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(54) Title: SYSTEMS AND METHODS FOR IMPROVED COLUMN OPERATION IN OFFSHORE ENVIRONMENTS

(57) Abstract: Systems and methods for improved column operation in offshore environments by using a co-current contactor system in floating production, storage and offloading (FPSO) systems.

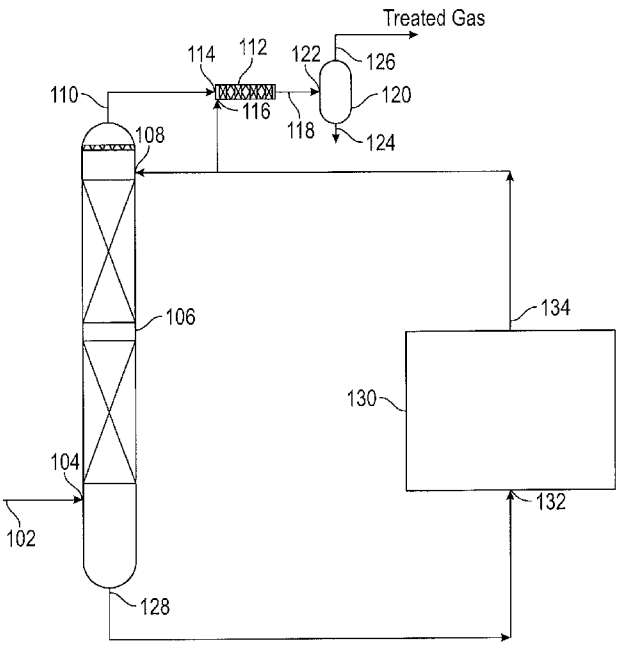


FIG. 1

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SYSTEMS AND METHODS FOR IMPROVED COLUMN OPERATION IN OFFSHORE ENVIRONMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The priority of U.S. Provisional Patent Application No. 61/837,169, filed June 19, 2013, is hereby claimed and the specification thereof is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] Not applicable.

FIELD OF THE DISCLOSURE

[0003] The present disclosure generally relates to systems and methods for improved column operation in offshore environments. More particularly, the present disclosure relates to improved column operation in offshore environments by using a co-current contactor system in floating production, storage and offloading (FPSO) systems.

BACKGROUND OF THE DISCLOSURE

[0004] Offshore processing of natural gas or oil associated gas is becoming a more and more attractive alternative to conventional land-based facilities. Marginal gas fields can be economically developed by means of the FPSO concept. Offshore processing plants on floating structures can be production units for liquefied natural gas (LNG), liquefied petroleum gas (LPG), methanol, gas to liquid (GTL), or ammonia. The ability to station the FPSO vessel directly over fields avoids expensive offshore pipelines. In addition, once the existing field is depleted, the production facility can be moved to a new location to continue production.

[0005] One of the critical technical challenges for the FPSO concept is the influence of

movement, acceleration and static tilt on the performance of distillation and absorption columns, such as demethanizer, deethanizer, depropanizer, glycol-based dehydration system, or acid gas removal absorber columns. For these units, the uniform countercurrent gas and liquid flow is disturbed by motion leading to reduced heat and mass transfer. Their efficiency is thus, often influenced by the deviations from the vertical position.

[0006] Though amine-based acid gas removal is a well proven technology for onshore applications, offshore conditions may result in not contacting some of the untreated or insufficiently treated feed gas due to movement or tilt of the absorber. The problem is especially severe for floating LNG FPSO, since the liquefaction process requires CO_2 to be reduced to less than 50 ppm to avoid risk of the freeze out and blockage of heat exchangers at cryogenic temperatures. Even a small bypass may have an adverse impact on liquefaction system operation with off-specification (off-spec.) treated gas having an excess of CO_2 exceeding about 50ppm, and may require the process to shut down resulting in production losses.

[0007] Moreover, various studies have established that distillation or absorption column movement due to sea conditions can negatively affect separation efficiency in the column. In a 50mm diameter distillation column, for example, a 50% reduction in efficiency at an inclination of 2.5 degrees was reported. In addition, a 16% reduction in efficiency at an inclination of 1.2 degrees for a 2 meter diameter one or two-pass tray column, and a 31% reduction in efficiency at an inclination of 1 degree for a 330mm diameter one-path tray column were reported.

[0008] These reported reductions in separation efficiency will have a significant impact on the equipment performance, and eventually the reliability of the operation. Availability of

production will suffer due to process shut down triggered by the off-spec treated gas from the acid gas removal unit. Equipment may need to be over-sized to offset the reduction in separation efficiency at higher sea states. Alternatively, proprietary equipment may need to be used to alleviate the uneven distribution problem.

SUMMARY OF THE DISCLOSURE

[0009] The present disclosure overcomes one or more deficiencies in the prior art by providing systems and methods for improved column operation in offshore environments by using a co-current contactor system in floating production, storage and offloading (FPSO) systems.

[0010] In one embodiment, the present disclosure includes co-current contact system for operating an absorption column in offshore environments, which comprises: i) a solvent regeneration unit having a rich amine input opening in fluid communication with a rich amine output line connected to the absorption column and a lean amine output line in fluid communication with a lean amine input opening in the absorption column; a static mixer having a static mixer input opening in fluid communication with the lean amine output line, a treated gas input opening in fluid communication with a treated gas output line connected to the absorption column and a static mixer output line; and iii) a separator having a separator input opening in fluid communication with the static mixer output line, a separator liquid output line and a separator vapor output line.

[0011] In another embodiment, the present disclosure includes a co-current contact system for operating a distillation column in offshore environments, which comprises: i) a static

mixer having a first static mixer input opening in fluid communication with a reflux pump output line connected to a reflux pump, a second static mixer input opening in fluid communication with a distillation column output line connected to the distillation column and a static mixer output line in fluid communication with a condenser input opening in a condenser; and ii) a reflux drum having a reflux drum input opening in fluid communication with a condenser output line connected to the condenser, a first reflux drum output line in fluid communication with a reflux pump input opening in the reflux pump and a second reflux drum output line.

[0012] In yet another embodiment, the present disclosure includes a method for operating an absorption column in offshore environments using a co-current contact system, which comprises: i) sending lean amine from a solvent regeneration unit to the co-current contact system, wherein the co-current contact system comprises a static mixer and a separator; ii) mixing the lean amine and a treated gas from the absorption column in the static mixer; and iii) separating the mixed lean amine and treated gas into a vapor and a liquid using the separator.

