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(54) **C3+ RECOVERY WITH MEMBRANES**

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(57) **ABSTRACT**

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A method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream is provided. This method includes separating a light ends stream from a fractionator, thereby producing a stream rich in hydrocarbons containing three or more carbon atoms, and a stream lean in hydrocarbons containing three or more carbon atoms, separating the stream lean in hydrocarbons containing three or more carbon atoms in a membrane unit, thereby producing a permeate stream enriched in hydrocarbons containing three or more carbon atoms and a retentate stream, and separating the stream rich in hydrocarbons containing three or more carbon atoms in one or more separation columns, thereby producing one or more streams selected from the group consisting of a propylene stream, a propane stream, a butane stream, a light cat naptha stream, and a heavy cat naptha stream.

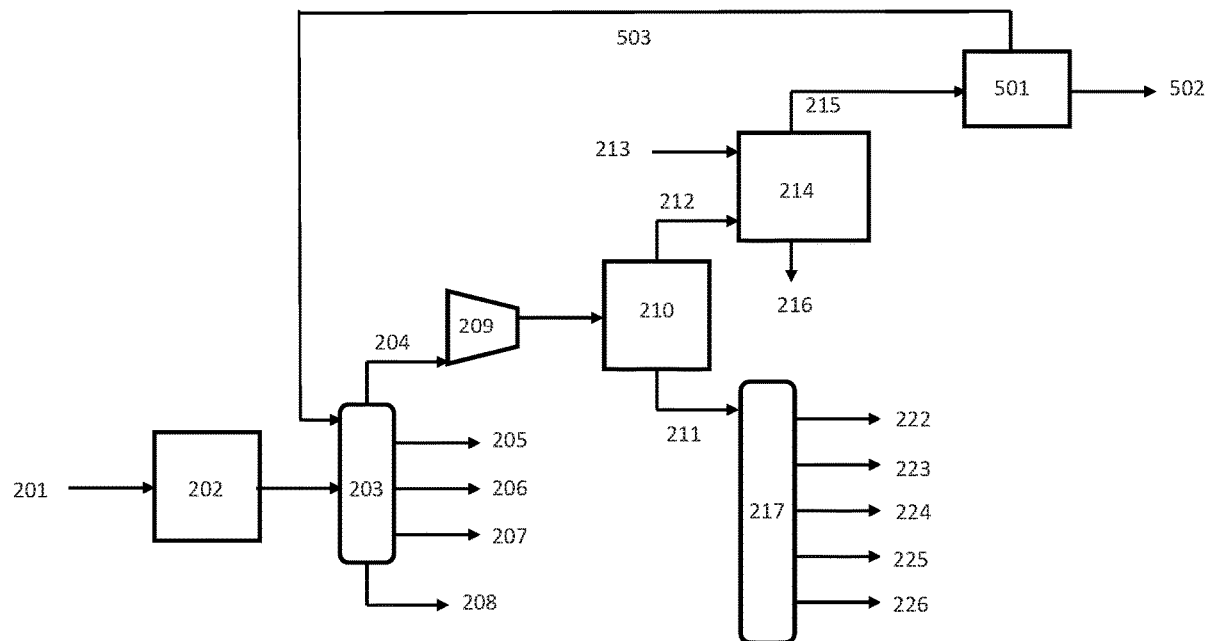
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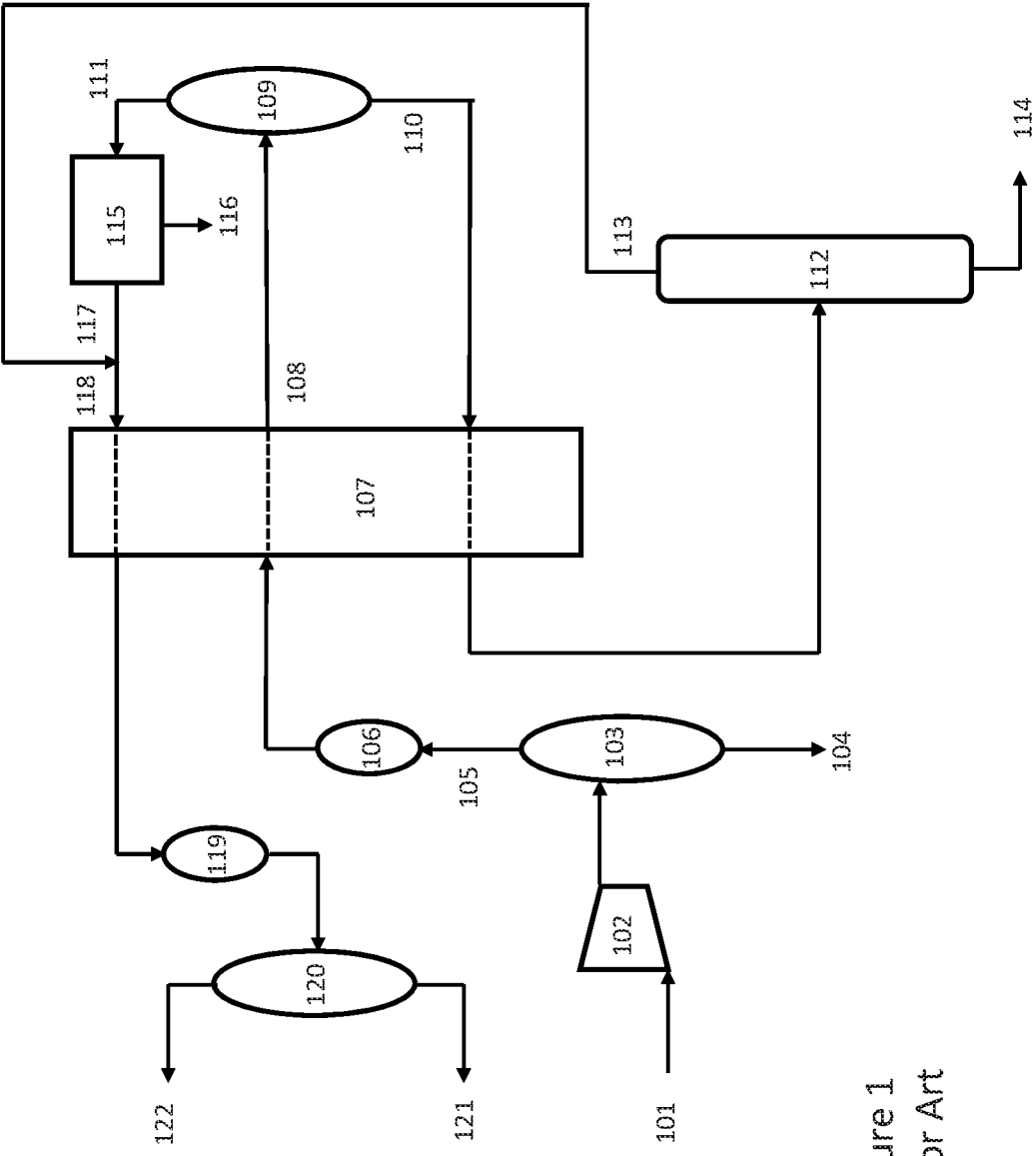


