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Ducote, Jr.

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(54) **GAS STREAM COMPONENT REMOVAL SYSTEM AND METHOD**

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F25J 1/02 (2006.01)

(52) **U.S. Cl.**
CPC ***F25J 1/0022*** (2013.01); ***F25J 1/0225*** (2013.01); ***F25J 1/0238*** (2013.01); ***F25J 1/0283*** (2013.01); *F25J 2210/60* (2013.01); *F25J 2220/60* (2013.01); *F25J 2240/02* (2013.01)

(58) **Field of Classification Search**
CPC F25J 1/0238; F25J 1/0225; F25J 1/0022; F25J 1/0292; F25J 3/06; F25J 3/065; F25J 3/0645; F25J 3/0655; F25J 3/0209; F25J 3/0214; F25J 3/0252; F25J 2205/40;
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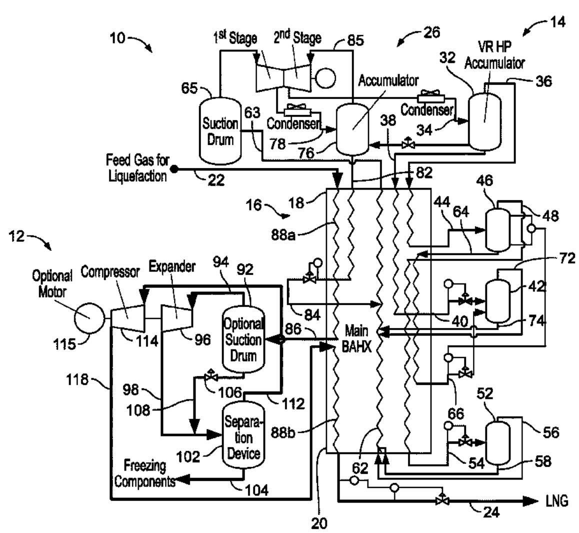
(57) **ABSTRACT**

A system for removing selected components from a gas stream has a heat exchanger including a first cooling passage configured to receive a feed gas stream and to provide a cooled feed gas stream. An expander receives at least a portion of the cooled feed gas stream. A separation device receives an expanded fluid stream from the expander and separates the expanded fluid stream into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature. A compressor receives the purified vapor stream at approximately the purified vapor temperature and produces a compressed vapor stream that is returned to the heat exchanger.

35 Claims, 5 Drawing Sheets



(58) **Field of Classification Search**
CPC .. F25J 2205/82; F25J 2210/06; F25J 2220/42; F25J 1/0237; F25J 1/0239
See application file for complete search history.

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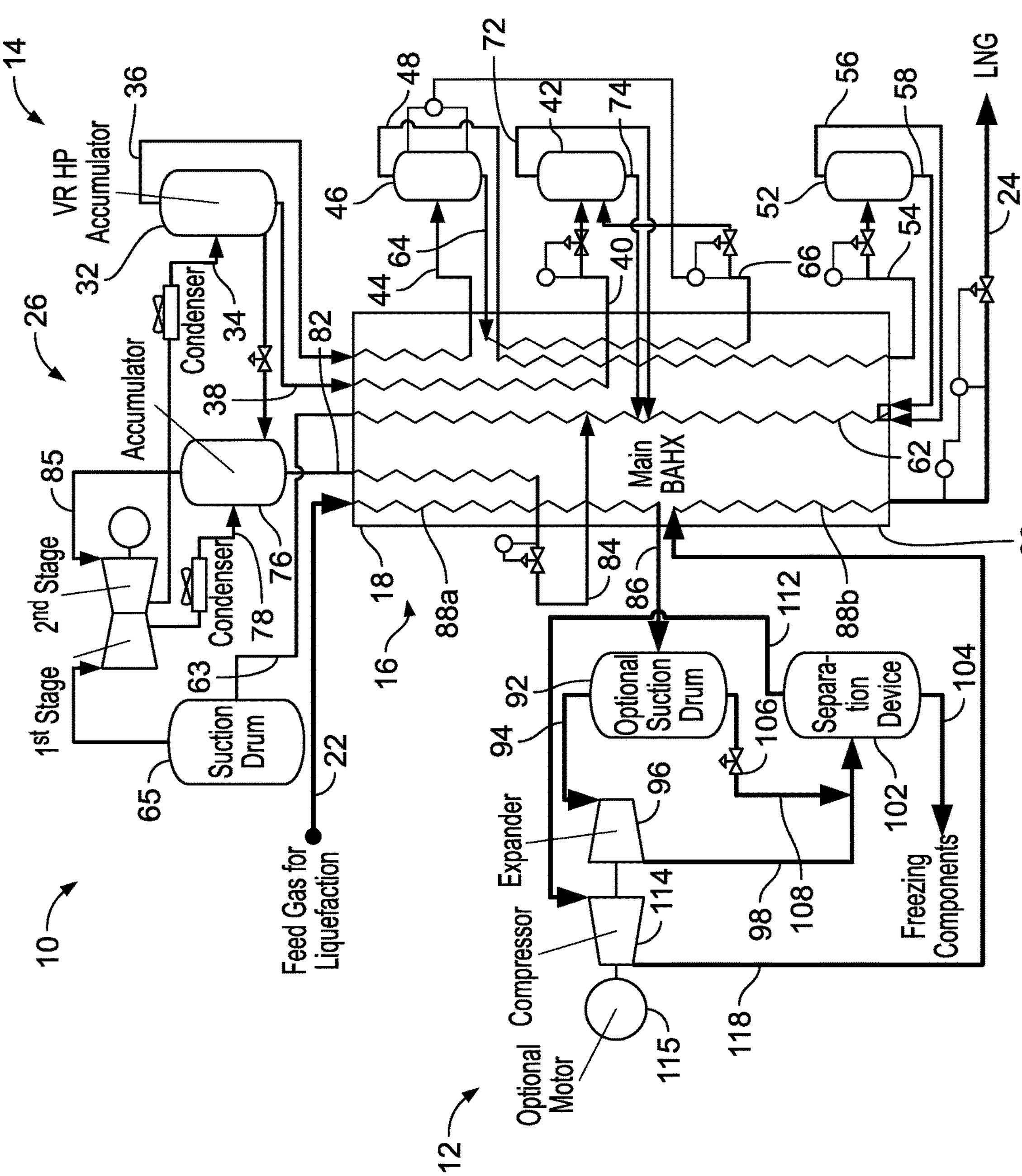


10
12
14
16
26
VR HP Accumulator
32
34
36
38
Accumulator
Condenser
Condenser
1st Stage
2nd Stage
Suction Drum
65
63
76
78
82
85
Feed Gas for Liquefaction
22
18
20
Main BAHX
40
42
44
46
48
52
54
56
58
62
64
66
72
74
84
86
88a
88b
LNG
24
Optional Suction Drum
92
94
96
Expander
Separation Device
102
104
106
108
112
98
Freezing Components
Compressor
114
Optional Motor
115
118