[0013] In yet another embodiment, the present disclosure includes a method for operating a distillation column in offshore environments using a co-current contact system, which comprises: i) sending a reflux liquid from a reflux drum to the con-concurrent contact system, wherein the co-current contact system comprises a static mixer and a condenser; ii) mixing the reflux liquid and a vapor from the distillation column in the static mixer; and iii) condensing the mixed reflux liquid and vapor into a mixed condensate using the condenser.

[0014] Additional aspects, advantages and embodiments of the disclosure will become apparent to those skilled in the art from the following description of the various embodiments

and related drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The present disclosure is described below with references to the accompanying drawings in which like elements are referenced with like reference numerals, and in which:

[0016] **FIG. 1** is a schematic diagram illustrating one embodiment of a co-current contact system for use in a conventional acid gas removal system according to the present disclosure.

[0017] **FIG. 2** is schematic diagram illustrating another embodiment of a co-currrent contact system for use in a conventional acid gas removal system according to the present disclosure.

[0018] **FIG. 3** is a schematic diagram illustrating yet another embodiment of a co-currrent contact system for use in a conventional acid gas removal system according to the present disclosure.

[0019] **FIG. 4** is a schematic diagram illustrating yet another embodiment of a co-currrent contact system for use in a conventional acid gas removal system according to the present disclosure.

[0020] **FIG. 5** is a schematic diagram illustrating another embodiment of a co-current contact system that may be used in place of the co-current contact system illustrated in **FIGS. 1-4**.

[0021] **FIG. 6** is a schematic diagram illustrating yet another embodiment of a co-current contact system that may be used in place of the co-current contact system illustrated in **FIGS. 1-4**

[0022] **FIG. 7** is a schematic diagram illustrating one embodiment of a co-current contact system for use with a distillation column according to the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] The subject matter of the present disclosure is described with specificity, however, the description itself is not intended to limit the scope of the disclosure. The subject matter thus, might also be embodied in other ways, to include different steps or combinations of steps similar to the ones described herein, in conjunction with other present or future technologies. Moreover, although the term "step" may be used herein to describe different elements of methods employed, the term should not be interpreted as implying any particular order among or between various steps herein disclosed unless otherwise expressly limited by the description to a particular order. While the present disclosure may be applied in the oil and gas industry, it is not limited thereto and may also be applied in other industries to achieve similar results.

[0024] The following description refers to **FIGS. 1-7**, which includes systems and methods for improved column operation in offshore environments using co-current contactor systems to improve mixing between incoming streams. In **FIGS. 1-7**, various embodiments of a co-current contact system are illustrated in an exemplary acid gas removal system or with an exemplary distillation column. In each embodiment, the co-current contact system includes a static mixer insensitive to motion, which provides mixing between the incoming streams. A static mixer may include, for example, of a series of motionless elements installed in a pipe. These elements promote mixing of two or more fluids, which flow through the pipe due to a

pressure gradient. Where needed, multiple stages of such mixing can be utilized. When used with an absorption column, the co-current contactor system is positioned downstream of the absorption column to treat the vapor leaving the absorption column overhead. When used with a distillation column, the co-current contactor system is positioned downstream of the distillation column before the condenser.

[0025] Referring now to **FIG. 1**, a schematic diagram illustrates one embodiment of a co-current contact system for use in a conventional acid gas removal system. The acid gas removal system includes an absorber **106** and a solvent regeneration unit **130**. The co-current contact system includes a static mixer **112** and a separator **120.** The absorber **106** has an input opening **104** located below the lower packed section adapted for fluid communication with a feed gas line **102**. The solvent regeneration unit **130** has a rich amine input opening **132** in fluid communication with a rich amine output line **128** at the bottom of the absorber **106** and a lean amine output line **134** in fluid communication with a lean amine input opening **108** near the top of the absorber **106**. The static mixer **112** has a static mixer input opening **116** in fluid communication with the lean amine output line **134**, a treated gas input opening **114** in fluid communication with a treated gas output line **110** from the top of the absorber **106**, and a static mixer output line **118**. For liquefaction applications, the treated gas output line **110** is generally specified to contain less than 50ppm CO_2 and less than 5mg/Nm^3 H_2S. The separator **120** has a separator input opening **122** in fluid communication with the static mixer output line **118**, a separator liquid output line **124**, and a separator vapor output line **126**.

[0026] Referring now to **FIG. 2**, a schematic diagram illustrates another embodiment of a

co-currrent contact system for use in a conventional acid gas removal system. The acid gas removal system includes an absorber **106** and a solvent regeneration unit **130**. The co-current contact system includes a static mixer **112** and a separator **120.** The absorber **106** has an input opening **104** located below the lower packed section adapted for fluid communication with a feed gas line **102**. The solvent regeneration unit **130** has a rich amine input opening **132** in fluid communication with a rich amine output line **128** at the bottom of the absorber **106** and a lean amine output line **134** in fluid communication with a lean amine input opening **108** near the top of the absorber **106**. The static mixer **112** has a static mixer input opening **116** in fluid communication with the lean amine output line **134**, a treated gas input opening **114** in fluid communication with a treated gas output line **110** from the top of the absorber **106**, and a static mixer output line **118**. For liquefaction applications, the treated gas output line **110** is generally specified to contain less than 50ppm CO_2 and less than 5mg/Nm^3 H_2S. The separator **120** has a separator input opening **122** in fluid communication with the static mixer output line **118**, a separator liquid output line **124**, and a separator vapor output line **126**. In this embodiment, a sufficient amount of lean amine from the lean amine output line **134** is sent to the static mixer **112** through the static mixer input opening **116** where it is mixed with the gas from the treated gas output line **110** as it enters the static mixer **112** through the treated gas input opening **114**. The resulting treated gas from the separator vapor output line **126** will meet acid gas specifications and semi-lean amine from the separator liquid output line **124** is combined with the lean amine from the lean amine output line **134** before entering the absorber **106** through the lean amine input opening **108**.