Figure 1
Prior Art

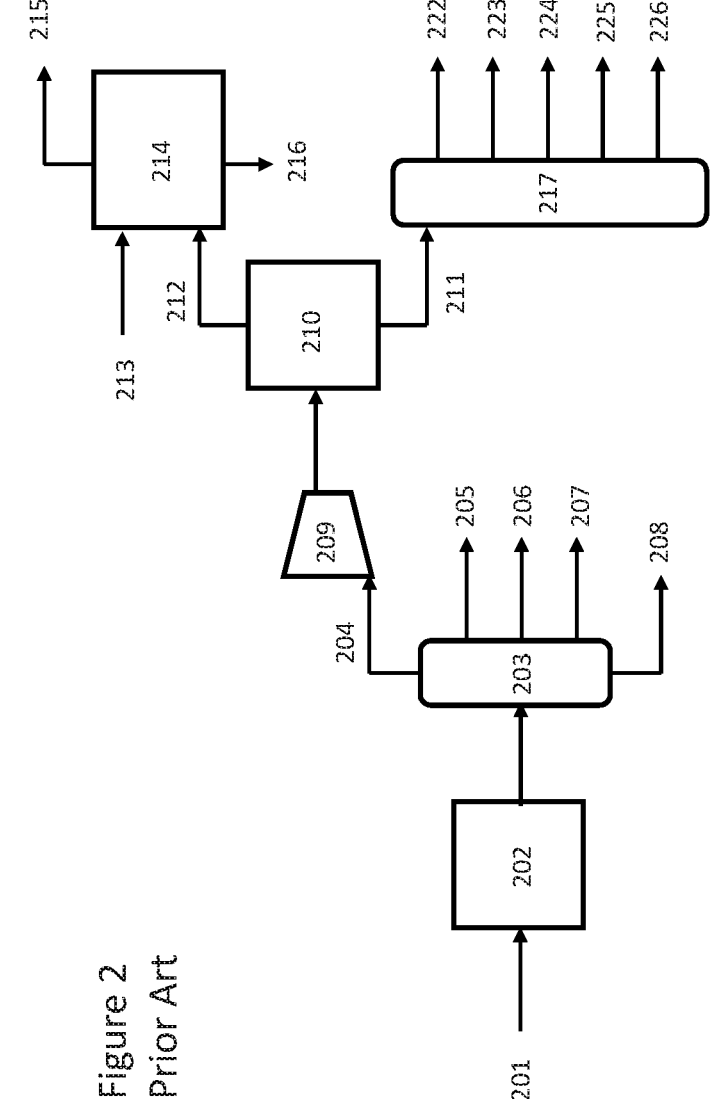


Figure 2
Prior Art

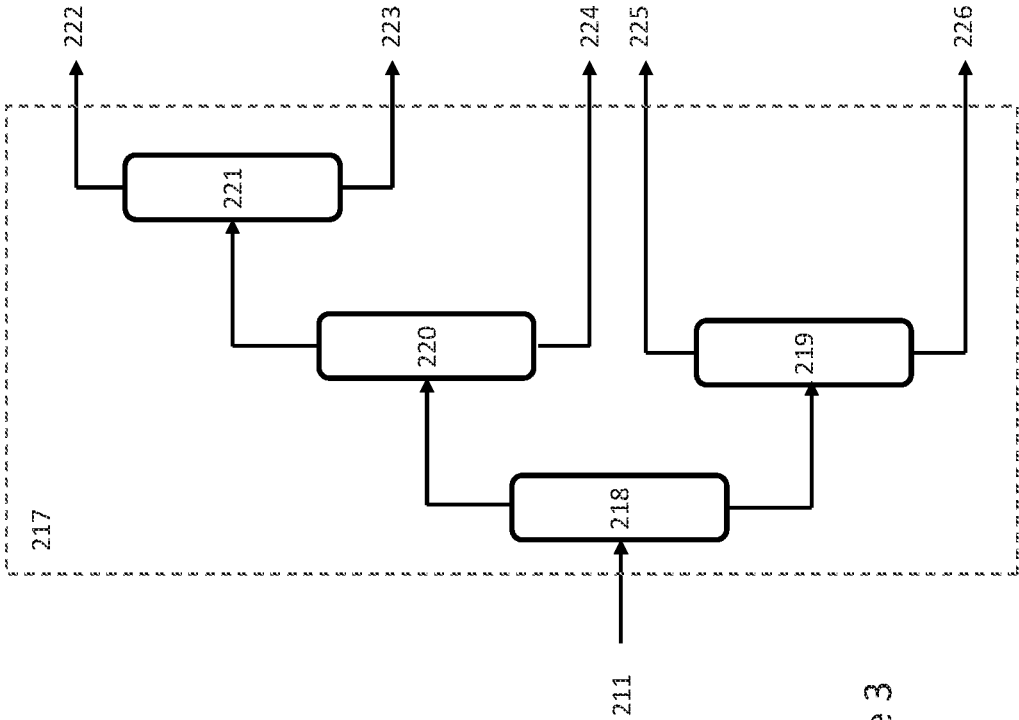


Figure 3

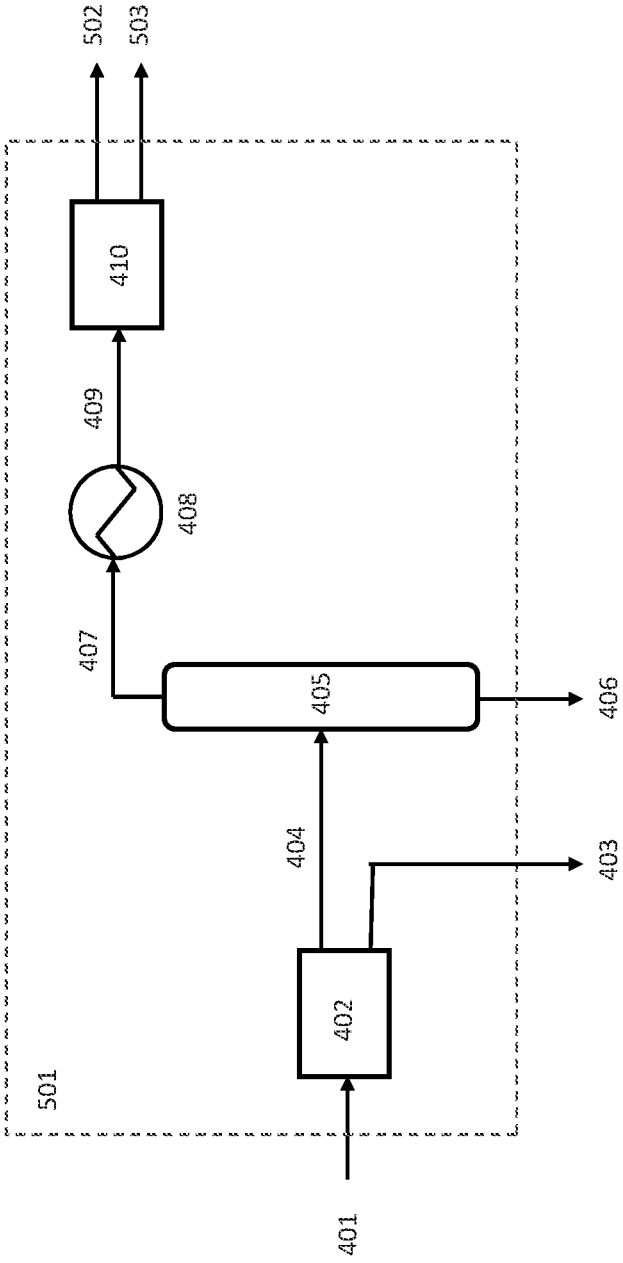


Figure 4

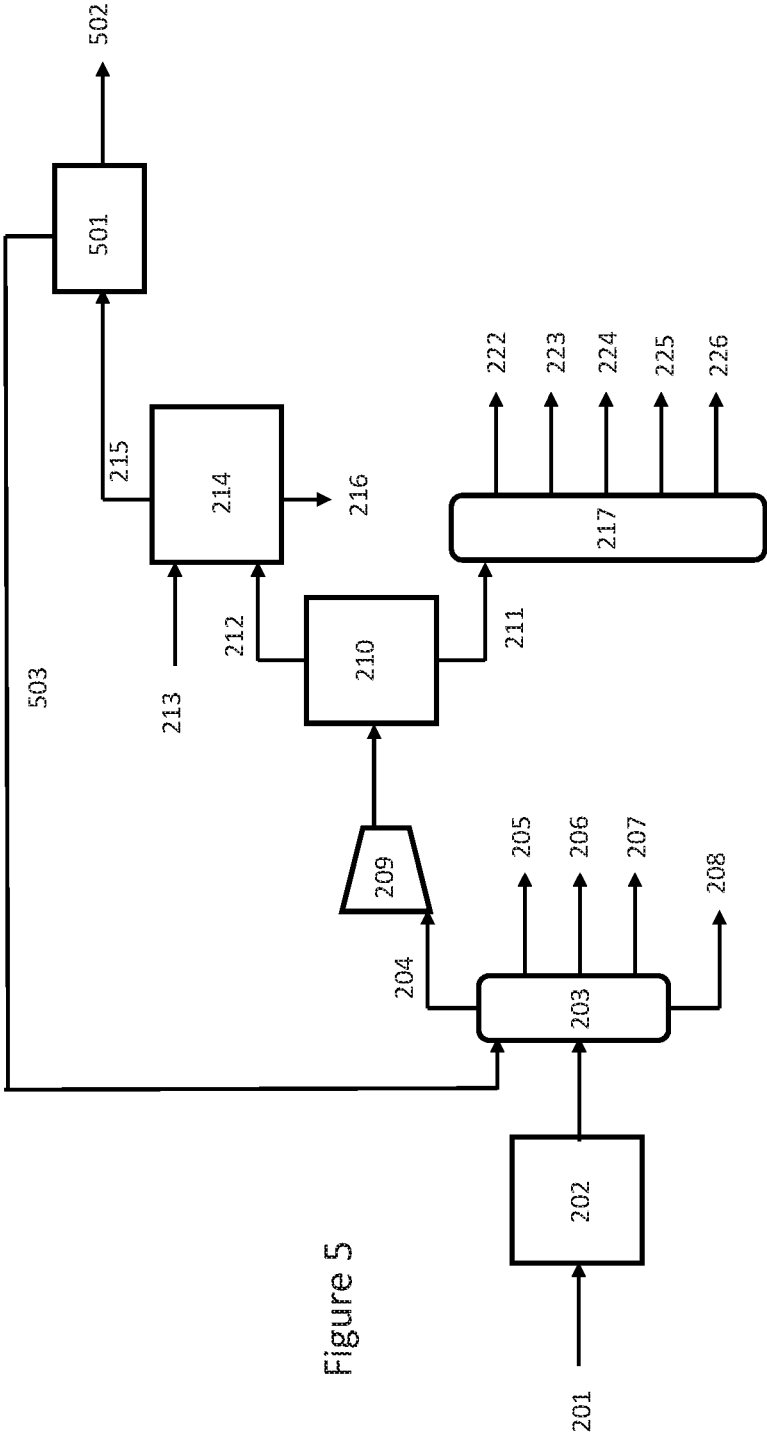