FIG. 1

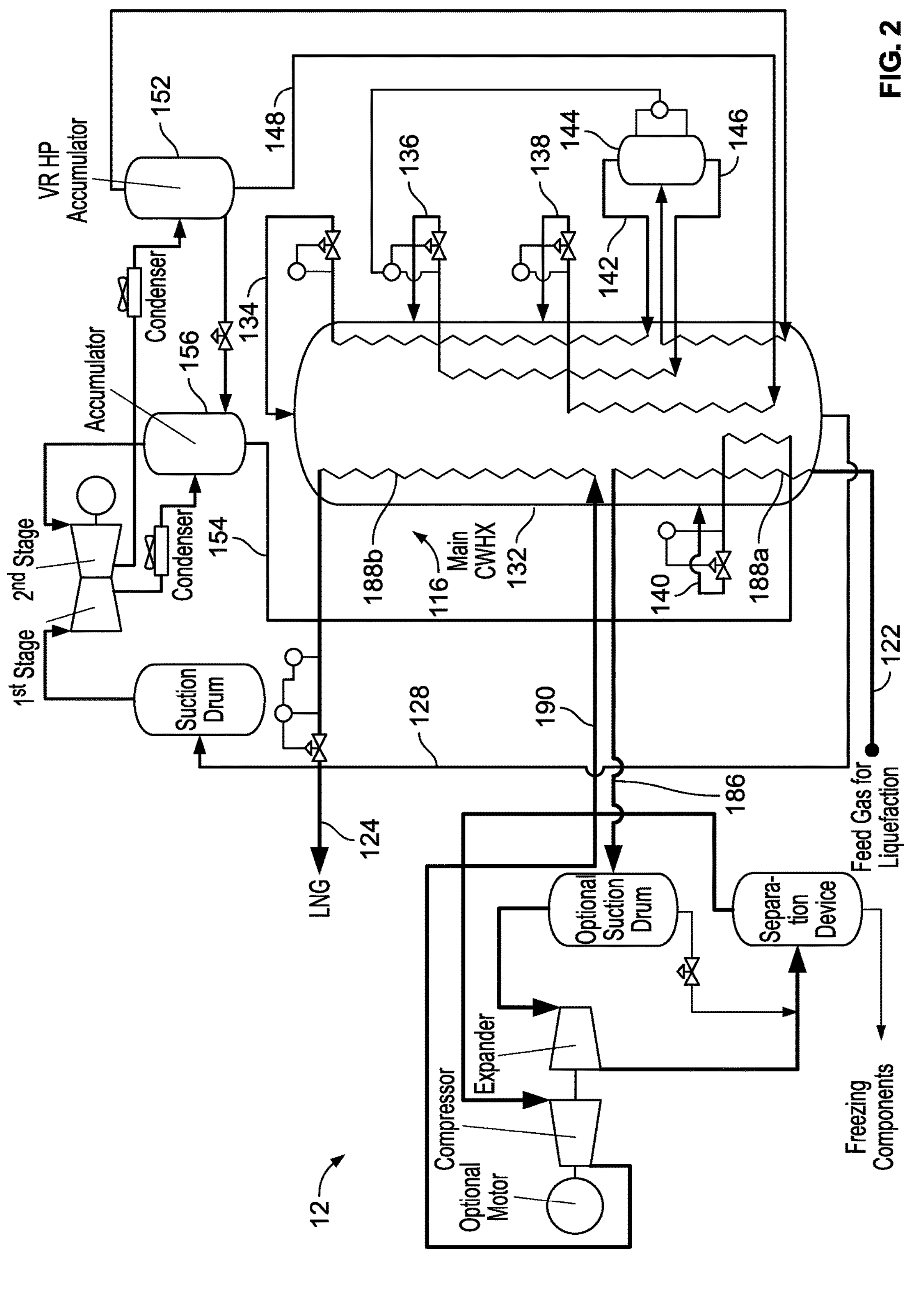

VR HP Accumulator
152
148
144
136
138
146
142
134
Condenser
Accumulator
156
2nd Stage
1st Stage
Condenser
154
188b
116
Main CWHX
132
140
188a
Suction Drum
128
190
122
186
124
LNG
Optional Suction Drum
Separa- tion Device
Feed Gas for Liquefaction
Expander
Compressor
Optional Motor
Freezing Components
12