[0027] Referring now to **FIG. 3,** a schematic diagram illustrates yet another embodiment of a co-currrent contact system for use in a conventional acid gas removal system. The acid gas removal system includes an absorber **106** and a solvent regeneration unit **130**. The co-current contact system includes a static mixer **112** and a separator **120.** The absorber **106** has an input opening **104** located below the lower packed section adapted for fluid communication with a feed gas line **102**. The solvent regeneration unit **130** has a rich amine input opening **132** in fluid communication with a rich amine output line **128** at the bottom of the absorber **106** and a lean amine output line **134** in fluid communication with a lean amine input opening **108** near the top of the absorber **106**. The static mixer **112** has a static mixer input opening **116** in fluid communication with the lean amine output line **134**, a treated gas input opening **114** in fluid communication with a treated gas output line **110** from the top of the absorber **106**, and a static mixer output line **118**. For liquefaction applications, the treated gas output line **110** is generally specified to contain less than 50ppm CO_2 and less than 5mg/Nm^3 H_2S. The separator **120** has a separator input opening **122** in fluid communication with the static mixer output line **118**, a separator liquid output line **124**, and a separator vapor output line **126**. In this embodiment, a sufficient amount of lean amine from the lean amine output line **134** is sent to the static mixer **112** through the static mixer input opening **116** where it is mixed with the gas from the treated gas output line **110** as it enters the static mixer **112** through the treated gas input opening **114**. The resulting treated gas from the separator vapor output line **126** will meet acid gas specifications and semi-lean amine from the separator liquid output line **124** is sent to the absorber **106** through another lean amine input opening **304**. In this manner, the semi-lean

amine will not dilute the lean amine from the lean amine output line **134**.

[0028] Referring now to **FIG. 4**, a schematic diagram illustrates yet another embodiment of a co-currrent contact system for use in a conventional acid gas removal system. The acid gas removal system includes an absorber **106** and a solvent regeneration unit **130**. The co-current contact system includes a static mixer **112** and a separator **120.** The absorber **106** has an input opening **104** located below the lower packed section adapted for fluid communication with a feed gas line **102**. The solvent regeneration unit **130** has a rich amine input opening **132** in fluid communication with a rich amine output line **128** at the bottom of the absorber **106** and a lean amine output line **134** in fluid communication with a lean amine input opening **108** near the top of the absorber **106**. The static mixer **112** has a static mixer input opening **116** in fluid communication with the lean amine output line **134**, a treated gas input opening **114** in fluid communication with a treated gas output line **110** from the top of the absorber **106**, and a static mixer output line **118**. For liquefaction applications, the treated gas output line **110** is generally specified to contain less than 50ppm CO_2 and less than 5mg/Nm^3 H_2S. The separator **120** has a separator input opening **122** in fluid communication with the static mixer output line **118**, a separator liquid output line **124**, and a separator vapor output line **126**. In this embodiment, a sufficient amount of lean amine from the lean amine output line **134** is sent to the static mixer **112** through the static mixer input opening **116** where it is mixed with the gas from the treated gas output line **110** as it enters the static mixer **112** through the treated gas input opening **114**. The resulting treated gas from the separator vapor output line **126** will meet acid gas specifications and semi-lean amine from the separator liquid output line **124** is sent to the solvent

regenerator unit **130** through a semi-lean amine input opening **404**.

[0029] Referring now to **FIG. 5**, a schematic diagram illustrates another embodiment of a co-current contact system that may be used in place of the co-current contact system illustrated in **FIGS. 1-4**. The co-current contact system includes another static mixer **504** and another separator **512**. The another static mixer **504** has another static mixer input opening **506** in fluid communication with the separator vapor output line **126** for carrying treated gas, a lean amine input opening **508** in fluid communication with the lean amine output line **134**, and another static mixer output line **510**. The another separator **512** has another separator input opening **514** in fluid communication with the another static mixer output line **510**, another separator liquid output line **516** for carrying semi-lean amine, and another separator vapor output line **518** for carrying twice treated gas. In this embodiment, feed gas from the treated gas input opening **114** is mixed in the static mixer **112** with lean amine from the static mixer input opening **116**. Treated gas from the separator **120** is further mixed in the another static mixer **504** with lean amine from the lean amine input opening **508**. The treated gas from the another static mixer **504** will meet acid gas specifications and the semi-lean amine from the another separator liquid output line **516** and the separator liquid output line **124** is sent to the absorber **106**.

[0030] Referring now to **FIG. 6,** a schematic diagram illustrates yet another embodiment of a co-current contact system that may be used in place of the co-current contact system illustrated in **FIGS. 1-4**. The co-current contact system includes another static mixer **504** and another separator **512**. The another static mixer **504** has another static mixer input opening **506** in fluid communication with the separator vapor output line **126** for carrying treated gas, a lean

amine input opening **508** in fluid communication with the lean amine output line **134**, and another static mixer output line **510**. The another separator **512** has another separator input opening **514** in fluid communication with the another static mixer output line **510**, another separator liquid output line **516** for carrying semi-lean amine, and another separator vapor output line **518** for carrying twice treated gas. In this embodiment, feed gas from the treated gas input opening **114** is mixed in the static mixer **112** with semi-lean amine from the another separator output line **516**. Treated gas from the separator **120** is further mixed in the another static mixer **504** with lean amine from the lean amine input opening **508**. The treated gas from the another static mixer **504** will meet acid gas specifications and the semi-lean amine from the another separator liquid output line **516** is sent to the first static mixer **112**. The semi-lean amine from the separator **120** is more enriched with CO_2 than the semi-lean amine from the another separator **512**. In this manner, the total required lean amine flow rate is reduced compared to the embodiment described in reference to **FIG. 5**.

[0031] Referring now to **FIG. 7**, is a schematic diagram illustrates another embodiment of a co-current contact system for use with a distillation column. The co-current contact system includes a static mixer **706**, a condenser **714**, a reflux drum **720**, and a reflux pump **730**. The distillation column **704** has a distillation column output line **705** and a distillation column input opening **734**. The static mixer **706** has a first static mixer input opening **708** in fluid communication with a reflux pump liquid output line **732**, a second static mixer input opening **710** in fluid communication with the distillation column output line **705** and a static mixer output line **712** in fluid communication with a condenser input opening **716**. The reflux drum **720** has a

reflux drum input opening **722** in fluid communication with a condenser output line **718**, a first reflux drum output line **724** in fluid communication with a reflux pump input opening **728** on the reflux pump **730**, and a second reflux drum output vapor line **726**. The reflux pump liquid output line **732** is in fluid communication with the distillation column input opening **734** and the static mixer input opening **708**. In this embodiment, a portion of the reflux in the reflux pump liquid output line **732** is split and mixed with vapor from the distillation column output line **705** in the static mixer **706**. In this manner, the overall separation is enhanced and multiple stages of such mixing, as illustrated in **FIGS. 5-6**, may be added.