Figure 5

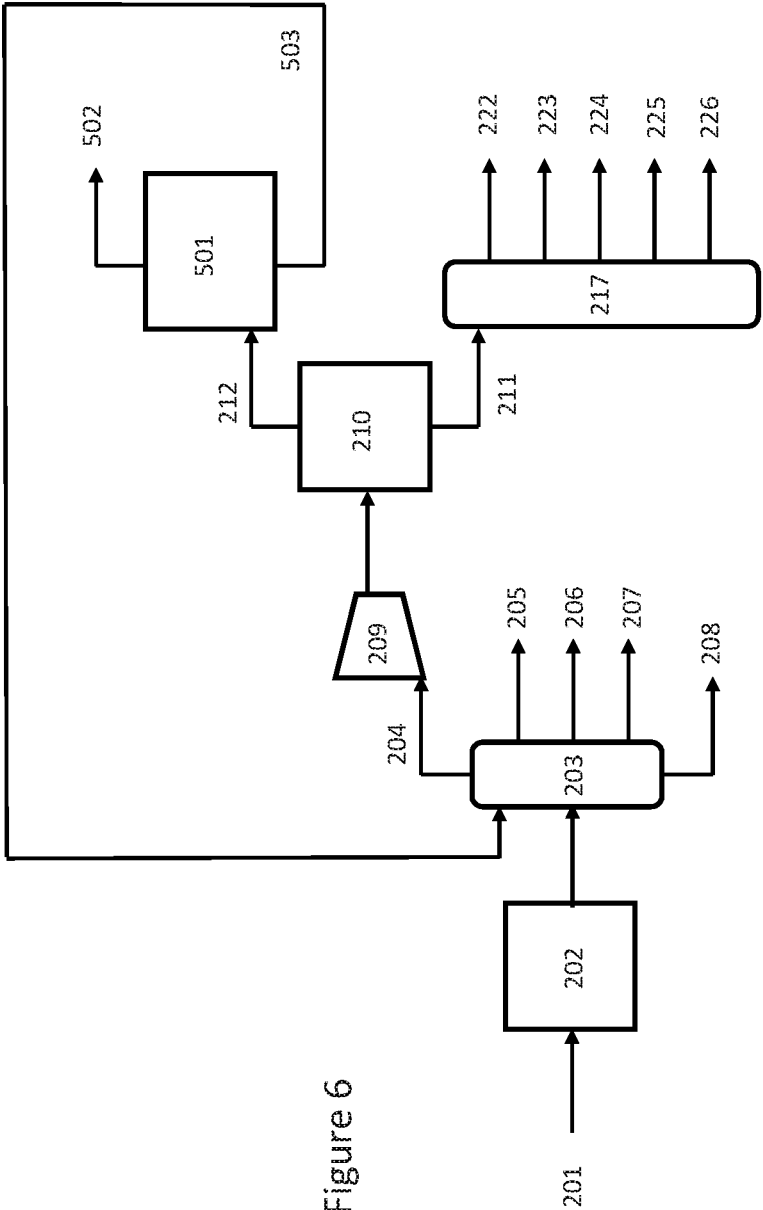


Figure 6

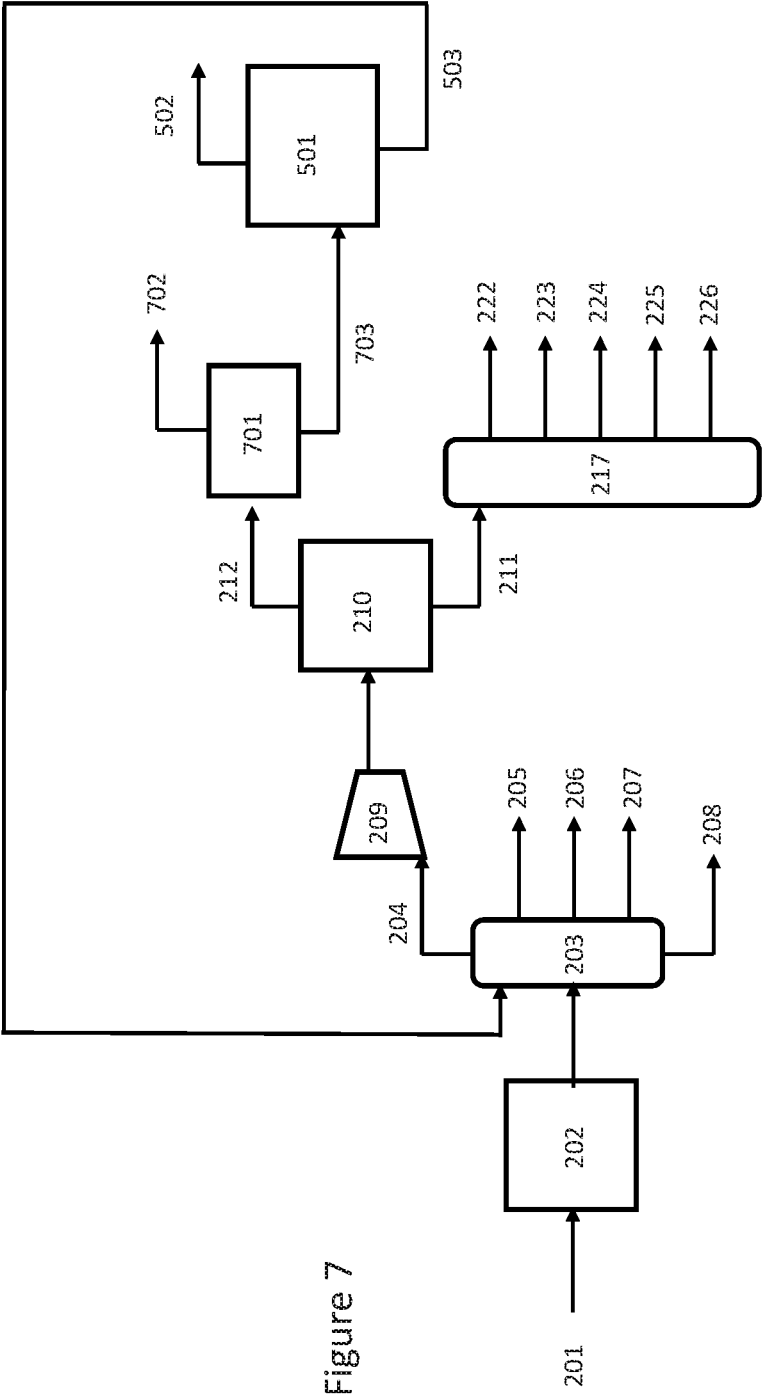


Figure 7

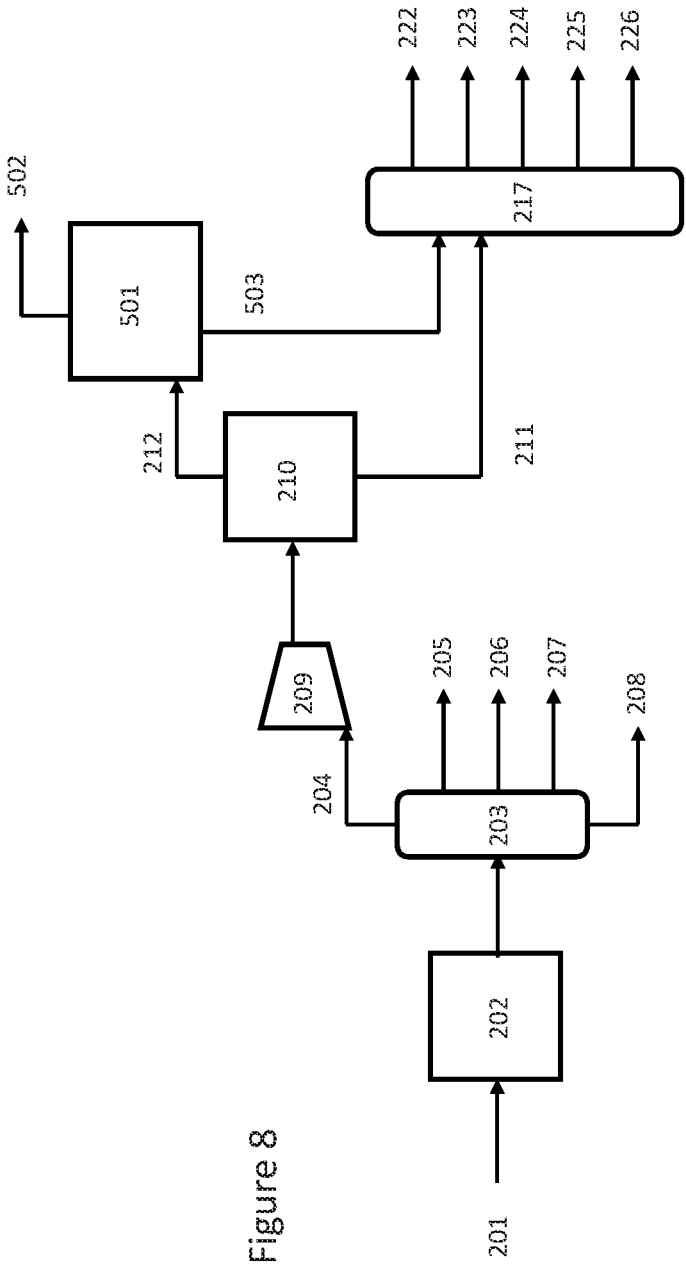


Figure 8

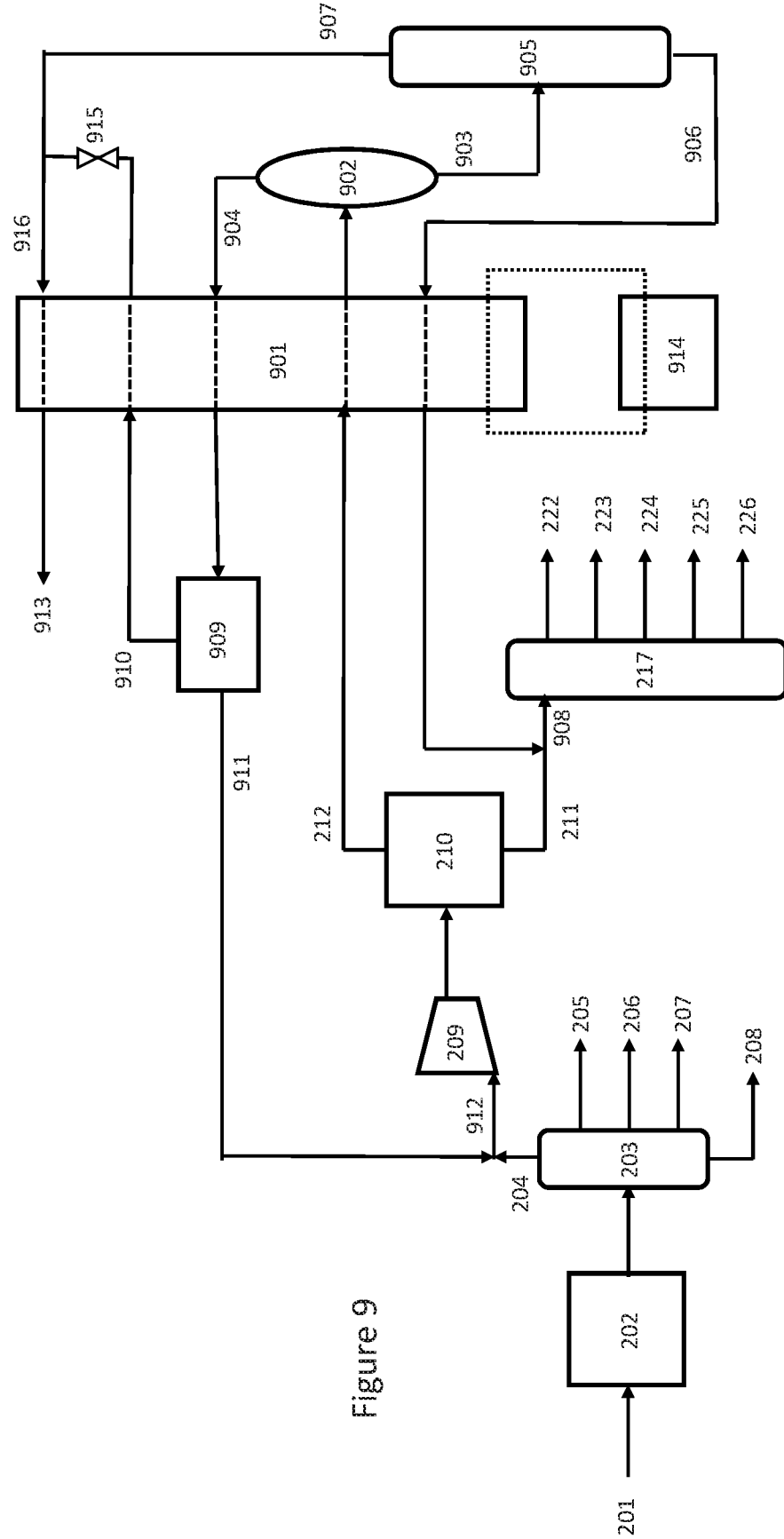


Figure 9

C3+ RECOVERY WITH MEMBRANES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 USC 119(e) to U.S. Provisional Application No. 62/824,613, filed Mar. 27, 2019, the entire contents of each being incorporated herein by reference.

