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Inventor(s)	Vipperla; Ravikumar et al.

Cryogenic Carbon Capture System and Method with Integrated Liquid Natural Gas Vaporizer

Abstract

A desublimating heat exchanger receives a cooled process gas stream from a pre-cool heat exchanger and includes a clean gas outlet, a contact liquid inlet and a slurry outlet. A contact liquid heat exchanger communicates with the contact liquid inlet of the desublimation heat exchanger and warms a liquid natural gas stream to provide cooling within the contact liquid heat exchanger. The desublimating heat exchanger contacts the cooled process gas stream with the cooled contact liquid so that carbon dioxide is absorbed within the contact liquid whereby a carbon dioxide laden slurry stream and a carbon dioxide depleted clean process gas stream are formed. The clean process gas stream passes through the clean gas outlet to the pre-cool heat exchanger and the slurry stream passes through the slurry outlet. The pre-cool heat exchanger warms the clean process gas stream to provide cooling for the process gas stream. A solid separation device communicates with the contact inlet of the desublimating heat exchanger and separates the carbon dioxide laden slurry stream from the desublimating heat exchanger into a condensed carbon dioxide stream and a contact liquid stream.

Inventors: **Vipperla; Ravikumar (Katy, TX), Hoeger; Christopher (Orem, UT), Baxter; Larry (Orem, UT)**

Applicant: **Chart Energy & Chemicals, Inc.** (Ball Ground, GA)

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Background/Summary

CLAIM OF PRIORITY [0001] This application claims the benefit of U.S. Provisional Application No. 63/553,399, filed Feb. 14, 2024, the contents of which are hereby incorporated by reference.

FIELD OF THE DISCLOSURE
[0002] The present disclosure relates generally to systems and methods for purifying gases and, more particularly, to a system and method that integrates cryogenic carbon capture with liquid natural gas vaporization.
BACKGROUND
[0003] Gas purification of carrier or feed gases has been an important process in industry for many years. An example is the processing of combustion flue gases. Combustion flue gas consists of the exhaust gas from a fireplace, oven, furnace, boiler, steam generator, or other combustor. The combustion fuel sources include coal, natural gas, liquid hydrocarbons, black liquor and biomass. Combustion flue gas varies greatly in composition depending on the method of combustion and the source of fuel. Combustion using air leads to most of the flue gas consisting of nitrogen. The non-nitrogen flue gas consists of mostly carbon dioxide (or CO.sub.2), water, and unconsumed oxygen. Small amounts of carbon monoxide, nitrogen oxides, sulfur dioxide, and trace amounts of hundreds of other chemicals are present, depending on the source. Entrained dust and soot will also be present in most combustion flue gas streams.
[0004] The separation of carbon dioxide from light gases such as nitrogen is called carbon capture and is important for reducing CO.sub.2 emissions and their associated environmental impacts. It is commonly believed that this CO.sub.2 represents a significant factor in increasing the greenhouse effect and global warming. Therefore, there is a clear need for efficient methods of capturing CO.sub.2 from flue gases to produce a concentrated stream of CO.sub.2 that can readily be transported to a safe storage site or to a further application.
[0005] Natural gas is often liquefied for storage and transport because the liquefaction reduces the volume of the fluid and lowers storage and handling equipment costs. After the resulting liquid natural gas (LNG) reaches its use point, however, it typically must be vaporized for use as natural gas.
[0006] It has been recognized in the prior art that the heat required for vaporizing LNG may be provided by cryogenic carbon capture systems. More specifically, with reference to FIG. **1**, LNG from a storage tank **10** may be provided, either directly or by pump **12**, to a cryogenic carbon capture system **14**. The cryogenic carbon capture system **14** receives flue gas **16**, which contains CO.sub.2 and light gases such as nitrogen, from a combustion source. The cryogenic carbon capture system **14** uses the refrigeration provided by the LNG to separate the flue gas **16** into a CO.sub.2 stream **18** and a light gases stream **20**. The resulting vaporized natural gas exits the cryogenic carbon capture system **14** as stream **22**. If stream **22** is not fully vaporized, additional heating may be provided by a heat exchanger **24**. Furthermore, or alternatively, the natural gas fluid