[0032] Any of the foregoing co-current contact systems may be further modified as illustrated in **FIGS. 5** and **6**. And, the various embodiments of the co-current contact system illustrated in **FIGS. 1-7** may be applied in a new system or may be used in preexisting systems with conventional absorption and/or distillation columns.

[0033] While the present disclosure has been described in connection with presently preferred embodiments, it will be understood by those skilled in the art that it is not intended to limit the disclosure to those embodiments. It is therefore, contemplated that various alternative embodiments and modifications may be made to the disclosed embodiments without departing from the spirit and scope of the disclosure defined by the appended claims and equivalents thereof.

CLAIMS

1. A co-current contact system for operating an absorption column in offshore environments, which comprises:

a solvent regeneration unit having a rich amine input opening in fluid communication with a rich amine output line connected to the absorption column and a lean amine output line in fluid communication with a lean amine input opening in the absorption column;

a static mixer having a static mixer input opening in fluid communication with the lean amine output line, a treated gas input opening in fluid communication with a treated gas output line connected to the absorption column and a static mixer output line; and

a separator having a separator input opening in fluid communication with the static mixer output line, a separator liquid output line and a separator vapor output line.

2. The system of claim 1, wherein the separator liquid output line is connected to the lean amine output line.

3. The system of claim 1, wherein the separator liquid output line is connected to another lean amine input opening in the absorption column.

4. The system of claim 1, wherein the separator liquid output line is connected to a semi-lean amine input opening in the solvent regenerator unit.

5. The system of claim 1, further comprising:

another static mixer having another static mixer input opening in fluid communication with the separator vapor output line, a lean amine input opening in fluid

communication with the lean amine output line and another static mixer output line; and

another separator having another separator input opening in fluid communication with the another static mixer output line, another separator liquid output line and another separator vapor output line.

6. The system of claim 1, further comprising:

another static mixer having another static mixer input opening in fluid communication with the separator vapor output line, a lean amine input opening in fluid communication with the lean amine output line and another static mixer output line; and

another separator having another separator input opening in fluid communication with the another static mixer output line, another separator liquid output line in fluid communication with the static mixer input opening and another separator vapor output line.

7. The system of claim 1, wherein the static mixer comprises a pipe and a plurality of stationery elements position within the pipe.

8. The system of claim 1, wherein the rich amine output line is connected to a bottom of the absorption column, the treated gas output line is connected to a top of the absorption column and the lean amine input opening is positioned near the top of the absorption column.

9. A co-current contact system for operating a distillation column in offshore environments, which comprises:

a static mixer having a first static mixer input opening in fluid communication

with a reflux pump output line connected to a reflux pump, a second static mixer input opening in fluid communication with a distillation column output line connected to the distillation column and a static mixer output line in fluid communication with a condenser input opening in a condenser; and

a reflux drum having a reflux drum input opening in fluid communication with a condenser output line connected to the condenser, a first reflux drum output line in fluid communication with a reflux pump input opening in the reflux pump and a second reflux drum output line.

10. The system of claim 9, wherein the reflux pump liquid output line is in fluid communication with the distillation column input opening and the static mixer input opening.

11. A method for operating an absorption column in offshore environments using a co-current contact system, which comprises

sending lean amine from a solvent regeneration unit to the co-current contact system, wherein the co-current contact system comprises a static mixer and a separator;

mixing the lean amine and a treated gas from the absorption column in the static mixer; and

separating the mixed lean amine and treated gas into a vapor and a liquid using the separator.

12. The method of claim 11, wherein the treated gas contains less than about 50ppm CO_2 and less than about 5mg $N_m^3H_2S$.

13. The method of claim 11, further comprising combining the liquid comprising

semi-lean amine with the lean amine from the solvent regeneration unit.

14. The method of claim 13, sending the combined semi-lean amine and lean amine to only the absorption column.

15. The method of claim 11, sending the semi-lean amine to only the absorption column.

16. The method of claim 11, sending the semi-lean amine to only the solvent regeneration unit.

17. A method for operating a distillation column in offshore environments using a co-current contact system, which comprises:

sending a reflux liquid from a reflux drum to the con-concurrent contact system, wherein the co-current contact system comprises a static mixer and a condenser;

mixing the reflux liquid and a vapor from the distillation column in the static mixer; and

condensing the mixed reflux liquid and vapor into a mixed condensate using the condenser.

18. The method of claim 17, further comprising separating the mixed condensate into a vapor and a liquid using the reflux drum.

19. The method of claim 18, wherein the liquid comprises the reflux.

20. The method of claim 17, further comprising sending the reflux liquid form the reflux drum to the distillation column.