BACKGROUND

[0002] Off-gases or natural gas contain various components like NGLs (C3+ components) which can be monetized separately. Most traditional plants remove NGLs via cryogenic plants but those technologies usually are very expensive and consume a lot of power required by external refrigeration cycles. A less costly technology that can be used to concentrate NGLs is membrane technology.

[0003] Membranes with ability to separate light ends from C2+/C3+ hydrocarbons already exist but their performance limits their application in less economical systems where CAPEX or OPEX are usually prohibitive. An example of such system, which can be considered as state-of-the art, is illustrated in FIG. 1.

[0004] Feed gas stream 101 is compressed in feed compressor 102, then introduced into first phase separator 103. The compressed feed gas stream may be cooled in a heat exchanger (not shown) prior to admission into first phase separator 103. First phase separator 103 produces first condensate stream 104 and damp gas stream 105. Damp gas stream 105 is then introduced into first dehydration unit 106.

[0005] The dehydrated gas stream is cooled in heat exchanger 107, wherein it forms at least partially condensed stream 108. At least partially condensed stream is then introduced into second phase separator 109. Second phase separator 109 produces C3+ rich liquid stream 110 and C3+ lean gas stream 111. C3+ rich liquid stream 110 is then warmed in heat exchanger 107, producing warmed C3+ rich liquid stream 123. Warmed C3+ rich liquid stream 123 is then introduced into separator drum 112. Separator drum 112 may be a flash drum or a distillation column.

[0006] Separator drum 112 produces overhead gas stream 113 which is enriched in methane, and C3+ liquid product stream 114. C3+ lean gas stream 111 then enters membrane separator 115, thereby producing permeate stream 116 and retentate stream 117. Permeate stream 116 may be combined with feed gas stream 101 (not shown). Retentate stream 117 then combined with overhead gas stream 113, thus producing first combined stream 118. First combined stream 118 is heated in heat exchanger 107 then dried in second dehydration unit 119. Dried retentate stream is then introduced into third phase separator 120. Third phase separator 120 produces second condensate stream 121 and fuel gas stream 122.

[0007] There is a need in the industry for a process optimized for propylene recovery.

SUMMARY

[0008] A method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream is provided. This method includes separating a light ends stream from a fractionator, thereby producing a stream rich in hydrocarbons containing three or more carbon atoms, and a stream lean in hydrocarbons containing three or more

carbon atoms, separating the stream lean in hydrocarbons containing three or more carbon atoms in a membrane unit, thereby producing a permeate stream enriched in hydrocarbons containing three or more carbon atoms and a retentate stream, and separating the stream rich in hydrocarbons containing three or more carbon atoms in one or more separation columns, thereby producing one or more streams selected from the group consisting of a propylene stream, a propane stream, a butane stream, a light cat naphtha stream, and a heavy cat naphtha stream.

[0009] A method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream, including combining a light ends stream from a fractionator including hydrocarbons containing three or more carbon atoms and a permeate stream to form a combined stream, separating the combined stream in main absorption unit, thereby producing a stream rich in hydrocarbons containing three or more carbon atoms, and a stream lean in hydrocarbons containing three or more carbon atoms, separating an at least partially condensed stream lean in hydrocarbons containing three or more carbon atoms in a cold separator, thereby producing a liquid stream, and a vapor stream, warming the vapor stream to ambient temperature, then separating the ambient temperature stream in a membrane unit, thereby producing the permeate stream and a retentate stream, and separating the stream rich in hydrocarbons containing three or more carbon atoms in one or more separation columns, thereby producing one or more streams selected from the group consisting of a propylene stream, a propane stream, a butane stream, a light cat naphtha stream, and a heavy cat naphtha stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a further understanding of the nature and objects for the present invention, reference should be made to the following detailed description, taken in conjunction with the accompanying drawings, in which like elements are given the same or analogous reference numbers and wherein:

[0011] FIG. 1 is a schematic representation of a method for separating light ends from heavier hydrocarbon streams as known to the prior art.

[0012] FIG. 2 is a schematic representation of a typical fluidic catalytic cracking (FCC) plant as known to the prior art.

[0013] FIG. 3 is a schematic representation illustrating the details of a series of separating columns in accordance with one embodiment of the present invention.

[0014] FIG. 4 is a schematic representation illustrating the details of a membrane separation system in accordance with one embodiment of the present invention.

[0015] FIG. 5 is a schematic representation of a method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream including a secondary absorber and a membrane system, in accordance with one embodiment of the present invention.

[0016] FIG. 6 is a schematic representation of a method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream in which a secondary absorber is replaced by a membrane system, in accordance with one embodiment of the present invention.

[0017] FIG. 7 is a schematic representation of a method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream which includes a carbon

dioxide removal system, in accordance with one embodiment of the present invention.

[0018] FIG. 8 is a schematic representation of a method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream which includes introducing a C3+ enriched permeate stream into the separation columns, in accordance with one embodiment of the present invention.

[0019] FIG. 9 is a schematic representation of a method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream including an ambient temperature membrane system, in accordance with one embodiment of the present invention.

Element Numbers

[0020] 101=feed gas stream
 [0021] 102=feed compressor
 [0022] 103=first phase separator
 [0023] 104=first condensate stream
 [0024] 105=damp gas stream
 [0025] 106=first dryer
 [0026] 107=heat exchanger
 [0027] 108=at least partially condensed stream
 [0028] 109=second phase separator
 [0029] 110=C3+ rich liquid stream
 [0030] 111=C3+ lean gas stream
 [0031] 112=distillation column
 [0032] 113=overhead gas stream (from distillation column)
 [0033] 114=C3+ liquid product stream (from distillation column)
 [0034] 115=membrane separator
 [0035] 116=permeate stream
 [0036] 117=retentate stream
 [0037] 118=first combined stream
 [0038] 119=second dryer
 [0039] 120=third phase separator
 [0040] 121=second condensate stream
 [0041] 122=fuel gas stream
 [0042] 201=feed gas stream
 [0043] 202=fluidic catalytic cracker (FCC) unit
 [0044] 203=fractionator
 [0045] 204=light end stream (from fractionator)
 [0046] 205=light cycle oil (LCO) stream (from fractionator)
 [0047] 206=medium cycle oil (MOO) stream (from fractionator)
 [0048] 207=heavy cycle oil (HCO) stream (from fractionator)
 [0049] 208=slurry stream (from fractionator)
 [0050] 209=fractionator overhead stream compressor
 [0051] 210=main absorber
 [0052] 211=main absorber output stream
 [0053] 212=main absorber off-gas stream
 [0054] 213=lean oil from fractionator
 [0055] 214=secondary absorber
 [0056] 215=secondary absorber off-gas stream
 [0057] 216=rich oil to fractionator
 [0058] 217=separation columns
 [0059] 218=debutanizer column
 [0060] 219=gasoline splitting column
 [0061] 220=depropanizer column
 [0062] 221=propane splitting column
 [0063] 222=propylene stream