FIG. 2

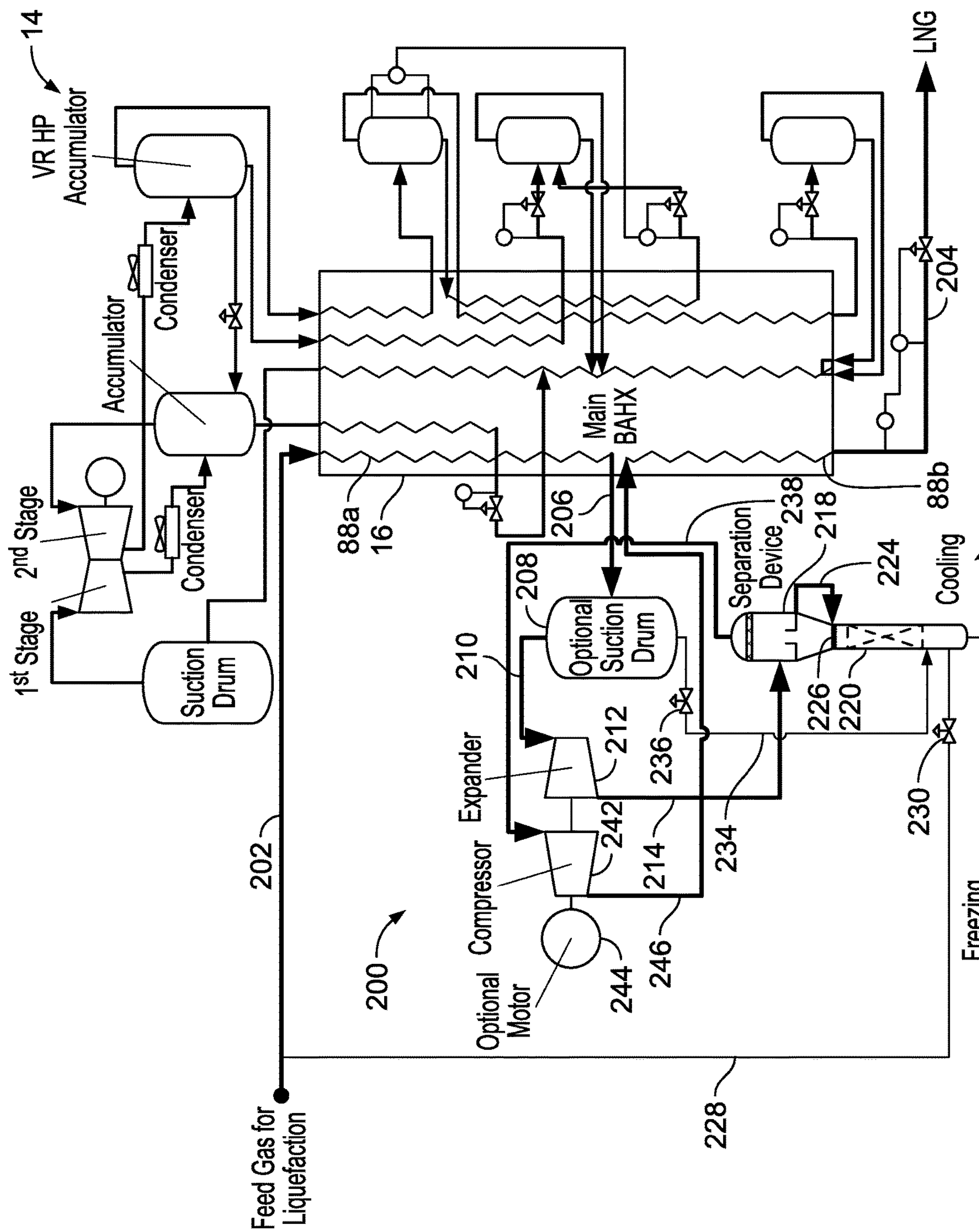
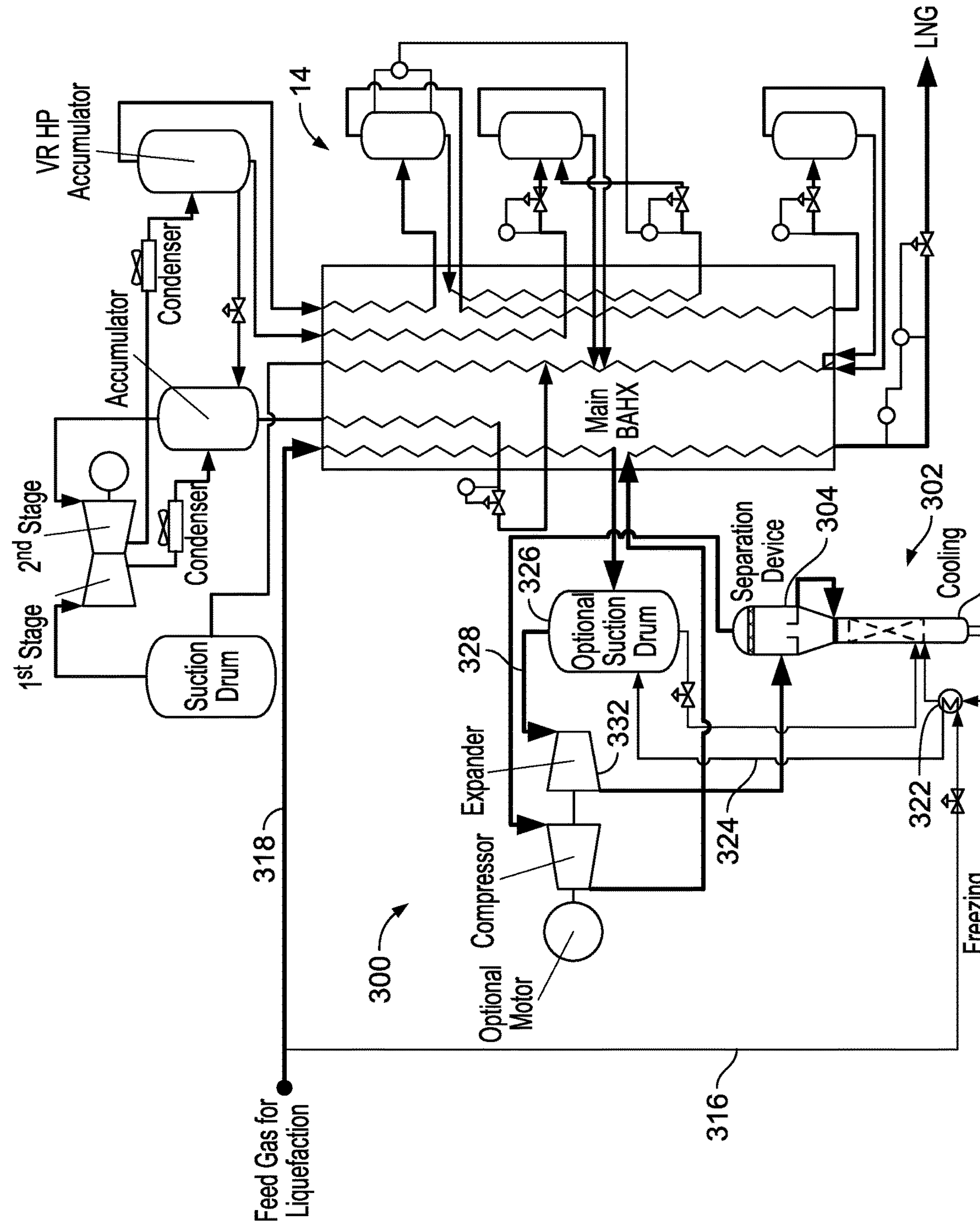

14
VR HP Accumulator
Accumulator
Condenser
Condenser
2nd Stage
1st Stage
Suction Drum
Main BAHX
LNG
88a
16
206
238
88b
216
Separation Device
218
224
Cooling
208
Optional Suction Drum
210
212
236
226
220
232
Expander
242
214
234
230
Compressor
246
244
Optional Motor
200
202
228
Freezing Components
Feed Gas for Liquefaction

FIG. 3



VR HP Accumulator
14
LNG
Accumulator
Condenser
Condenser
2nd Stage
1st Stage
Suction Drum
Main BAHX
302
Separation Device
304
306
Cooling
314
308
322
326
Optional Suction Drum
328
332
324
Expander
Compressor
Optional Motor
300
318
316
Feed Gas for Liquefaction
Freezing Components