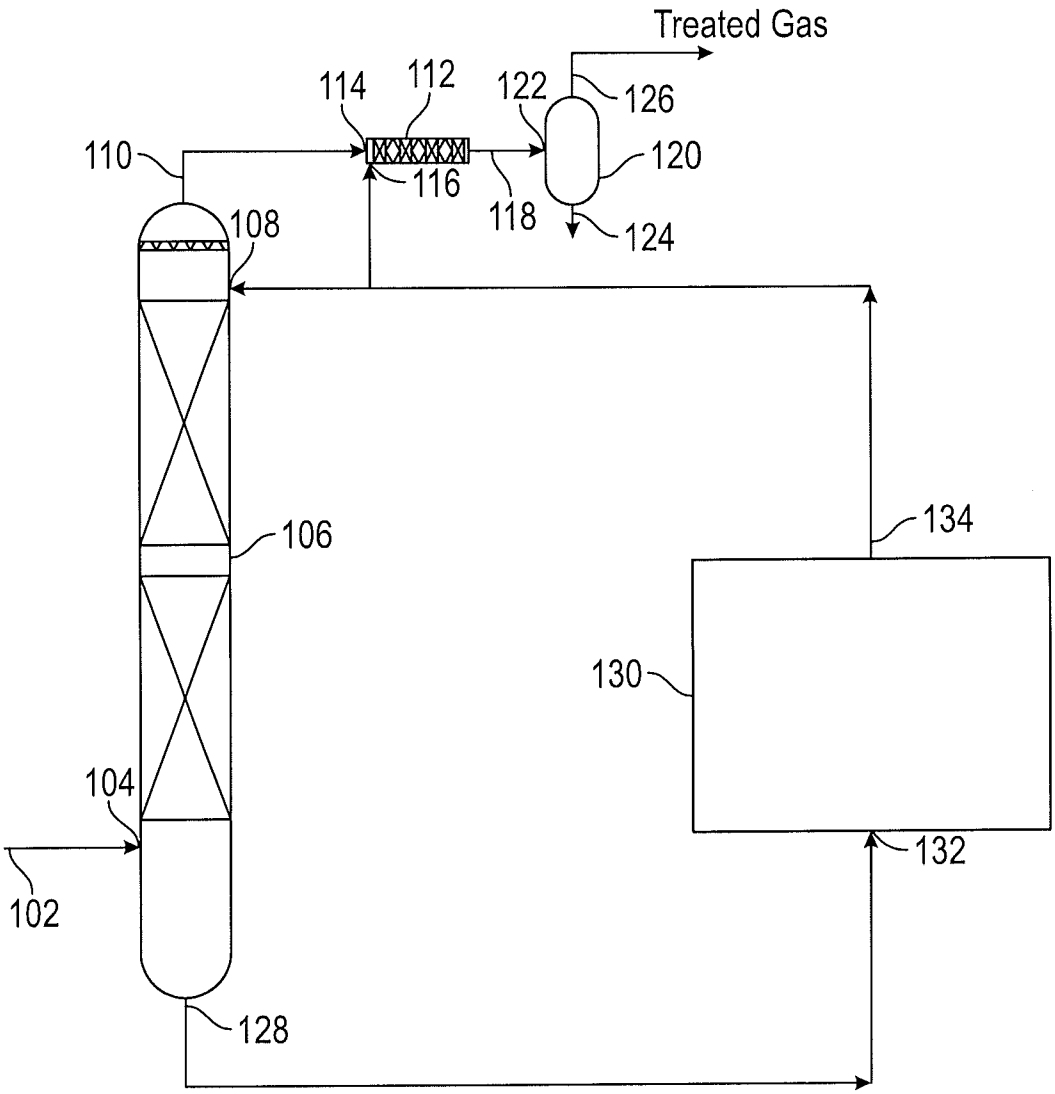

Treated Gas
114
112
122
126
110
120
116
118
124
108
106
134
130
104
102
132
128

FIG. 1

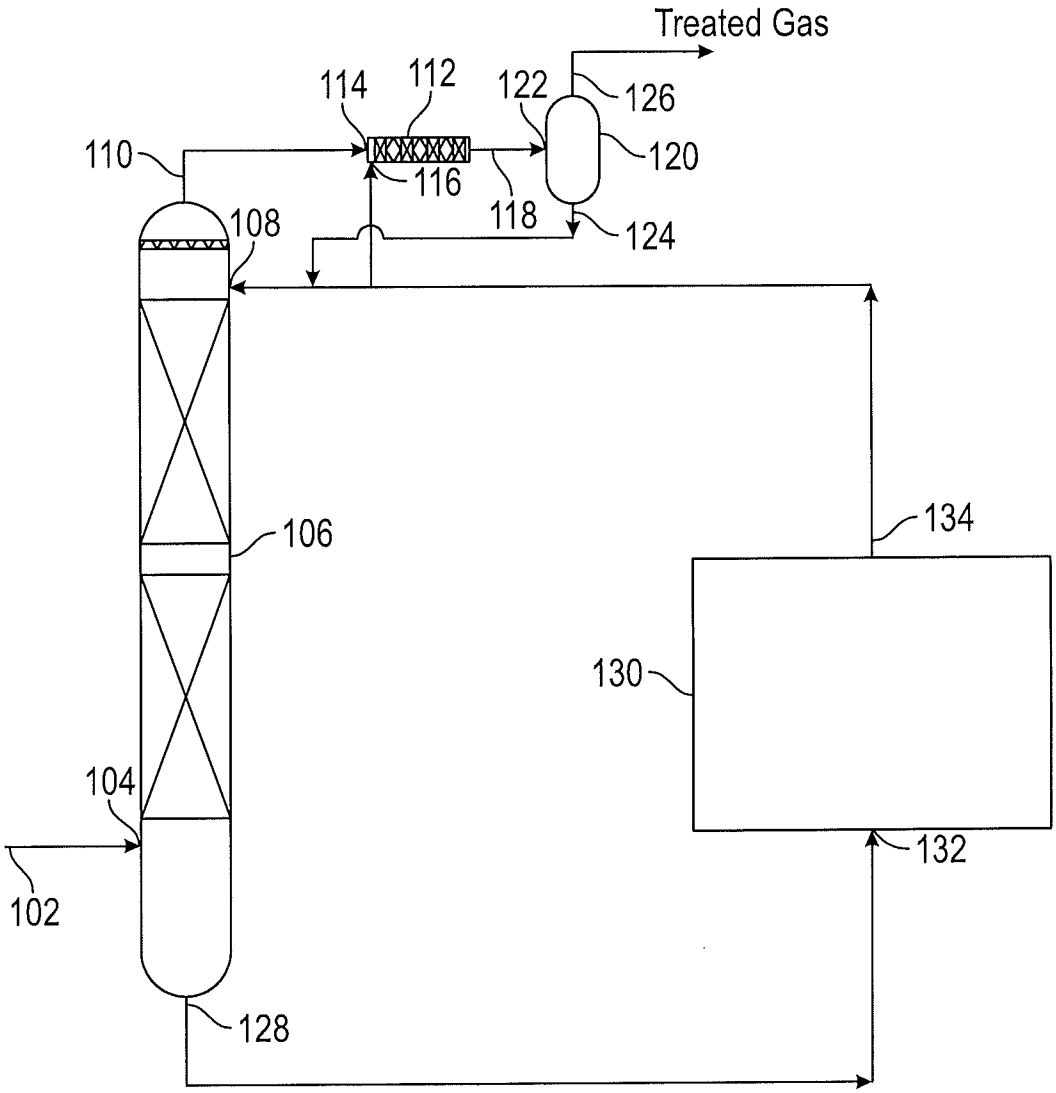

Treated Gas
114
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122
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118
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124
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134
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102
128

