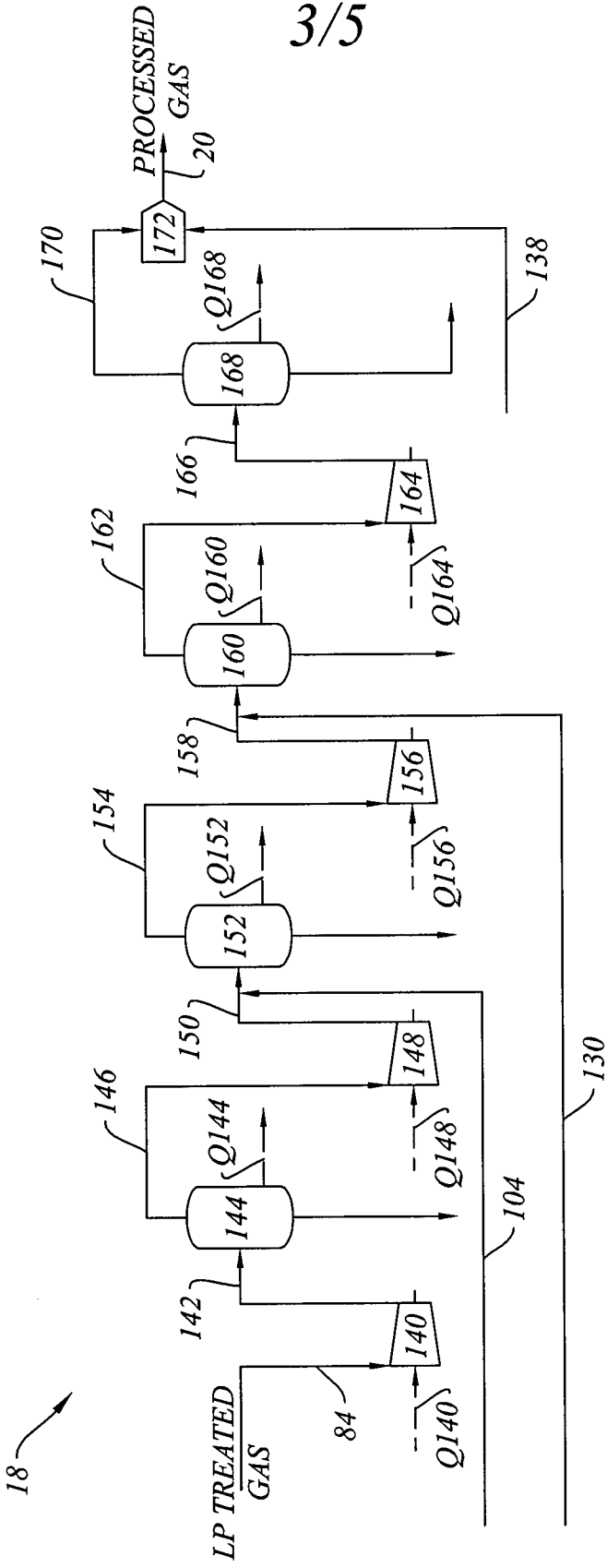


FIG. 4

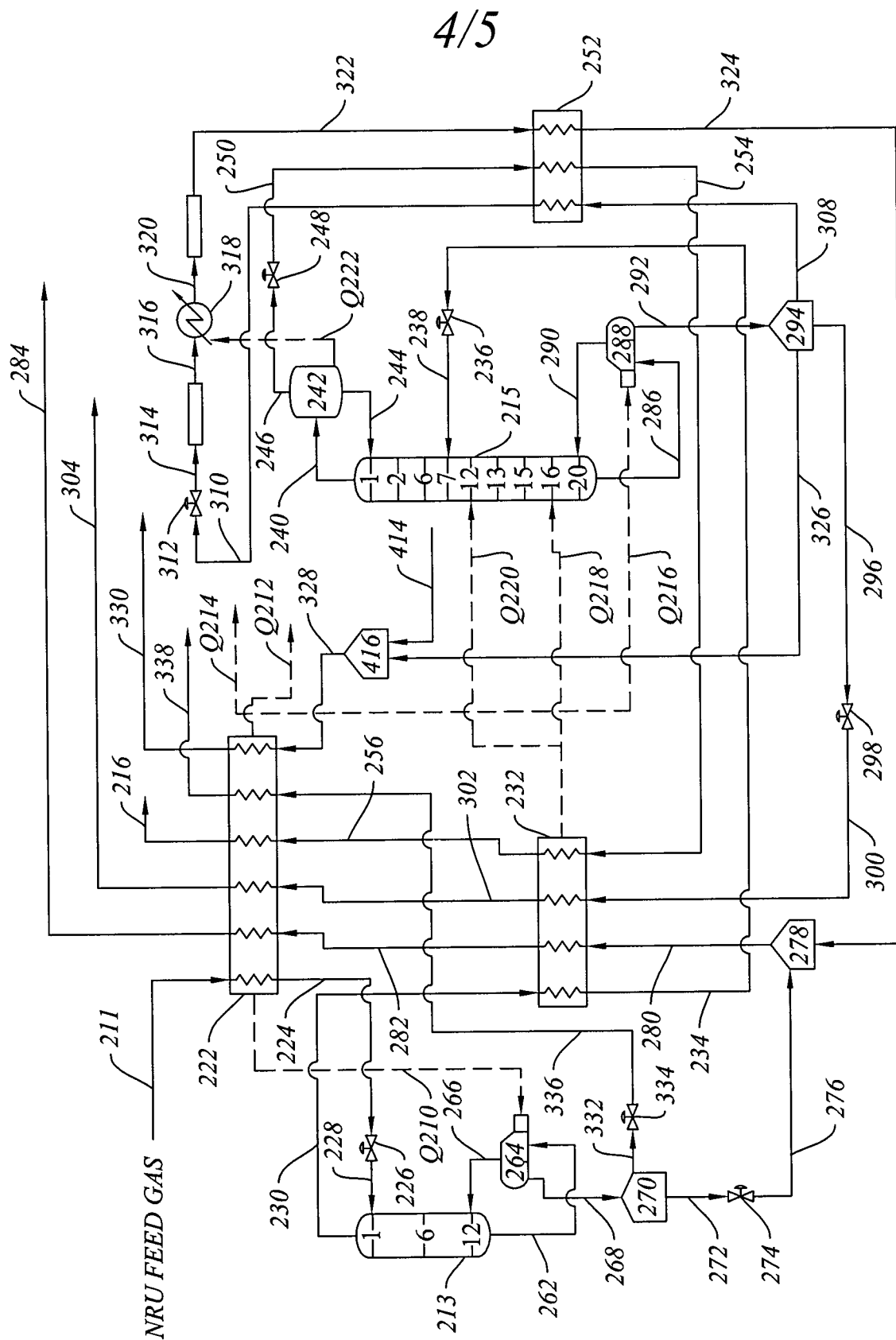


FIG. 5

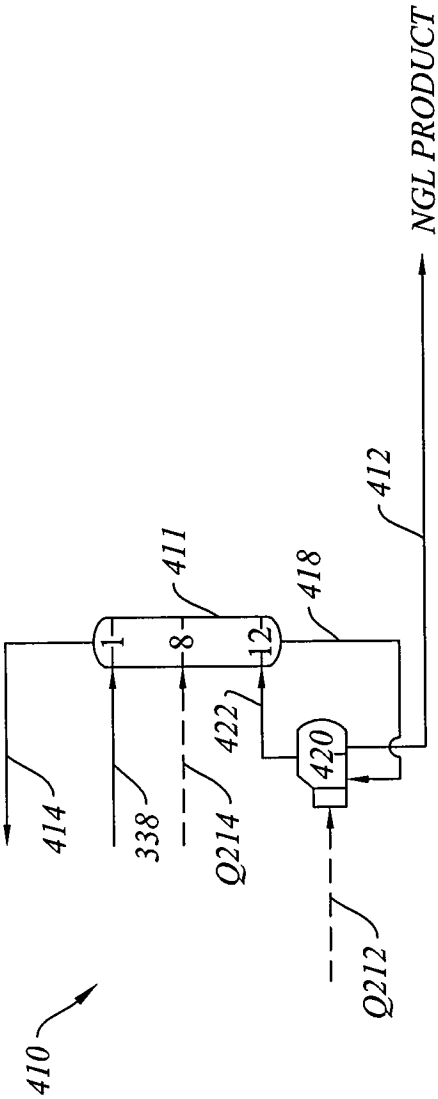


FIG. 6

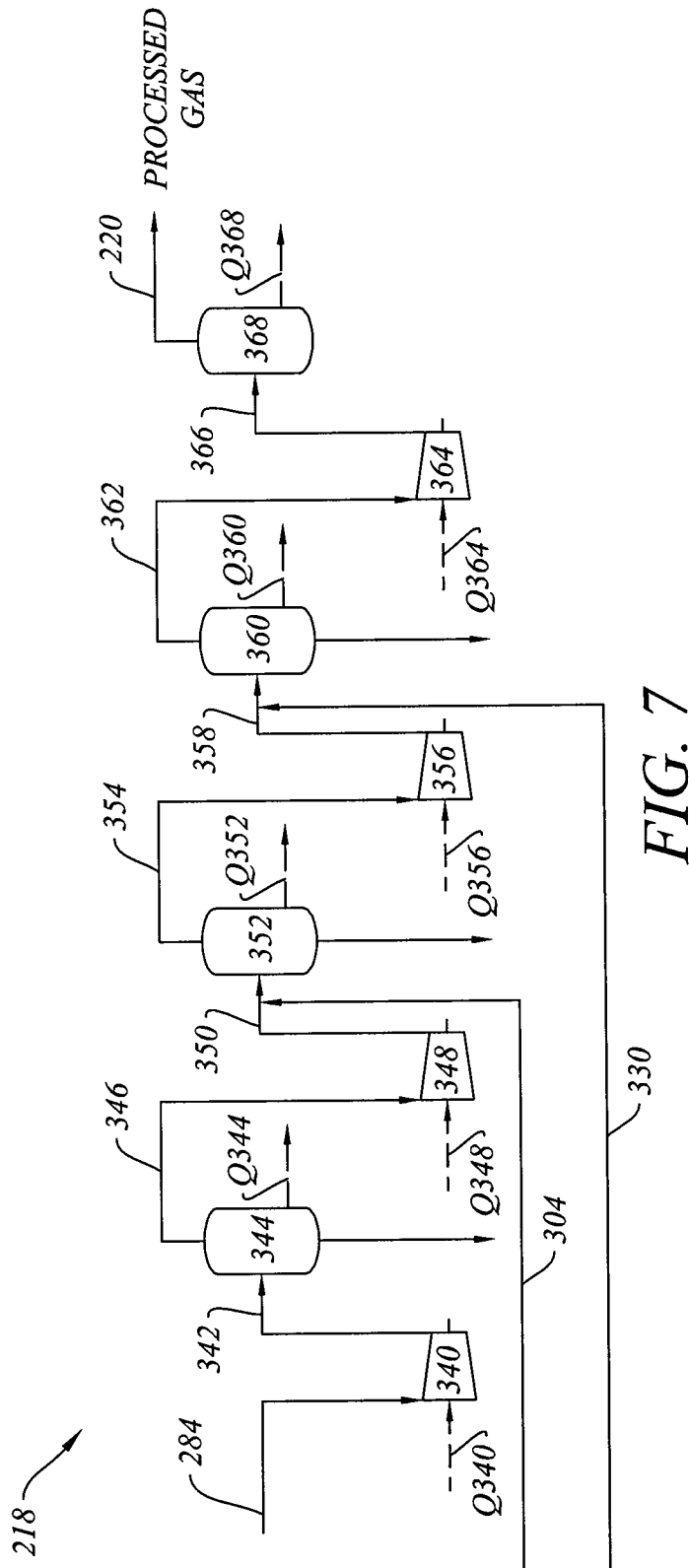


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2012/041284

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F25J 3/08 (2012.01)

USPC - 62/618

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)

IPC(8) - B01D 3/14; C01B 21/04; C07C 7/00, 7/04, 7/09; C10G 5/00, 5/06; F25J 3/00, 3/02, 3/06, 3/08 (2012.01)

USPC - 62/606, 611, 612, 614, 617, 618, 619, 620, 621, 622, 623, 625, 630, 631, 927; 202/152, 153, 154, 158; 203/71; 208/308, 347, 350, 354, 355; 585/800, 802

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)

PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,331,461 A (KARBOSKY et al) 25 May 1982 (25.05.1982) entire document	1-102
A	WO 2009/144423 A2 (COURT et al) 03 December 2009 (03.12.2009) entire document	1-102
A	US 5,051,120 A (PAHADE et al) 24 September 1991 (24.09.1991) entire document	1-102
A	US 4,474,591 A (ARAND et al) 02 October 1984 (02.10.1984) entire document	1-102
A	US 4,411,677 A (PERVIER et al) 25 October 1983 (25.10.1983) entire document	1-102

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 July 2012

Date of mailing of the international search report

07 AUG 2012

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