FIG. 4

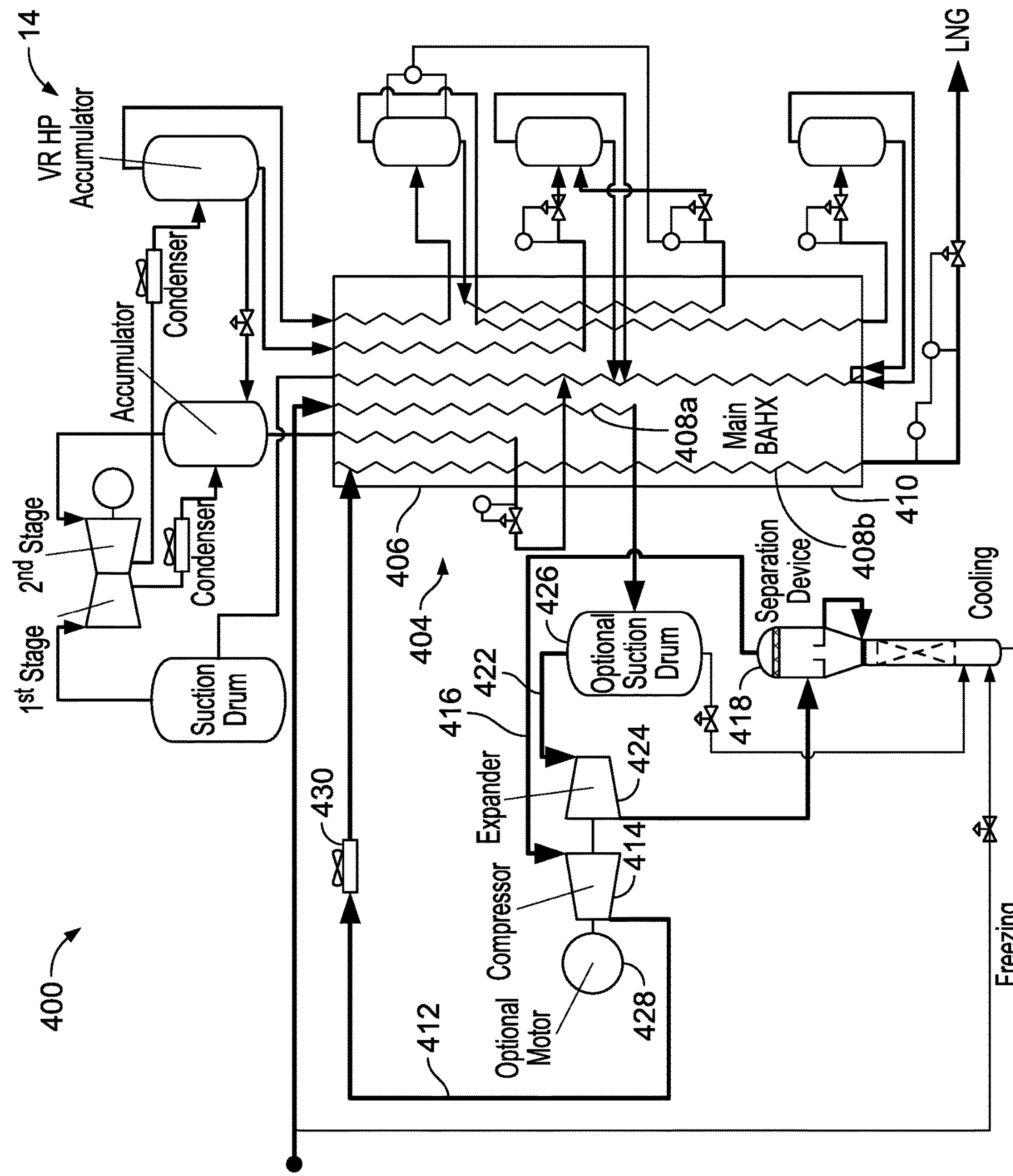

400
14
VR HP Accumulator
Accumulator
Condenser
Condenser
2nd Stage
1st Stage
Suction Drum
LNG
408a
Main BAHX
410
408b
406
404
426
Optional Suction Drum
Separation Device
418
Cooling
422
416
424
Expander
414
Compressor
430
412
Optional Motor
428
Freezing Components

FIG. 5

GAS STREAM COMPONENT REMOVAL SYSTEM AND METHOD

CLAIM OF PRIORITY

This application claims the benefit of U.S. Provisional Application No. 63/034,112, filed Jun. 3, 2020, the contents of which are hereby incorporated by reference.

FIELD OF THE DISCLOSURE

The present invention relates generally to systems and methods for cooling or liquefying gases and, more particularly, to a system and method for removing selected components from such gases.

BACKGROUND

Natural gas is often liquefied under pressure for storage, use and transport. The reduction in volume that results from liquefaction permits containers of more practical and economical design to be used.

Natural gas is typically obtained from underground reservoirs via drilling or similar operations. The resulting natural gas streams, while primarily methane, may contain components such as heavy hydrocarbons (including, for example, butane, ethane, pentane and propane, benzenes, xylenes, heptanes, octanes and heavier components), carbon dioxide, hydrogen, nitrogen and water.

Liquefaction is typically accomplished by chilling the natural gas through indirect heat exchange by one or more refrigeration cycles in one or more heat exchangers. If components such as heavy hydrocarbons are present in a gas stream during liquefaction, such components may freeze and impair operation of the liquefaction heat exchanger. It also may be desirable to recover components as products. In addition, liquid natural gas of higher purity produces less greenhouse gases such as carbon dioxide when it is burned as a fuel.

SUMMARY OF THE DISCLOSURE

There are several aspects of the present subject matter which may be embodied separately or together in the methods, devices and systems described and claimed below. These aspects may be employed alone or in combination with other aspects of the subject matter described herein, and the description of these aspects together is not intended to preclude the use of these aspects separately or the claiming of such aspects separately or in different combinations as set forth in the claims appended hereto

In one aspect, a system for removing selected components from a gas stream includes a heat exchanger having a first cooling passage configured to receive a feed gas stream and to provide a cooled feed gas stream. An expander is configured to receive at least a portion of the cooled feed gas stream. A separation device is configured to receive an expanded fluid stream from the expander and to separate the expanded fluid stream into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature. A compressor is configured to receive the purified vapor stream at approximately the purified vapor temperature and to produce a compressed vapor stream that is returned to the heat exchanger.

In another aspect, a system for liquefying a feed gas includes a heat exchanger having a first cooling passage and a second cooling passage. The first cooling passage is configured to receive a feed gas stream so that a cooled feed gas stream is formed. A mixed refrigerant compression system is in communication with the heat exchanger and configured to cool the first and second cooling passages. A liquefied gas outlet line is connected to an outlet of the second cooling passage. An expander is configured to receive at least a portion of the cooled feed gas stream from the first cooling passage. A separation device is configured to receive an expanded fluid stream from the expander and to separate the expanded fluid stream into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature. A compressor is configured to receive the purified vapor stream at approximately the purified vapor temperature and to produce a compressed vapor stream. The second cooling passage is configured to receive and liquefy the compressed vapor stream.

In still another aspect, a process is provided for removing selected components from a gas stream and includes the steps of cooling a feed gas stream to provide a cooled feed gas stream, expanding the cooled feed gas stream to provide an expanded gas stream, separating the expanded gas stream into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature; and compressing the purified vapor stream to provide a compressed vapor stream.

In yet another aspect, a method of liquefying a gas feed stream includes the steps of cooling a gas feed gas stream to provide a cooled feed gas stream, expanding the cooled feed gas stream to provide an expanded gas stream, separating the expanded gas stream into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature, compressing the purified vapor stream to provide a compressed vapor stream and cooling the compressed vapor stream to form a liquefied gas stream.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a process flow diagram and schematic illustrating a first embodiment of the system of the disclosure;

FIG. **2** is a process flow diagram and schematic illustrating a second embodiment of the system of the disclosure;

FIG. **3** is a process flow diagram and schematic illustrating a third embodiment of the system of the disclosure;

FIG. **4** is a process flow diagram and schematic illustrating a fourth embodiment of the system of the disclosure;

FIG. **5** is a process flow diagram and schematic illustrating a fifth embodiment of the system of the disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

Mixed refrigerant liquefaction systems and methods including embodiments of the component removal system of the disclosure are illustrated in FIGS. **1-5**. It should be noted that while the embodiments are illustrated and described below in terms of systems for removing freezing components and liquefying natural gas to produce liquid natural gas, the technology of the disclosure may be used with systems that liquefy or cool other types of gases. In addition, the technology of the disclosure may be used to perform separation of any selected components that freeze or condense out at temperatures warmer that the final desired liquid natural gas or other product temperature, but colder than the inlet temperature of the gas stream.