FIG. 2

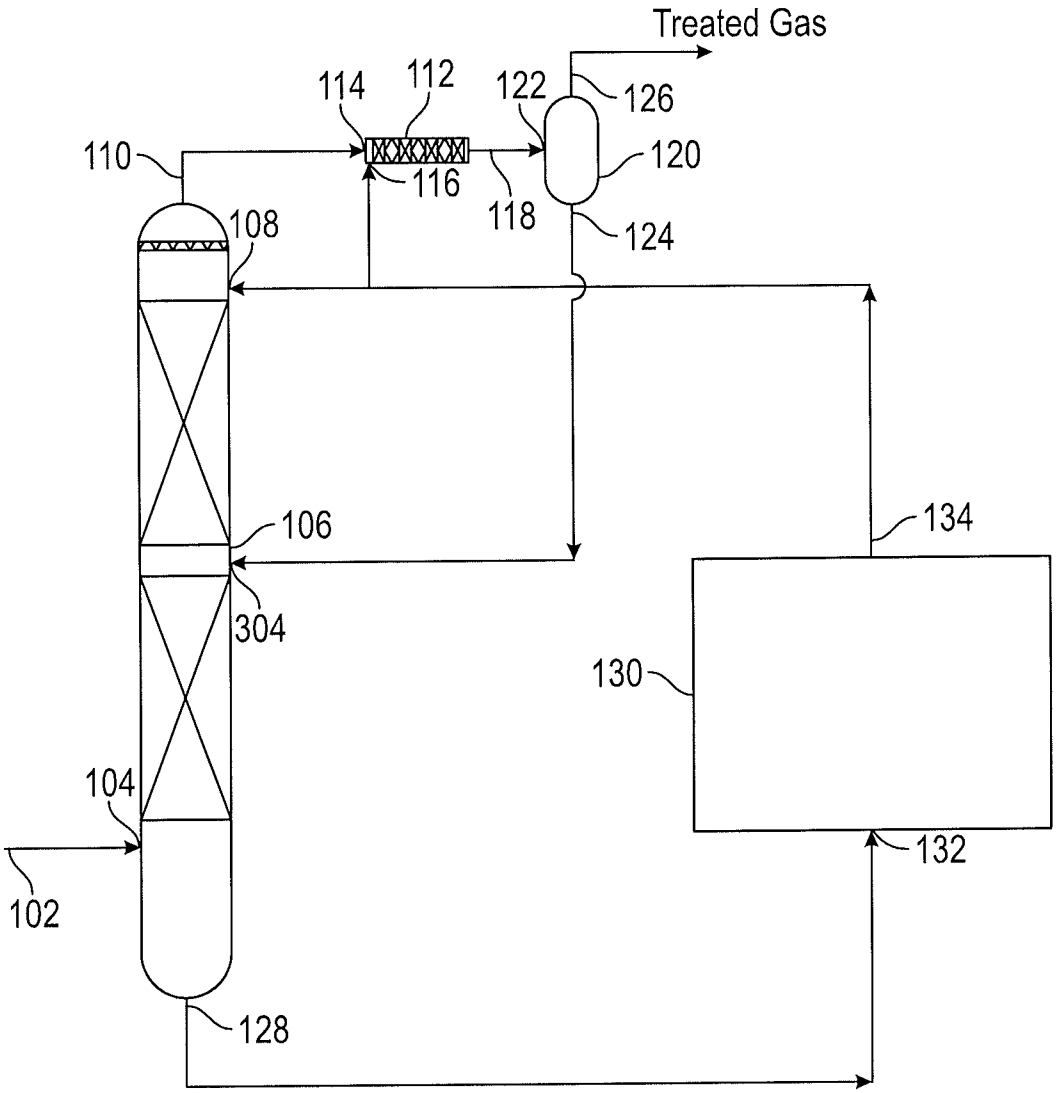

Treated Gas
114
112
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124
106
134
304
130
104
132
102
128