stream may be expanded via expansion device **26** to reduce the pressure of the stream. A system that integrates cryogenic carbon capture and LNG vaporization is disclosed in commonly owned U.S. Pat. No. 9,410,736 to Baxter, the contents of which are hereby incorporated by reference.
[0007] New technologies that integrate cryogenic carbon capture with LNG vaporization to provide efficiency and/or cost advantages are desirable.
SUMMARY OF THE DISCLOSURE
[0008] 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.
[0009] In one aspect, a system for separating carbon dioxide from a process gas includes a pre-cool heat exchanger configured to receive and cool a process gas stream so that a cooled process gas stream is formed. A desublimating heat exchanger includes a process gas inlet configured to receive the cooled process gas stream from the pre-cool heat exchanger, a clean gas outlet, a contact liquid inlet and a slurry outlet. A contact liquid heat exchanger is in fluid communication with the contact liquid inlet of the desubimation heat exchanger and is configured to receive and warm a liquid natural gas stream to provide cooling within the contact liquid heat exchanger. The desublimating heat exchanger is configured to contact the cooled process gas stream received from the pre-cool heat exchanger with contact liquid cooled by the contact liquid heat exchanger so that carbon dioxide is absorbed within the contact liquid whereby a carbon dioxide laden slurry stream and a carbon dioxide depleted clean process gas stream are formed. The clean process gas stream directed through the clean gas outlet to the pre-cool heat exchanger and the slurry stream directed through the slurry outlet. The pre-cool heat exchanger is configured to warm the clean process gas stream to provide cooling for the process gas stream. A solid separation device is in fluid communication with the contact liquid inlet of the desublimation heat exchanger and is configured to receive the carbon dioxide laden slurry stream from the slurry outlet of the desublimating heat exchanger and to separate the slurry stream into a condensed carbon dioxide stream and a contact liquid stream.
[0010] In another aspect, a system for separating carbon dioxide from a process gas includes a pre-cool heat exchanger configured to receive and cool a process gas stream so that a cooled process gas stream is formed. A desublimating heat exchanger includes a process gas inlet configured to receive the cooled process gas stream from the pre-cool heat exchanger, a clean gas outlet, a contact liquid inlet and a slurry outlet. A solid separation device is configured to direct a contact liquid to the contact liquid inlet of the desublimating heat exchanger. The desublimating heat exchanger is configured to contact the cooled process gas stream received from the pre-cool heat exchanger with contact liquid from the solid separation device so that carbon dioxide is absorbed within the contact liquid whereby a carbon dioxide laden slurry stream and a carbon dioxide depleted clean process gas stream are formed. The clean process gas stream is directed through the clean gas outlet to the pre-cool heat exchanger and the slurry stream is directed through the slurry outlet to a contact liquid heat exchanger. The pre-cool heat exchanger is configured to warm the clean process gas stream to provide cooling for the process gas stream. The contact liquid heat exchanger is configured to receive and warm a liquid natural gas stream to cool the slurry stream. The contact liquid heat exchanger is also configured to direct the cooled slurry stream to the solid separation device. The solid separation device is configured to separate the carbon dioxide laden slurry stream into a condensed carbon dioxide stream and a contact liquid stream.
[0011] In another aspect, a method for separating carbon dioxide from a process gas includes the steps of: pre-cooling a process gas stream by warming a clean process gas stream so that a cooled process gas stream is formed; cooling a contact liquid by warming a liquid natural gas stream so

that a cooled contact liquid stream is formed; contacting the cooled process gas stream with the cooled contact liquid stream so that carbon dioxide is absorbed within the contact liquid whereby a carbon dioxide laden slurry stream and a carbon dioxide depleted clean process gas stream are formed, where the clean process gas stream is warmed to cool the process gas stream, and separating the slurry stream into a condensed carbon dioxide stream and a contact liquid stream.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is a simplified process flow diagram illustrating the primary components of a prior art cryogenic carbon capture system integrated with a liquid natural gas vaporization system.