With reference to FIG. **1**, a system including an embodiment of the component removal system of the disclosure is indicated in general at **10**. The system includes a selected component removal system, indicated in general at **12** integrated into a liquefaction system, indicated in general at **14**. The basic liquefaction system, including a mixed refrigerant compressor system, may be, as examples only, as described in commonly owned U.S. Pat. No. 9,441,877 to Gushanas et al. or U.S. Pat. No. 10,480,851 to Ducote, Jr. el., the contents of each of which are hereby incorporated by reference.

Generally, with reference to FIG. **1**, the system includes a multi-stream main heat exchanger, indicated in general at **16**, having a warm end portion **18** and a cold end portion **20**. The heat exchanger receives a high pressure natural gas feed stream **22** that is cooled and liquefied in the main heat exchanger via removal of heat via heat exchange with refrigeration streams. As a result, a product stream **24** of liquid natural gas (LNG) is produced. The multi-stream design of the heat exchanger allows for convenient and energy-efficient integration of several streams into a single heat exchanger. Suitable heat exchangers, such as a brazed aluminum heat exchanger (BAHX), may be purchased from Chart Energy & Chemicals, Inc. of Ball Ground, Georgia. The plate and fin multi-stream heat exchanger available from Chart Energy & Chemicals, Inc. offers the further advantage of being physically compact.

Alternative designs and types of heat exchangers may be substituted for the BAHX illustrated at **16** in FIG. **1**.

The system of FIG. **1**, including heat exchanger **16**, may be configured to perform other gas processing options known in the art. These processing options may require the gas stream to exit and reenter the heat exchanger one or more times and may include, as described in further detail below, selected component removal and natural gas liquids recovery.

The removal of heat is accomplished in the heat exchanger using a mixed refrigerant that is processed and reconditioned using a mixed refrigerant compressor system indicated in general at **26**. The mixed refrigerant compressor system includes a high pressure accumulator **32** that receives and separates a mixed refrigerant (MR) mixed-phase stream **34** after a last compression and cooling cycle. While an accumulator drum **32** is illustrated, alternative separation devices may be used, including, but not limited to, another type of vessel, a cyclonic separator, a distillation unit, a coalescing separator or mesh or vane type mist eliminator. High pressure vapor refrigerant stream **36** exits the vapor outlet of the accumulator **32** and travels to the warm end portion **18** of the heat exchanger **16**.

High pressure liquid refrigerant stream **38** exits the liquid outlet of accumulator **32** and also travels to the warm end of the heat exchanger. After cooling in the heat exchanger, it travels as mixed phase stream **40** to mid-temp standpipe **42**.

After the high pressure vapor stream **36** from the accumulator **32** is cooled in the heat exchanger **16**, a mixed phase stream **44** flows to a cold vapor separator **46**. A resulting vapor refrigerant stream **48** exits the vapor outlet of the separator **46** and, after cooling in the heat exchanger **16**, travels to cold temperature standpipe **52** as mixed-phase stream **54**. Vapor and liquid streams **56** and **58** exit the cold temperature standpipe **52** and feed into the primary refrigeration passage **62** at the cold end **20** of the heat exchanger **16**.

A vaporized mixed refrigerant stream **63** exits the warm end **18** of the heat exchanger and, after passing through an optional suction drum **65**, is directed to the inlet of a compressor of an initial compression and cooling cycle.

A liquid stream **64** exits the cold vapor separator **46**, is cooled in heat exchanger **16** and exits the heat exchanger as mixed-phase stream **66**. Mixed phase stream **66** is directed to the mid-temp standpipe **42** and combined with the mixed phase stream **40** from the liquid outlet of accumulator **32**. Vapor and liquid streams **72** and **74** exit the mid-temp standpipe and feed into the primary refrigeration passage **62** as illustrated.

An interstage separation device **76** receives and separates a mixed refrigerant mixed-phase stream **78** after the initial compression and cooling cycle. While a separation drum **76** is illustrated, alternative separation devices may be used, including, but not limited to, another type of vessel, a cyclonic separator, a distillation unit, a coalescing separator or mesh or vane type mist eliminator. A liquid stream **82** exits the liquid outlet of the interstage separation device, is cooled in heat exchanger **16**, and the resulting stream **84** is expanded and directed to the primary refrigeration passage **62**. A vapor stream **85** exits a vapor outlet of the interstage separation device and travels to the last compression and cooling cycle of the compression system. In alternative embodiments of the system, the interstage separation device may include only a vapor outlet, or it may be eliminated entirely.

In accordance with the disclosure, the component removal system **12** receives a cooled gas feed stream **86**, which is produced by cooling feed gas stream **22** in a first cooling passage **88***a* of the main heat exchanger **16**.

Cooled feed gas stream **86**, after withdrawal from the main heat exchanger **16**, is directed to an optional suction drum **92**. A vapor stream **94** from the suction drum travels to an expander **96**, which is preferably an expansion turbine, so that the gas stream pressure is reduced below the critical pressure. This causes the components that would freeze and/or other components that would condense in the main heat exchanger to condense so that a mixed-phase stream **98** is formed. This mixed-phase stream **98** travels to a separation device **102**, where a liquid stream **104** containing the condensed freezing components and other selected components is withdrawn from the bottom.

While an expansion turbine is illustrated as the expander **96**, alternative expansion devices including, but not limited to, expansion valves or orifices could be used.

Any liquid collected in the suction drum **92** may be directed to the mixed phase stream **98** traveling to the separation device by opening a drain valve **106** in a liquid drain line **108** exiting the bottom of the suction drum. This prevents potential damage to the expander **96**. Alternatively, the liquid from the suction drum may go directly into the separation device **102** after exiting valve **106**.

As indicated above, the suction drum **92**, and thus liquid line **108** and drain valve **106**, is optional and thus may be omitted with the feed stream withdrawn from the main heat exchanger being routed directly to the inlet of the expander **96**. Or, in an alternative embodiment, the stream routed to the inlet of the expander **96** may be slightly heated (such as by a passage through a portion of the heat exchanger **16** or a dedicated heat exchanger) to vaporize any liquid in the stream or hot gas bypass of the feed gas.

A purified methane-rich vapor stream **112** exits the top of the separation device **102** at a purified vapor temperature and is directed to a compressor (or compressors) **114**, which may be powered by the expander **96** (in versions of the system where the expander is a turbine) or a motor **115**, or a combination of both. Use of the expander to power the compressor recovers energy from the high pressure gas stream received by the expander.

The ideal pressure for optimal efficiency for the stream returning to the heat exchanger for liquefaction (the "return pressure") is a pressure corresponding to a temperature (the "return temperature") that is nearly equal to the temperature of the suction drum or stream exiting heat exchanger passage **88***a*. By receiving the vapor stream **112** at the purified vapor temperature (or at approximately the purified vapor temperature due to potential incidental warming of the purified vapor stream as it flows from the separation device **102** to the compressor inlet), the compressor **114** "cold compresses" the vapor stream **112** to a higher pressure and a temperature, where the temperature of the compressed stream is approximately equal to or slightly below the temperature of the vapor in the suction drum **92** or the cooled gas stream **86** withdrawn from the main heat exchanger. The return temperature of the vapor stream **118** exiting the compressor is ideally near or below the temperature of the gas in the suction drum **92** (or stream **86**) because the system does not heat the vapor exiting the separation device **102** prior to entry into the compressor **114**. Furthermore, by having cold vapor enter the compressor **114**, the pressure of the vapor exiting the compressor is higher and the temperature is lower than if the vapor from the separation device **102** was heated prior to entry into the compressor (for the same compressor power level). As a result, the refrigeration power required for a given level of liquid natural gas production is reduced or, conversely, a higher liquid natural gas production is obtained if the refrigeration power is fixed. The compressed vapor stream **118** is returned to a second cooling passage **88***b* of the heat exchanger **16** at a return pressure and a return temperature to be liquefied so that LNG product stream **24** is produced.