[0064] 223=propane stream
 [0065] 224=butane stream
 [0066] 225=light cat naptha stream
 [0067] 226=heavy cat naptha stream
 [0068] 401=feed gas stream
 [0069] 402=filter
 [0070] 403=particulate (from filter)
 [0071] 404=inlet stream (to phase separator)
 [0072] 405=phase separator
 [0073] 406=liquid (from phase separator)
 [0074] 407=vapor (from phase separator)
 [0075] 408=heat exchanger
 [0076] 409=heated vapor (from heat exchanger)
 [0077] 410=membrane separator
 [0078] 501=membrane separator
 [0079] 502=off-gas (retentate) stream (from membrane separator)
 [0080] 503=C3+ enriched (permeate) stream (from membrane separator)
 [0081] 701=CO2 removal unit
 [0082] 702=CO2 rich stream
 [0083] 703=CO2 lean stream
 [0084] 901=economizer
 [0085] 902=cold separator
 [0086] 903=phase separator liquid stream
 [0087] 904=phase separator vapor stream
 [0088] 905=deethanizer column
 [0089] 906=bottom stream (from deethanizer column)
 [0090] 907=light end fraction stream (from deethanizer column)
 [0091] 908=combined stream (entering separation column)
 [0092] 909=membrane separator
 [0093] 910=off-gas (retentate) stream (from membrane separator)
 [0094] 911=C3+ rich (permeate) stream (from membrane separator)
 [0095] 912=combined stream (entering fractionator overhead stream compressor)
 [0096] 913=off-gas
 [0097] 914=refrigeration unit (propane)
 [0098] 915=JT valve
 [0099] 916=third combined stream

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0100] Illustrative embodiments of the invention are described below. While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

[0101] It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developer's specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be com-

plex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

[0102] As used herein, the term “ambient temperature” is defined as the temperature of the surrounding air. Ambient temperature may be defined as between 32 and 150 F. Ambient temperature may be defined as between 32 and 100 F. Ambient temperature may be defined as between 50 and 80 F. Ambient temperature may be defined as between 65 and 75 F.

[0103] Fluid Catalytic Cracking (FCC) is a common technology that has been used for many years inside refineries. They are typically used for cracking crude oil into different fractions. Turning to FIG. 2, a typical FCC plant as known to the art is illustrated. Feed gas stream **201** is introduced into FCC reactor unit **202**. The output stream from FCC reactor unit **202** is then introduced into fractionator **203**, which produces one or more of the following streams: light ends stream **204**, light cycle oil stream **205**, medium cycle oil stream **206**, heavy cycle oil stream **207** and slurry stream **208**. Light ends stream **204** may pass through a knock-out drum (not shown), and then is compressed in fractionator overhead stream compressor **209** and sent to main absorber **410**.

[0104] Main absorber **210** produces output stream **211** and off-gas stream **212**. Off-gas stream **212** and a lean oil stream **213** from the fractionator are introduced into secondary absorber **214**. Secondary absorber **214** may be a sponge absorber. Secondary absorber **214** produces a rich oil stream **216** that is returned to fractionator **203**, and off-gas stream **215**.

[0105] Output stream **211** is then introduced into separation column **217**. In the interest of simplicity, separation column **217** is shown on FIGS. 2 and 5-9 as a single unit. However as shown in FIG. 3, separation column **217** may be series of columns. In one embodiment, the feed stream, in this case main absorber off-gas stream **211**, is introduced into debutanizer column **218**. Debutanizer column **218** sends a bottom stream to gasoline splitting column **219** and a top stream to depropanizer column **220**. Gasoline splitting column **219** produces light cat naphtha stream **225** and high cat naphtha stream **226**. Depropanizer column **220** sends a top stream to propane splitting column **221** and produces butane stream **224**. Propane splitting column **221** produces propylene stream **222** and propane stream **223**.

[0106] Downstream of FCC unit **202** is typically the main fractionator **203**, which recovers the different fractions of oil (light and heavy, gasoline and gas). The gas portion **204** is mainly composed with the light components and is treated in the gas plant for separation in different sub-components. Polypropylene **222** is one of the lightest components typically recovered from an FCC refinery in the gas plant. The gas plant typically also recovers propane **223**, butane **224**, light cycle naphtha **225**, or high cycle naphtha **226**, each of these streams being additionally processed or further purified into sub-components.

[0107] Not all of the polypropylene (nor the other light ends) is recovered and the unrecovered propylene is usually exiting the process through the FCC off-gas (or gas plant off-gas, or secondary absorber off-gas) and burnt as fuel or flared (not shown). Maximizing the recovery of the propylene is key to maximize the revenue streams of a refinery. While achieving high recovery is possible, it can often result in capital intensive technologies, thus making it more eco-

nomical to burn the propylene rather than recovering it. Propylene recovery ratios are therefore typically in the range of 90-96%. Propylene is recovered in the gas plant in successive debutanizer, depropanizer and C3 splitter. The propylene recovery ratio can be improved to its higher limit using a larger amount of refrigeration energy in the system, which may be produced, for example, by a propane refrigeration cycle.

[0108] The unrecovered propylene is present in the secondary absorber off-gas **214**. In secondary absorber **214**, because the absorption is achieved through lean oil, the highest fractions are the most recovered but the propylene recovery is not optimized. A typical composition of the inlet and the off-gas of the secondary absorber off-gas is shown in Table 1, along with the recovery achieved in the secondary absorber. The secondary absorber off-gas is typically sent to a fuel gas system (or flared).

TABLE 1

Wt %	412	415	Recovery
H2O	0.30%	0.40%	N/A
OXYGEN	0.00%	0.00%	N/A
NITROGEN	8.50%	10.20%	N/A
CO	0.00%	0.00%	N/A
CO2	2.50%	3.00%	N/A
HYSULFIDE	0.80%	0.90%	N/A
HYDROGEN	2.20%	2.60%	N/A
METHANE	20.40%	24.20%	N/A
ETHYLENE	18.10%	20.70%	N/A
ETHANE	20.30%	22.80%	N/A
PROPENE	8.20%	8.10%	23.17%
PROPANE	1.40%	1.40%	22.22%
C4	7.60%	4.70%	51.90%
C5	5.90%	0.30%	96.05%
C6+	3.60%	0.00%	99.99%
Others	0.20%	0.70%	N/A
Total flow	18 ton/h	14 ton/h	

[0109] The proposed improvement is using membrane technology, and integration of such membrane technology into the FCC separation system, and in particular membranes selective for C3+(or C2+) over C2- (or C1-), to improve the overall recovery of propylene beyond state-of-the-art FCC. The membrane technology that is used may be the “rubbery-type”.

[0110] In one embodiment, a membrane system is used to treat the off-gas of the secondary adsorber (FIG. 5) and in another embodiment a membrane system directly replaces the secondary absorber (FIG. 6). The concept is similar for both, with a slightly different stream to manage. The stream at the inlet of the secondary absorber still contains some C6+ while the off-gas doesn't.

[0111] In the interest of simplicity, membrane separator **502** is shown on FIGS. 5-8 as a single unit. However as shown in FIG. 4, membrane separator **501** may comprise, at least, a filter **402** and a heat exchanger **408**. Membrane **501** may further comprise a phase separator **405** as described below.