[0013] FIG. **2** is a simplified process flow diagram illustrating the primary components of an embodiment of the system of the disclosure.

[0014] FIG. **3** is a simplified process flow diagram of the system of FIG. **2** with an additional heater for the LNG stream.

[0015] FIG. **4** is a simplified process flow diagram of the system of FIG. **3** where the contact liquid is routed through the additional heat exchanger.

[0016] FIG. **5** is a process flow diagram and schematic of an embodiment of the system of the disclosure.

[0017] FIG. **6** is a process flow diagram and schematic of an alternative embodiment of the system of the disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0018] It should be noted herein that the lines, conduits, piping, passages and similar structures and the corresponding streams are sometimes both referred to by the same element number set out in the figures.

[0019] Also, as used herein, and as known in the art, a heat exchanger is that device or an area in the device wherein indirect heat exchange occurs between two or more streams at different temperatures, or between a stream and the environment. In addition, all heat exchangers referenced herein may be incorporated into one or more heat exchanger devices or may each be individual heat exchanger devices. As used herein, the terms “communication”, “communicating”, and the like generally refer to fluid communication unless otherwise specified. And although two fluids in communication may exchange heat upon mixing, such an exchange would not be considered to be the same as heat exchange in a heat exchanger, although such an exchange can take place in a heat exchanger.

[0020] As used herein, the terms, “high”, “middle”, “warm”, “cold” and the like are relative to comparable streams, as is customary in the art.

[0021] Any column or tower referenced in the following description may, as non-limiting examples only, be a spray tower, a packed column, and/or a trayed column.

[0022] Reference numerals that are introduced in the specification in association with a drawing figure may be repeated in one or more subsequent figures for shared elements or components without additional description in the specification in order to provide context for other features.

[0023] In the claims, letters are used to identify claimed steps (e.g. a., b. and c.). These letters are used to aid in referring to the method steps and are not intended to indicate the order in which the claimed steps are performed, unless and only to the extent that such order is specifically recited in the claims.

[0024] Embodiments of the process and method of the disclose separate a CO.sub.2-containing process gas stream into a liquid-phase CO.sub.2 stream of arbitrary purity (including beverage-grade CO.sub.2) and a CO.sub.2-depleted stream containing the remaining light gases. The light gases could include N.sub.2, O.sub.2, and Ar in the case of treating a flue gas stream, H.sub.2, CO and possibly CH_4 in the case of treating a producer gas or syngas stream, and H_2 in the case of treating a hydrogen production stream.

[0025] In an embodiment of the system and method of the disclosure illustrated in FIG. **2**, a stream of LNG from a storage tank **40** may be provided, either directly or by pump **42**, to a cryogenic carbon capture system **44**. While a storage tank is illustrated for the LNG, the cryogenic capture system **44** may receive the LNG from another source or type of storage.

[0026] The cryogenic carbon capture system **44** receives flue gas **46**, which contains CO_2 and light gases such as nitrogen, from a combustion source. As explained in greater detail below, the cryogenic carbon capture system **44** uses the refrigeration provided by the LNG to separate the flue gas **46** into a CO_2 stream **48** and a light gases stream **50**. The resulting vaporized natural gas exits the cryogenic carbon capture system **44** as stream **52**. If stream **52** is not fully vaporized, additional heating may be provided by a heat exchanger **54**. Furthermore, or alternatively, a natural gas fluid stream may be expanded via expansion device **56** to reduce the pressure of the stream. As an example only, the expansion device **56** may be a turbine.

[0027] In the cryogenic carbon capture system **44** of FIG. **2**, flue gas stream **46**, after initial processing including cooling which may use the LNG, travels to a direct-contact desublimating heat exchanger where CO_2 is captured by further cooling using a cryogenic contacting liquid stream **62** to the temperature required to capture the design amount of CO_2 as a condensed phase in the contacting liquid. The required temperature depends on the amount of CO_2 in the process gas, the desired capture amount, and the type and initial CO_2 loading of the contact liquid and, as an example only, may be around −106° C. for 90% capture from a process gas stream containing 16% CO_2 and a typical hydrocarbon contact liquid. The gas-phase CO_2 of the flue gas stream **46** condenses in the contact liquid stream **62** as either an absorbed gas, a desublimated solid, or a combination of both, to form a slurry stream.