While first and second cooling passages **88***a* and **88***b* of FIG. **1** are illustrated as being part of a single heat exchanger **16**, in alternative embodiments, the passages **88***a* and **88***b* may be incorporated into separate heat exchangers that are arranged in series. In addition, passages running parallel to passage **88***a* may be formed in the same or in additional heat exchangers. The same applies for passage **88***b* (and for passages corresponding to passages **88***a* and **88***b* in the remaining embodiments)

The process shown is for a natural gas liquefaction process, however, the system and process illustrated at **12** may be used with any other process that requires separating at least part of the incoming feed gas at a lower pressure and temperature and benefits from returning the feed gas at a higher pressure.

As illustrated in FIG. **2**, the component removal system **12** of FIG. **1** may be implemented as part of a liquefaction process that uses a coil wound heat exchanger (CWHX), indicated in general at **116**. Such heat exchangers are well known in the art and, as examples only, may be purchased from Linde plc of Dublin, Ireland, or Air Products and Chemicals, Inc. of Allentown, Pennsylvania.

As illustrated in FIG. **2**, the heat exchanger **116** receives a high pressure natural gas feed stream **122** that is cooled and liquefied in the main heat exchanger via removal of heat via heat exchange with refrigeration streams. As a result, a product stream **124** of liquid natural gas (LNG) is produced.

A compression system provides mixed refrigerant streams to, and receives a mixed refrigerant stream **128** from, the heat exchanger **116** and conditions the mixed refrigerant in the same manner as compression system **26** of FIG. **1**.

As is known in the art, the CWHX heat exchanger **116** includes a shell **132** that receives the conditioned mixed refrigerant streams **134**, **136**, **138** and **140**. Mixed refrigerant stream **134** is formed by cooling and expanding the vapor stream **142** from the cold vapor separator **144**. Mixed refrigerant stream **136** is formed by cooling and expanding the liquid stream **146** from the cold vapor separator **144**. Mixed refrigerant stream **138** is formed by cooling and expanding the liquid stream **148** from the high pressure accumulator **152**. Mixed refrigerant stream **140** is formed by cooling and expanding the liquid stream **154** from the interstage separation device **156**.

The cooling passages **188***a* and **188***b* of the heat exchanger **116**, and the passages used to cool the mixed refrigerant, are formed by tube bundles wrapped around a core or mandrel and positioned within the shell **132** of the heat exchanger. As a result, the exterior surfaces of the tube bundles are exposed to the mixed refrigerant streams **134**, **136**, **138** and **140** entering the shell.

Similar to the system and process of FIG. **1**, the component removal system **12** receives a cooled gas feed stream **186**, which is produced by cooling feed gas stream **122** in a first cooling passage **188***a* of the main heat exchanger **116**. The cooled gas feed stream **186** is processed in the component removal system **12** in the same manner described above with reference to FIG. **1** and a compressed vapor stream **190** is returned to a second cooling passage **188***b* of the heat exchanger **116** to be liquefied so that LNG product stream **124** is produced.

An alternative embodiment of the component removal system is indicated in general at **200** in FIG. **3**. The liquefaction system **14** operates in the same manner as illustrated in FIG. **1** and therefore also includes a main heat exchanger **16** including first and second cooling passages **88***a* and **88***b*.

As explained below, the component removal system **200** of FIG. **3** uses a stripping gas to remove light components from the freezing components and other selected components so that the light components are added to the LNG product stream.

With reference to FIG. **3**, and as in previous embodiments, a natural gas feed stream **202** is cooled and liquefied in the main heat exchanger **16** via removal of heat via heat exchange with refrigeration streams. As a result, a product stream **204** of liquid natural gas (LNG) is produced.

The component removal system **200** receives a cooled gas feed stream **206**, which is produced by cooling feed gas stream **202** in the first cooling passage **88***a* of the main heat exchanger **16**.

Cooled feed gas stream **206**, after withdrawal from the main heat exchanger **16**, is directed to an optional suction drum **208**. A vapor stream **210** from the suction drum travels to an expander **212**, which is preferably an expansion turbine, so that the gas stream pressure is reduced below the critical pressure. This causes the components that would freeze and/or other selected components that would condense in the main heat exchanger to condense so that a mixed-phase stream **214** is formed. While an expansion turbine is illustrated as the expander **212**, alternative expansion devices including, but not limited to, expansion valves or orifices could be used.

This mixed-phase stream **214** travels to a separation column, indicated in general at **216**. The column **216** includes a separation section **218** and a stripping section **220**. As is known in the art, the stripping section **220** may include mesh pads, trays, packing and similar components.

Mixed-phase stream **214** enters the separation section **218** of the column and is separated into vapor and liquid portions. The liquid portion flows down into the stripping section **220** directly and/or through an internal or external distribution arrangement including, for example, distribution line **224** and distribution device **226**.

A stripping gas is provided through stripping gas line **228** which directs a portion of the feed gas stream **202** to the bottom portion of the stripping section **220** under the control of valve **230**. Alternatively, stripping gas may be withdrawn from stream **88***a* at a colder temperature.

A liquid stream **232** containing the condensed freezing components and other selected components is withdrawn from the bottom of the column **216**.

Any liquid collected in the suction drum **208** may be directed to the stripping section **220** of column **216** by opening a drain valve **236** in a liquid line **234** exiting the bottom of the suction drum. This prevents potential damage to the expander **212**.

The suction drum **208**, and thus liquid line **234** and drain valve **236**, is optional and thus may be omitted with the feed stream withdrawn from the main heat exchanger being routed directly to the inlet of the expander **212**.

A purified methane-rich vapor stream **238** exits the top of the separation column **216** and is directed to a compressor **242**, which may be powered by the expander **212** (in versions of the system where the expander is a turbine) or a motor **244**, or a combination of both. By receiving the vapor stream at the temperature of the separation device, the compressor **242** "cold compresses" the vapor stream **238** to a higher pressure and a temperature, where the temperature of the compressed gas stream is ideally approximately equal to or slightly below the temperature of the vapor in the suction drum **208** or the cooled gas stream **206** withdrawn from the main heat exchanger. The outlet temperature of the vapor stream **246** exiting the compressor is near or below the temperature of the gas in the suction drum **208** (or stream **206**) because the system does not heat the vapor exiting the separation column **216** prior to entry into the compressor **242**. Furthermore, by having cold vapor enter the compressor **242**, the pressure of the vapor exiting the compressor is higher than if the vapor from the separation column **216** was heated prior to entry into the compressor (for the same compressor power level). As a result, the refrigeration power required for a given level of liquid natural gas production is reduced or, conversely, a higher liquid natural gas production is obtained if the refrigeration power is fixed. The compressed vapor stream **246** is returned to the second cooling passage **88***b* of the heat exchanger **16** to be liquefied so that LNG product stream **204** is produced.