FIG. 3

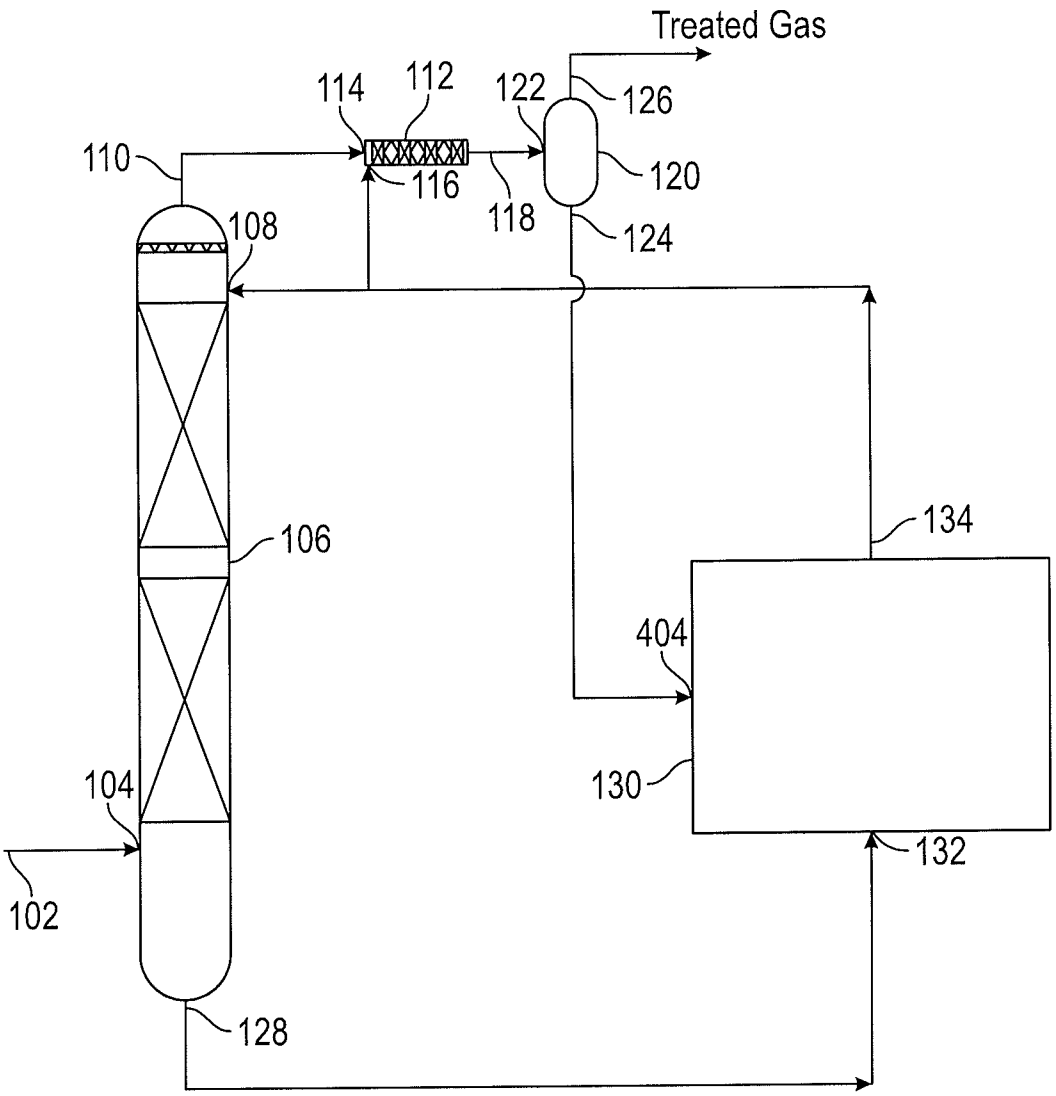

Treated Gas
114
112
122
126
110
116
118
120
108
124
106
134
404
104
130
102
132
128

FIG. 4

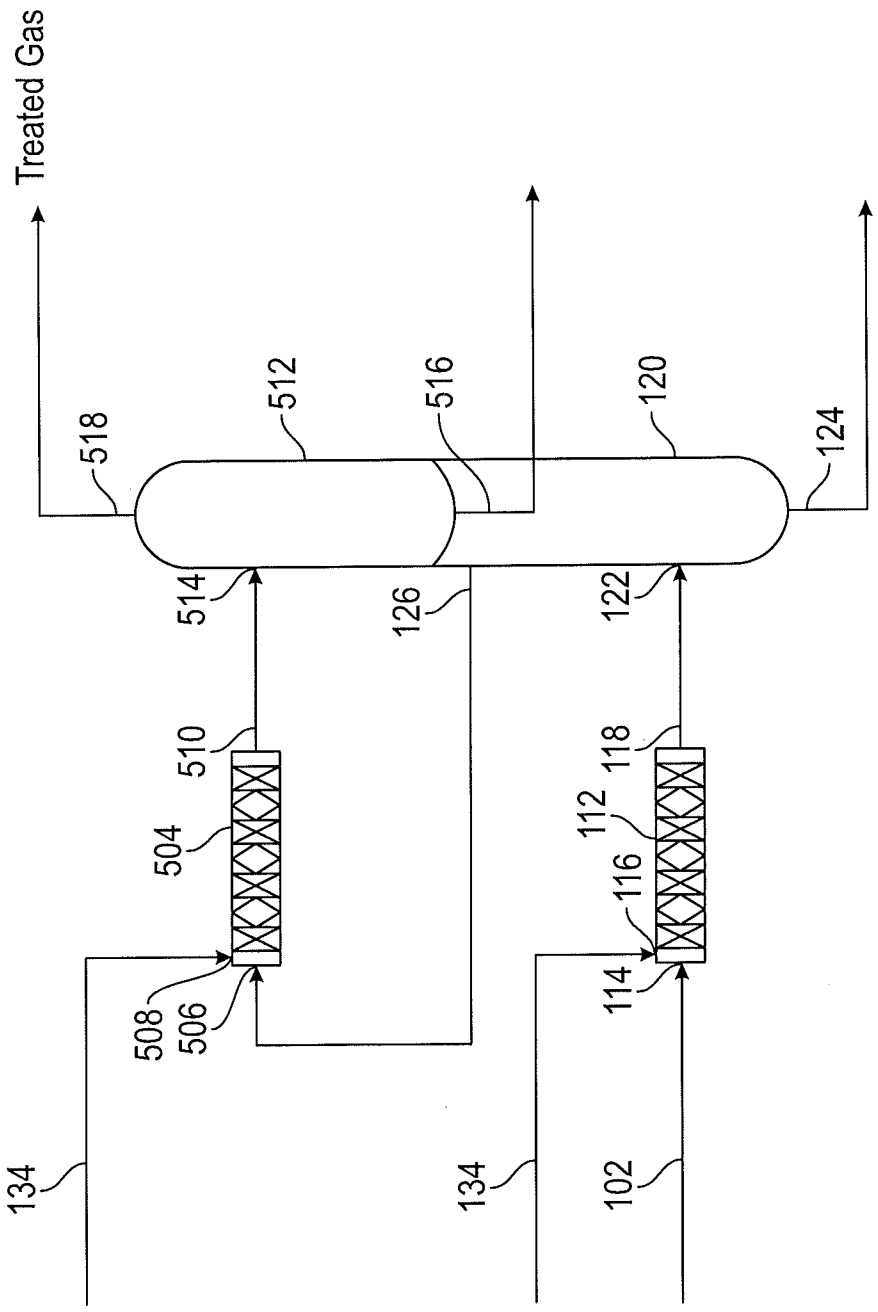

Treated Gas
518
512
516
120
124
514
126
122
510
118
504
112
116
508
506
114
134
134
102