[0112] The feed gas **401** to be treated is first sent to filter **402**, which produces particulate stream **403** and phase separator inlet stream **404**. Feed gas stream **401** may be the off-gas stream **215** from secondary absorber **214**, or it may be the off-gas stream **212** from the main absorber **210**. The typical composition for stream **212** below in Table 2. Stream **404** is then introduced into separation drum **405**, which separates the liquid phase **406** from the gaseous phase **407**.

A first portion of the C3+ fraction is recovered in this drum which can be sent back to the fractionator or to the inlet of any system that would ensure its separation into all the sub-components (not shown). Gaseous fraction **407** is then heated by external heat source **408** before entering membrane separator **410**, thus remaining above dew point and preventing formation of liquid through the membrane. Membrane permeate **503** will be a C3+ enriched stream that can be re-injected back to the fractionator or to the inlet of any system that would ensure its separation into all the sub-components (not shown). Membrane retentate **502** is also produced.

[0113] Such a membrane system can achieve a recovery of up to 70% in propylene. If we assume a typical propylene recovery of 94% in the gas plant, 70% propylene recovery in the membrane system applied to the absorber off-gas will boost the overall refinery propylene recovery to 98.2%. This is not only a significant revenue gain but also it exceeds the typical 96% recovery achievable in a gas plant when adding propane refrigeration.

TABLE 2

Name	501	504	506	507	509	512	511
Vapor Fraction	0.88	0.88	0.00	1.00	1.00	1.00	1.00
Temperature [F.]	100.0	100.0	100.0	100.0	150.0	146.4	141.6
Pressure [psig]	202.9	202.9	202.9	202.9	200.0	5.0	189.9
Molar Flow [MMSCFD]	10.3	10.3	1.2	9.1	9.1	2.4	6.7
Mass Flow [lb/hr]	18000	18000	3873	14127	14127	4353	9774
HC Dew Point [F.]	162.6	162.6	296.8	100.0	99.4	32.3	77.5
HHV [Btu/SCF]	1814.6	1814.6	3539.8	1584.4	1584.4	1971.1	1446.9
Methane	20.68%	20.68%	1.91%	23.18%	23.18%	13.31%	26.69%
Ethane	38.92%	38.92%	15.38%	42.06%	42.06%	48.39%	39.81%
Propylene	8.27%	8.27%	9.04%	8.17%	8.17%	11.56%	6.96%
Propane	1.46%	1.46%	1.60%	1.44%	1.44%	2.04%	1.23%
i-Butane	2.43%	2.43%	5.11%	2.08%	2.08%	3.24%	1.66%
n-Butane	5.27%	5.27%	13.72%	4.14%	4.14%	6.47%	3.32%
i-Pentane	2.84%	2.84%	11.93%	1.62%	1.62%	3.22%	1.06%
n-Pentane	3.14%	3.14%	14.83%	1.58%	1.58%	3.13%	1.03%
n-Hexane	2.03%	2.03%	13.31%	0.52%	0.52%	1.13%	0.30%
n-Heptane	2.53%	2.53%	0.48%	2.81%	2.81%	3.92%	2.41%
CO2	8.61%	8.61%	0.28%	9.73%	9.73%	2.16%	12.42%
Nitrogen	1.62%	1.62%	12.38%	0.19%	0.19%	0.40%	0.11%
H2S	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
H2O	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Hydrogen	2.19%	2.19%	0.04%	2.48%	2.48%	1.03%	3.00%

[0114] Turning to FIG. 5, feed gas stream **201** is introduced into FCC unit **202**. The output stream from FCC unit **202** is then introduced into fractionator **203**, which produces light ends stream **204**, light cycle oil stream **205**, medium cycle oil stream **206**, heavy cycle oil stream **207** and slurry stream **208**. Light ends stream **204** is compressed in fractionator overhead stream compressor **209** and sent to main absorber **210**.

[0115] Main absorber **210** produces output stream **211** and off-gas stream **212**. Off-gas stream **212** and a lean oil stream **213** from the fractionator are introduced into secondary absorber **214**. Secondary absorber **214** produces a rich oil stream **216** that is returned to fractionator **203**, and off-gas stream **215**.

[0116] Off-gas stream **215** is then introduced into membrane separator **501**, which produces retentate off-gas stream

502 and C3+ enriched permeate stream **503**. C3+ enriched permeate stream **503** is then recycled back to fractionator **203**.

[0117] Output stream **211** is then introduced into separation column **217**, which produces, at least propylene stream **222**, propane stream **223**, butane stream **224**, light cat naphtha stream **225**, and high cat naphtha stream **226**.

[0118] This embodiment allows the utilization of membranes on FCC secondary absorber off-gas to improve the overall C3+ recovery of the plant without use of external refrigeration.

[0119] Turning to FIG. 6, feed gas stream **201** is introduced into FCC unit **202**. The output stream from FCC unit **202** is then introduced into fractionator **203**, which produces light ends stream **204**, light cycle oil stream **205**, medium cycle oil stream **206**, heavy cycle oil stream **207** and slurry stream **208**. Light ends stream **204** is compressed in fractionator overhead stream compressor **209** and sent to main absorber **210**.

[0120] Main absorber **210** produces output stream **211** and off-gas stream **212**. Off-gas stream **212** is then introduced into membrane separator **501**, which produces retentate off-gas stream **502** and C3+ enriched permeate stream **503**. C3+ enriched permeate stream **503** is then recycled back to fractionator **203**.

[0121] Output stream **211** is then introduced into separation column **217**, which produces, at least propylene stream **222**, propane stream **223**, butane stream **224**, light cat naphtha stream **225**, and high cat naphtha stream **226**.

[0122] This embodiment also allows the replacement of the full secondary absorber by a membrane unit which improves the overall recovery beyond the state-of-the-art values, while reducing the complexity and cost of the gas plant.

[0123] Turning to FIG. 7, feed gas stream 201 is introduced into FCC unit 202. The output stream from FCC unit 202 is then introduced into fractionator 203, which produces light ends stream 204, light cycle oil stream 205, medium cycle oil stream 206, heavy cycle oil stream 207 and slurry stream 208. Light ends stream 204 is compressed in fractionator overhead stream compressor 209 and sent to main absorber 210.

[0124] Main absorber 210 produces output stream 211 and off-gas stream 212. Off-gas stream 212 is then introduced into carbon dioxide removal unit 701, which carbon dioxide rich stream 702 and carbon dioxide poor stream 703. Carbon dioxide poor stream 703 is then introduced into membrane separator 501, which produces retentate off-gas stream 502 and C3+ enriched permeate stream 503. C3+ enriched permeate stream 503 is then recycled back to fractionator 203.

[0125] Output stream 211 is then introduced into separation column 217, which produces, at least propylene stream 222, propane stream 223, butane stream 224, light cat naptha stream 225, and high cat naptha stream 226.

[0126] This embodiment addresses the situation where C3+ enriched stream 503 is recycled to fractionator 203 or the inlet of fractionator overhead stream compressor 209 (not shown). This stream contains carbon dioxide, and this carbon dioxide tends to enrich with the C3+. This can produce an undesirable size effect, as it will keep accumulating in the system and increase the recycle flowrate. This artificially large recycle flowrate may directly result in an oversizing of compressor 209. Reducing the recycle flowrate by removal of the accumulating CO₂ may be important.

[0127] In one embodiment, a second stage of membranes is added that would prevent the carbon dioxide from accumulating. Upstream of the rubbery membrane, a carbon dioxide selective glassy membrane may be installed in order to permeate preferentially carbon dioxide. Permeate flow can be kept to a minimum in order to limit losses of the products without accumulating carbon dioxide in the recycle loop. This carbon dioxide rich permeate may be routed to fuel (not shown).