An alternative version of the system of FIG. **3**, wherein a reboiler service has been added for the stripping section of the separation column, is presented in FIG. **4**. More specifically, a component removal system, indicated in general at **300** in FIG. **4**, includes a separation column **302** which features a separation section **304** and a stripping section **306**. A liquid stream **308** containing the condensed freezing components and other selected components is withdrawn from the bottom of the column **302**. In addition, a reboiler service including reboiler heat exchanger **322** receives a reboiler liquid stream **314** from the stripping section **306** of the column. Heat exchanger **322** also receives and cools a takeoff gas stream **316** that branches off of the primary natural gas feed stream **318** entering the liquefaction system. As a result, the liquid stream **314** from the column is at least partially vaporized and the resulting vapor stream is returned to the stripping section **306** of the column for use as a stripping gas. The cooled takeoff gas stream **324** exits the reboiler heat exchanger **322** and is directed to optional suction drum **326**. In embodiments where the suction drum **326** is omitted, the cooled takeoff gas stream **324** may be combined with the vapor stream **328** that enters the expander **332**. In an alternative embodiment, stream **316** may be replaced by a stream taken off of stream **88***a* (FIG. **1**) or any other heating medium.

The remaining aspects of the contamination system **300**, separation column **302** and the liquefaction system **14** of FIG. **4** operate in the same manner as described above with reference to FIG. **3**

An alternative embodiment of the component removal system is indicated in general at **400** in FIG. **5**. The liquefaction system **14** operates in the same manner as illustrated in FIG. **1**. The remaining aspects of the system of FIG. **5** are the same as the system of FIG. **3** with the exception of the treatment of the outlet stream **412** of the compressor **414**. The treatment of the compressor outlet stream of FIG. **5** may be used in any of the embodiments described above.

The system **400** includes a main heat exchanger **404** including a warm end portion **406**, a cold end portion **410** and first and second cooling passages **408***a* and **408***b*. As illustrated in FIG. **5**, the second cooling passage **408***b* is configured as a high pressure pass that passes at least partially through both the warm and cold end portions **406** and **410** of the heat exchanger.

In the embodiment of FIG. **5**, the compressor suction remains at approximately the purified vapor temperature where, as in previous embodiments, the purified vapor temperature is the temperature of the vapor stream **416** exiting the top of the separation device **418**. The discharge pressure of the compressor, and thus the pressure of stream **412**, is increased (with respect to the embodiments described above) to the point where the stream **412** is warmer than the temperature of the stream **422** entering expander **424** (or optional suction drum **426**). As a result, the gas stream **412** is warmer than in the previous embodiments, and thus the stream **412** is directed to the high pressure gas pass **408***b*. In this embodiment, power to the compressor by optional motor **428** may be required (either by itself or in addition to power provided by the expander turbine **424**). In addition, an optional compressor discharge conditioning heat exchanger **430** may be provided to condition (which may be either cooling or heating) stream **412** and provide heat integration with the liquefaction, condensate system or other processes prior to entry into the heat exchanger.

The component removal system embodiments presented above recompress a gas from a separation device, wherein selected components are removed from the gas, without warming the gas such that the compressor suction is cold, that is, at the temperature of the separation device. Power required for compression and discharge temperature of the compressor are proportional to the suction temperature. Therefore, compressing cold allows the compressor discharge pressure to be higher and the temperature to be lower than if the suction was warmed first, with the fixed power available, and the desired return temperature and return pressure to the main heat exchanger. As a result, the refrigeration power required for a given level of liquid natural gas production is reduced or, conversely, a higher liquid natural gas production is obtained if the refrigeration power is fixed.

While the preferred embodiments of the invention have been shown and described, it will be apparent to those skilled in the art that changes and modifications may be made therein without departing from the spirit of the invention, the scope of which is defined by the appended claims.

What is claimed is:

1. A system for removing selected components from a gas stream comprising:

a. a heat exchanger including a first cooling passage configured to receive a feed gas stream and to provide a cooled feed gas stream;

b. an expander configured to receive at least a portion of the cooled feed gas stream;

c. a separation device having a separation device vapor outlet, said separation device configured to receive an expanded fluid stream from the expander and to separate the expanded fluid stream into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature; and

d. a compressor configured to receive the purified vapor stream directly from the separation device vapor outlet at approximately the purified vapor temperature and to produce a compressed vapor stream that is returned to the heat exchanger, wherein the compressed vapor stream is compressed to a pressure corresponding to a temperature that is approximately equal to a temperature of the cooled gas stream.

2. The system of claim **1** further comprising a second cooling passage configured to receive the compressed vapor stream and wherein the heat exchanger includes a single main heat exchanger including the first and second cooling passages.

3. The system of claim **1** further comprising a second cooling passage configured to receive the compressed vapor stream and wherein the heat exchanger includes a first heat exchanger including the first cooling passage and a second heat exchanger including the second cooling passage.

4. The system of claim **1** further comprising a second cooling passage configured to receive the compressed vapor stream, a third cooling passage arranged in parallel with the first cooling passage so that the first and third cooling passages receive the feed gas stream and provide a cooled feed gas stream to the expander and a fourth cooling passage arranged in parallel with the second cooling passage so that the second and fourth cooling passages receive the compressed vapor stream.

5. The system of claim **4** wherein the first and second cooling passages are in a first heat exchanger and the third and fourth cooling passages are in a second heat exchanger.

6. The system of claim **1** further comprising a conditioning heat exchanger configured to receive compressed vapor from the compressor and to direct conditioned compressed vapor to the heat exchanger.

7. The system of claim **1** further comprising a suction drum configured to receive the cooled feed gas stream from the heat exchanger first cooling passage, said suction drum having a suction drum vapor outlet configured to direct at least a portion of the cooled feed gas stream to the expander.

8. The system of claim **7** wherein the suction drum has a suction drum liquid outlet and further comprising a liquid drain line configured to direct a fluid stream to the separation device.

9. The system of claim **1** wherein the expander is an expansion turbine and the compressor is powered by the expansion turbine.

10. The system of claim **1** wherein the separation device includes a separation column having a separation section and a stripping section wherein the separation section is configured to receive the expanded fluid stream from the expander, direct liquid to the stripping section and direct the purified vapor stream to the compressor and the contaminant liquid stream exits the stripping section;

and further comprising a stripping gas line configured to receive a portion of the feed gas stream and to direct the portion of the feed gas stream to the stripping section for use as a stripping gas.

11. The system of claim **10** wherein the stripping gas line includes an inlet configured to receive fluid from the first cooling passage of the heat exchanger.

12. The system of claim **10** further comprising a suction drum configured to receive the cooled feed gas stream from the heat exchanger first cooling passage, said suction drum having a suction drum vapor outlet configured to direct at least a portion of the cooled feed gas stream to the expander and a suction drum liquid outlet configured to direct a fluid stream to the stripping section.