FIG. 5

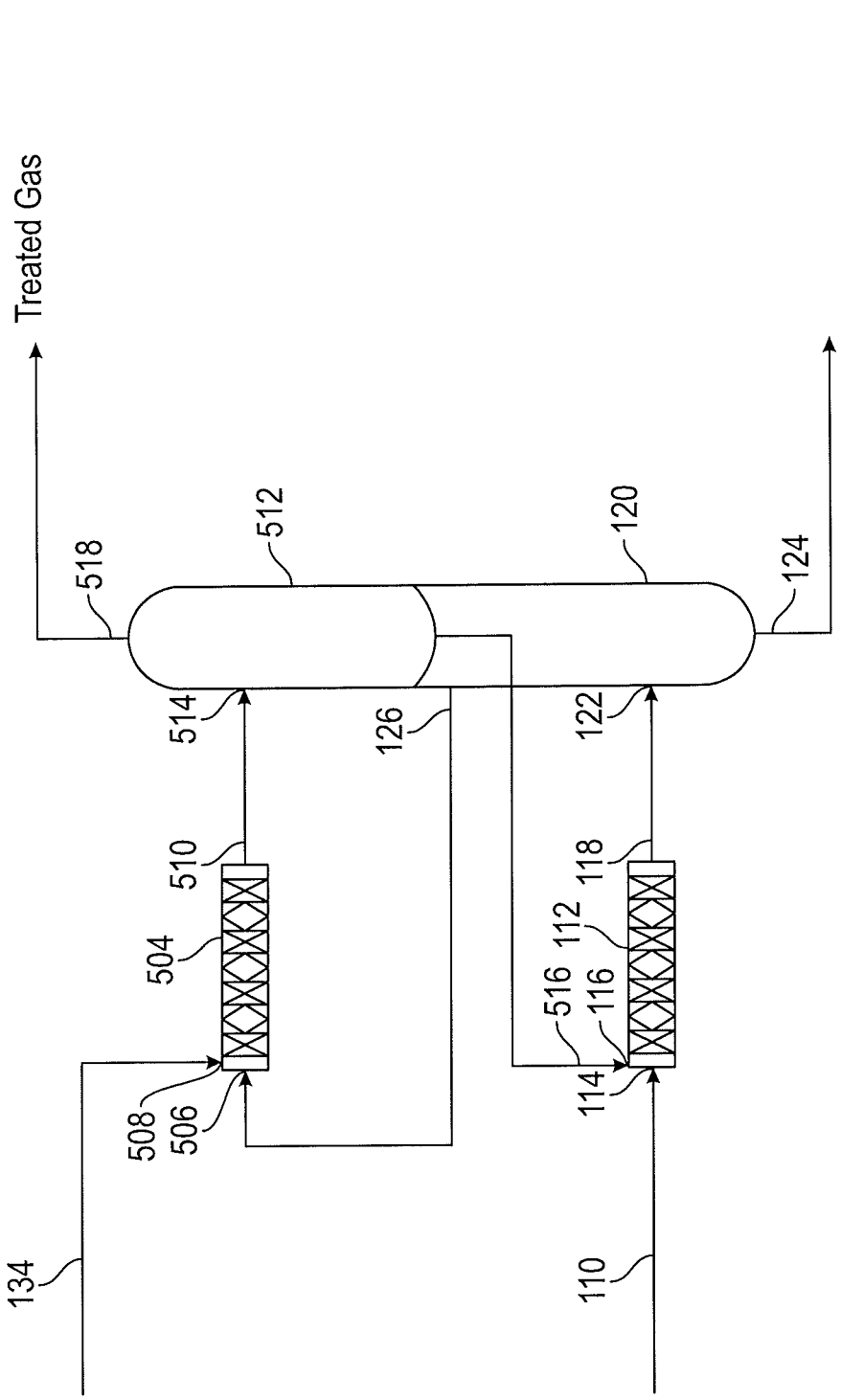

602
Treated Gas
518
512
120
124
514
126
122
510
504
118
112
516
116
508
506
114
134
110

FIG. 6

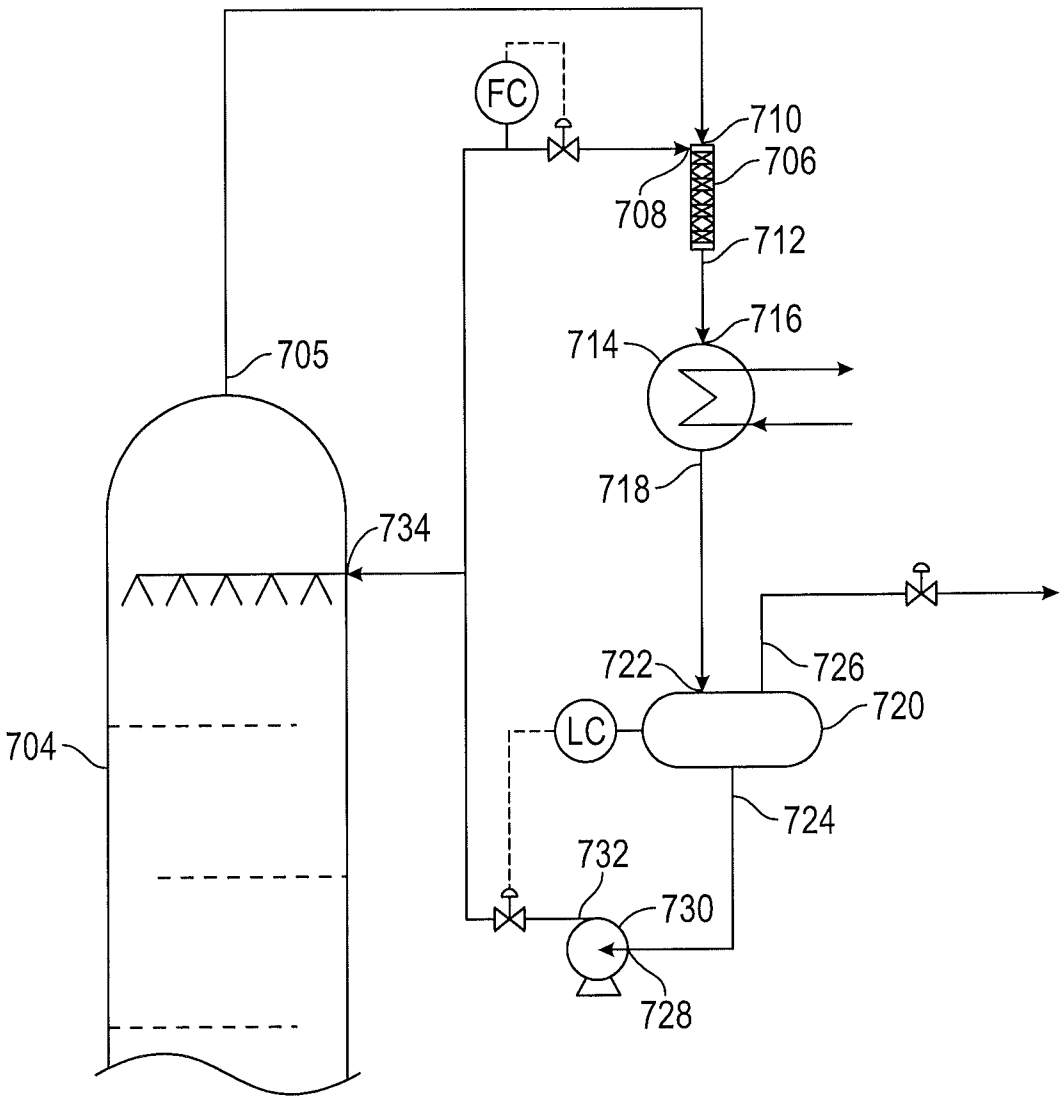

FC
710
706
708
712
716
714
705
718
734
722
726
720
LC
704
724
732
730
728

FIG. 7