[0128] Turning to FIG. 8, feed gas stream 201 is introduced into FCC unit 202. The output stream from FCC unit 202 is then introduced into fractionator 203, which produces light ends stream 204, light cycle oil stream 205, medium cycle oil stream 206, heavy cycle oil stream 207 and slurry stream 208. Light ends stream 204 is compressed in fractionator overhead stream compressor 209 and sent to main absorber 210.

[0129] Main absorber 210 produces output stream 211 and off-gas stream 212. Off-gas stream 212 is then introduced into carbon dioxide removal unit 701, which carbon dioxide rich stream 702 and carbon dioxide poor stream 703. Carbon dioxide poor stream 703 is then introduced into membrane separator 501, which produces retentate off-gas stream 502 and C3+ enriched permeate stream 503.

[0130] Output stream 211 and C3 enriched permeate stream 503 are then introduced into separation column 217, which produces, at least propylene stream 222, propane stream 223, butane stream 224, light cat naptha stream 225, and high cat naptha stream 226.

[0131] In another embodiment another membrane technology option, known as a “Dead-end glassy-type” membrane is utilized. With this membrane the recovered C3+ is recovered under pressure. It also has the advantage of

increasing the recovery with higher pressure without any refrigeration therefore achieving a close to 100% C3+ recovery higher than the “rubbery-type” membrane. This system requires to increase the pressure of the off-gas of the secondary absorber or of the light ends coming from the main absorber. The recovery of such system is directly linked to the compression power, and so the power of this system can be directly adjusted to the required recovery level.

[0132] Without compression, recovery in the higher range of 70% can be achieved, still well beyond the conventional recovery values and above the “rubbery-type” membranes. In addition to the higher recovery, because the rich stream is recovered under pressure it can be introduced directly under pressure in any of the separation column in 217. The recycle in 209 is not necessary anymore and so 209 doesn't need to be oversized. This embodiment has the advantage of improving the recovery up to 99.9%, which can be coupled with the removal of the secondary adsorber.

[0133] Turning to FIG. 9, the membrane unit can also be a more integrated design with propane refrigeration cycle 914 and deethanizer column 905, in lieu of the secondary absorber. This embodiment has the advantage of reaching higher C3+ recovery than single membrane system, up to 90% and slightly above.

[0134] C3+ recovery of the FCC gas plant is improved by replacing the secondary absorber with a combination of propane-cooled cold separator 902 and deethanizer 905, complemented by membrane unit 909 recycling the C3+ content 911 from the gaseous phase 904 of cold separator 902 to the inlet of the light end fractionation compressor 209.

[0135] The primary absorber off-gas 212 is cooled in economizer 901, using propane refrigeration cycle 914, where it is cooled down and sent to a cold separator 902. Gaseous phase 904 from cold separator 902 is sent to the innovative membrane system 909 after being heated up to about ambient temperature in the economizer 901. Membrane residual 910 then cooled in the economizer 901, expanded in JT valve 915, combined with deethanizer top stream 907, and combined stream 916 is heated up again in economizer 901. The cold point of economizer 901 remains provided by the cold expanded residual 916. The residual 913 is exported as fuel gas at ambient temperature.

[0136] Membrane permeate 911 recovers the C3+ that had been lost in the gaseous phase 904 of the cold separator 902 and is recycled back at the inlet of the light end compressor 209. Liquid phase 903 from cold separator 902 is sent to deethanizer 805. Light end fraction 907 is combined with expanded membrane residual 910, sent back to economizer 901 and exits the system as off-gas 913.

[0137] C3+ fraction 906 is recovered at the bottom of deethanizer column 905 and sent to de-C4 column 217 of the gas plant, where it will go through the existing separation steps of the gas plant. C3+ fraction 906 will generate significant revenue as it will now able to be processed in the downstream part of the gas plant.

[0138] Not shown on the scheme are the reboiler and condenser of de-ethanizer 905. Refrigeration unit 914 (preferably propane cycle type) could be used as a source of cold for the condenser, while some steam could be used for the reboiler.

[0139] One advantage of this embodiment is high recovery without a recycling compressor and a lower recycle flowrate.

Also, the de-ethanizer column is smaller than secondary absorber because less flowrate to treat.

[0140] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims. Thus, the present invention is not intended to be limited to the specific embodiments in the examples given above.

What is claimed is:

1. A method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream, comprising:

- a) separating a light ends stream (204) from a fractionator (203) comprising hydrocarbons containing three or more carbon atoms in main absorption unit (210), thereby producing a stream rich in hydrocarbons containing three or more carbon atoms (211), and a stream lean in hydrocarbons containing three or more carbon atoms (212),
- b) separating the stream lean in hydrocarbons containing three or more carbon atoms (212) in a membrane unit (501), thereby producing a permeate stream enriched in hydrocarbons containing three or more carbon atoms (503) and a retentate stream (502), and
- c) separating the stream rich in hydrocarbons containing three or more carbon atoms (211) in one or more separation columns (217), thereby producing one or more streams selected from the group consisting of a propylene stream, a propane stream, a butane stream, a light cat naptha stream, and a heavy cat naptha stream.

2. The method of claim 1, wherein the permeate stream enriched in hydrocarbons containing three or more carbon atoms (503) is recycled to the fractionator (203).

3. The method of claim 1, wherein the permeate stream enriched in hydrocarbons containing three or more carbon atoms (503) is sent to the one or more separation columns (217).

4. The method of claim 1, further comprising a secondary absorption unit (214),

- b1) wherein the stream lean in hydrocarbons containing three or more carbon atoms (212) is introduced into the secondary absorption unit (214), thereby producing a secondary absorber off-gas stream (215) which is sent to membrane unit (501), thereby producing the permeate stream enriched in hydrocarbons containing three or more carbon atoms (503) and the retentate stream (502), and

- b2) wherein the permeate stream enriched in hydrocarbons containing three or more carbon atoms (503) is recycled to the fractionator (203).

5. The method of claim 1, further comprising a carbon dioxide removal unit (701),

- b1) wherein the stream lean in hydrocarbons containing three or more carbon atoms (212) is introduced into the carbon dioxide removal unit (701), thereby producing a carbon dioxide lean stream (703) which is sent to membrane unit (501), thereby producing the permeate stream enriched in hydrocarbons containing three or more carbon atoms (503) and the retentate stream (502), and

- b2) wherein the permeate stream enriched in hydrocarbons containing three or more carbon atoms (503) is recycled to the fractionator (203).

6. The method of claim 1, wherein the one or more separation columns (217) comprise one or more units selected from the group consisting of a debutanizer column, a gasoline splitting column, a depropanizer column, and propane splitting column.

7. A method of separating hydrocarbons containing three or more carbon atoms from an off-gas stream, comprising:

- a) combining a light ends stream (204) from a fractionator (203) comprising hydrocarbons containing three or more carbon atoms and a permeate stream (911) to form a combined stream (912),

- b) separating the combined stream (912) in main absorption unit (210), thereby producing a stream rich in hydrocarbons containing three or more carbon atoms (211), and a stream lean in hydrocarbons containing three or more carbon atoms (212),

- c) separating an at least partially condensed stream lean in hydrocarbons containing three or more carbon atoms (212) in a cold separator (902), thereby producing a liquid stream (903), and a vapor stream (904),

- d) warming the vapor stream (904) to ambient temperature, then separating the ambient temperature stream in a membrane unit (909), thereby producing the permeate stream (911) and a retentate stream (910), and

- e) separating the stream rich in hydrocarbons containing three or more carbon atoms (211) in one or more separation columns (217), thereby producing one or more streams selected from the group consisting of a propylene stream, a propane stream, a butane stream, a light cat naptha stream, and a heavy cat naptha stream.

8. The method of claim 7, wherein the one or more separation columns (217) comprise one or more units selected from the group consisting of a separator, a debutanizer column, a gasoline splitting column, a depropanizer column, and propane splitting column.

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