[0028] As examples only, the contact liquid **62** and **64** can be any fluid with a freezing point below the frost or dew point of the condensable vapors and that is non-volatile or has low volatility. The low volatility minimizes the amount of contact liquid that escapes the direct-contact desublimation heat exchanger, which minimizes environmental impacts and costs. Examples of suitable contact liquids include, but are not limited to methyl cyclopentane, methyl cyclohexane, a variety of fluorinated or chlorinated hydrocarbons, or any compound or solution that has low vapor pressure at the temperature of system operation, has a manageable viscosity, and has no materials incompatibilities or unmanageable health and safety issues, including mixtures of such compounds.

[0029] In the cryogenic carbon capture system **44** of FIG. **2**, a light gas stream is separated from the slurry stream and exits the desublimating heat exchanger, and the cryogenic carbon capture system **44**, as light gas stream **50**. The CO_2 is separated from the slurry stream in a separation device, melted (if in the solid phase) and exits the cryogenic carbon capture system **44** as condensed CO_2 stream **48**. The warmed contact liquid stream, after removal of the CO_2, exits the separation device of the cryogenic carbon capture system **44** as stream **64**.

[0030] Further details of an example of the cryogenic carbon capture system **44** of FIG. **2** are disclosed in commonly assigned U.S. Pat. No. 8,764,885 to Baxter et al., the contents of which are hereby incorporated by reference. In addition, other details regarding the cryogenic carbon capture system **44** of FIG. **2** are provided in commonly owned U.S. Pat. No. 10,724,793 to Baxter, the contents of which are hereby incorporated by reference.

[0031] In accordance with the technology of the disclosure, warmed contact liquid stream **64** is directed to an indirect-contact heat exchanger **66** for cooling by the LNG stream from tank **40** to the temperature required to capture the design amount of CO_2.

[0032] In the system of FIG. **3**, an LNG heater **72** has been added to the system of FIG. **2**. The LNG heater may be required to warm the LNG from tank **40** to prevent freezing of the contact liquid in the heat exchanger **66**. As an example only, the temperature of the LNG exiting tank **40** may have a temperature of −160° C., while the contact liquid stream **64** may have a freezing temperature of −120° C. LNG heater **72** may warm the LNG to a temperature slightly above the freezing temperature of the contact liquid stream **64**. The flow rate of the contact liquid through the heat exchanger **66** should also be maintained at a sufficient level to avoid freezing within the heat exchanger **66**.

[0033] As examples only, LNG heater **72** may use ambient air to warm the LNG stream or it may be an electric heater.

[0034] In the system of FIG. **4**, the functionality of heat exchanger **66** of FIGS. **2** and **3** may be divided between first and second heat exchangers **74** and **76**. More specifically, the warmed contact liquid stream **64** is directed to an indirect-contact heat exchangers **74** and **76** for cooling by the LNG stream from tank **40** to the temperature required to capture the design amount of CO.sub.2. To avoid freezing of the contact liquid **64** in the colder heat exchanger **74**, ceramic sleeves may be provided to insulate the contact liquid passages from the LNG. Alternatively, the ceramic insulation may be provided for the LNG passages of the heat exchanger **74** to reduce the heat transfer from the contact liquid stream.

[0035] In an alternative embodiment of the system of FIG. **4**, an intermediate fluid may be directed through first and second heat exchangers **74** and **76** with the resulting cooled intermediate fluid used to cool the contact liquid used by the cryogenic carbon capture process **44** using an indirect-contact heat exchanger.