13. The system of claim **1** wherein the separation device includes a separation column having a separation section and a stripping section wherein the separation section is configured to receive the expanded fluid stream from the expander, direct liquid to the stripping section and direct the purified vapor stream to the compressor and wherein the liquid stream containing the selected components exits the stripping section;

and further comprising:

a reboiler heat exchanger configured to receive a reboiler liquid stream from the stripping section to at least partially vaporize the reboiler liquid stream and to direct a resulting stripping gas stream to the stripping section.

14. The system of claim **13** further comprising a takeoff gas line configured to receive a portion of the feed gas stream and to direct the portion of the feed gas stream to the reboiler heat exchanger wherein the portion of the feed gas stream is cooled as the reboiler liquid stream is warmed and vaporized and wherein the reboiler heat exchanger is configured to direct at least a portion of the cooled portion of the feed gas stream to the expander.

15. The system of claim **1** further comprising a second cooling passage configured to receive the compressed vapor stream, wherein the first and second cooling passages are positioned within the heat exchanger in a parallel configuration.

16. The system of claim **15** wherein the heat exchanger includes a warm end portion and a cold end portion with the second cooling passage forming a high pressure pass that passes at least partially through both the warm and cold end portions of the heat exchanger and wherein the first cooling passage passes through at least a portion of the warm end portion of the heat exchanger.

17. The system of claim **16** further comprising a conditioning heat exchanger configured to receive compressed vapor from the compressor and to direct conditioned compressed vapor to the high pressure pass.

18. A system for liquefying a feed gas comprising:

a. a heat exchanger having a first cooling passage and a second cooling passage, said first cooling passage configured to receive a feed gas stream at a feed gas stream temperature so that a cooled feed gas stream is formed;

b. a mixed refrigerant compression system in communication with the heat exchanger and configured to cool the first and second cooling passages;

c. a liquefied gas outlet line connected to an outlet of the second cooling passage;

d. an expander configured to receive at least a portion of the cooled feed gas stream from the first cooling passage;

e. a separation device having a separation device vapor outlet, said separation device configured to receive an expanded fluid stream from the expander and to separate the expanded fluid stream into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature;

f. a compressor configured to receive the purified vapor stream directly from the separation device vapor outlet at approximately the purified vapor temperature and to produce a compressed vapor stream, wherein the compressed vapor stream is compressed to a pressure corresponding to a temperature that is approximately equal to a temperature of the cooled gas stream;

g. said second cooling passage configured to receive and liquefy the compressed vapor stream;

h. wherein the separation device includes a separation column having a separation section and a stripping section wherein the separation section is configured to receive the expanded fluid stream from the expander, direct liquid to the stripping section and direct the purified vapor stream to the compressor and wherein the liquid stream containing selected components exits the stripping section; and

i. a stripping gas line configured to receive a vapor portion of the feed gas stream at the feed gas stream temperature and to direct the portion of the feed gas stream to the stripping section for use as a stripping gas.

19. The system of claim **18** wherein the heat exchanger includes a single main heat exchanger including the first and second cooling passages.

20. The system of claim **18** wherein the heat exchanger includes a first heat exchanger including the first cooling passage and a second heat exchanger including the second cooling passage.

21. The system of claim **18** further comprising a third cooling passage arranged in parallel with the first cooling passage so that the first and third cooling passages receive the feed gas stream and provide a cooled feed gas stream to the expander and a fourth cooling passage arranged in parallel with the second cooling passage so that the second and fourth cooling passages receive and liquefy the compressed vapor stream.

22. The system of claim **21** wherein the first and second cooling passages are in a first heat exchanger and the third and fourth cooling passages are in a second heat exchanger.

23. The system of claim **18** further comprising a conditioning heat exchanger configured to receive compressed vapor from the compressor and to direct conditioned compressed vapor to the heat exchanger.

24. The system of claim **18** further comprising a suction drum configured to receive the cooled feed gas stream from the heat exchanger first cooling passage, said suction drum having a suction drum vapor outlet configured to direct at least a portion of the cooled feed gas stream to the expander.

25. The system of claim **24** wherein the suction drum has a suction drum liquid outlet and further comprising a liquid drain line configured to direct a fluid stream to the separation device.

26. The system of claim **18** wherein the expander is an expansion turbine and the compressor is powered by the expansion turbine.

27. The system of claim **18** wherein the stripping gas line includes an inlet configured to receive fluid from the first cooling passage of the heat exchanger.

28. The system of claim **18** further comprising a suction drum configured to receive the cooled feed gas stream from the heat exchanger first cooling passage, said suction drum having a suction drum vapor outlet configured to direct at least a portion of the cooled feed gas stream to the expander and a suction drum liquid outlet configured to direct a fluid stream to the stripping section.

29. The system of claim **18** further comprising:

a reboiler heat exchanger configured to receive a reboiler liquid stream from the stripping section to warm and at least partially vaporize the reboiler liquid stream and to direct a resulting stripping gas stream to the stripping section; and

a takeoff gas line configured to receive a portion of the feed gas stream and to direct the portion of the feed gas stream to the reboiler heat exchanger wherein the portion of the feed gas stream is cooled as the reboiler liquid stream is warmed and partially vaporized and wherein the reboiler heat exchanger is configured to direct at least a portion of the cooled portion of the feed gas stream to the expander.

30. The system of claim **18** wherein the heat exchanger includes a warm end portion and a cold end portion with the second cooling passage forming a high pressure pass that passes at least partially through both the warm and cold end portions of the heat exchanger and wherein the first cooling passage passes through at least a portion of the warm end portion of the heat exchanger.

31. The system of claim **30** further comprising a conditioning heat exchanger configured to receive compressed vapor from the compressor and to direct conditioned compressed vapor to the high pressure pass.

32. A method for removing selected components from a gas stream comprising the steps of:

a. cooling a feed gas stream to provide a cooled feed gas stream;

b. expanding the cooled feed gas stream to provide an expanded gas stream;

c. separating the expanded gas stream using a separation device having a separation device vapor outlet into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature; and

d. compressing the purified vapor stream using a compressor after the compressor receives the purified vapor stream directly from the separation device vapor outlet at approximately the purified vapor temperature to provide a compressed vapor stream, wherein the compressed vapor stream is compressed to a pressure corresponding to a temperature that is approximately equal to a temperature of the cooled gas stream.

33. The method of claim **32** wherein the gas stream is a natural gas stream.

34. A method of liquefying a gas feed stream comprising the steps of:

a. cooling a gas feed gas stream to provide a cooled feed gas stream;

b. expanding the cooled feed gas stream to provide an expanded gas stream;

c. separating the expanded gas stream using a separation device having a separation device vapor outlet into a liquid stream containing selected components and a purified vapor stream having a purified vapor temperature;

d. compressing the purified vapor stream using a compressor after the compressor receives the purified vapor stream directly from the separation device vapor outlet at approximately the purified vapor temperature to provide a compressed vapor stream, wherein the compressed vapor stream is compressed to a pressure corresponding to a temperature that is approximately equal to a temperature of the cooled gas stream; and

e. cooling the compressed vapor stream to form a liquefied gas stream.

35. The method of claim **34** wherein the gas stream is a natural gas stream.

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