[0036] With reference to FIG. **5**, which presents a more detailed view of an embodiment of the system and method of the disclosure, a pre-treated flue gas is directed as process gas **100** to a pre-cool heat exchanger such as cooling tower **102** which, as an example only, may be a direct contact cooling tower that uses a chilled water stream **104** to provide cooling. The pre-cool cooling tower **102** cools the process gas stream **100** to just above 0° C. (as an example only). The resulting cooled stream is directed to a blower **106**, such as a compressor. After leaving the blower **106**, the pressurized process gas stream travels through a second heat exchanger such as a second cooling tower **108**, which provides cooling via water stream **112**.

[0037] The cooled and pressurized process stream **114** exiting the second cooling tower **108** travels to a desiccant dryer **116**, where moisture is recovered from the process gas with a resulting dried process gas stream exiting the dryer as stream **118**. A CO.sub.2-depleted “clean” light gas stream is also formed and exits the dryer as clean light gas stream **122**.

[0038] Suitable desiccant dryers are well known in the art. As an example only, the desiccant dryer **116** may incorporate the technology disclosed in U.S. Patent Application Publication No. US 2019/0128604 (U.S. patent application Ser. No. 15/795,953) to Baxter et al, the contents of which are hereby incorporated by reference.

[0039] Cooling water for cooling towers **102** and **108** enters the system as stream **124** and is cooled in a heat exchanger such as cooling tower **126**. Cooling within cooling tower **126** is provided by a cooled light gas stream **128**, the provision of which will be explained below. A warmed clean light gas stream exits cooling tower **126** as stream **132**, which joins the clean light gas stream **122** exiting the desiccant dryer **116**, with the resulting combined stream exiting the system.

[0040] The dried process gas stream **118** exiting the desiccant dryer **116** is directed to a multi-stream pre-cool heat exchanger **134** where it is further cooled, preferably to near its frost point (typically −95 to −105° C.).

[0041] The resulting pre-cooled process stream **136** is directed to a direct-contact desublimating heat exchanger, such as cooling tower **140**, where CO.sub.2 is captured by further cooling the process gas stream, using a cryogenic contacting liquid stream **142**, to the temperature required to capture the design amount of CO.sub.2 as a condensed phase in the contacting liquid. The required temperature depends on the amount of CO.sub.2 in the process gas, the desired capture amount, and the type and initial CO.sub.2 loading of the contact liquid and, as an example only, typically is around −106° C. for 90% capture from a process gas stream containing 16% CO.sub.2 and a typical hydrocarbon contact liquid. The gas-phase CO.sub.2 of the further-cooled process gas stream condenses in the contact liquid stream **142** as either an absorbed gas, a desublimated solid, or a combination of both, to form slurry stream **144**. All other species below their dew/frost points may also condense in this stage, which commonly includes most species less volatile than CO.sub.2 including most pollutants and other contaminants (NO.sub.2, SO.sub.2, SO.sub.3, Hg, VOCs, PCHs).

[0042] As noted previously, and as an example only, the direct-contact desublimating heat exchanger **140** may use technology disclosed in commonly assigned U.S. Pat. No. 8,764,885 to Baxter et al., the contents of which are hereby incorporated by reference.

[0043] A CO.sub.2-depleted process gas stream **146** (i.e. "clean" flue gas) exits the top of the desublimating heat exchanger **140** and is split into streams **148***a* and **148***b*, both of which pass through pre-cool heat exchanger **134** and are warmed to provide cooling therein. Warmed clean light gas stream **148***a* exits the pre-cool heat exchanger **134** as clean light gas stream **128** and is directed to cooling water cooling tower **126** to provided refrigeration therein, as noted previously. Steam **148***b*, after warming in heat exchanger **134** is directed through regeneration gas heater **149** where it is further warmed and then directed to the desiccant dryer **116** for moisture removal.

[0044] The CO.sub.2-laden slurry stream **144** is pumped via cryogenic pump **145** to contact liquid cooling heat exchangers **150** and **152** where it is cooled prior to exiting the second heat exchanger **152** as cooled slurry stream **154**.

[0045] Cooled slurry stream **154** is pumped via slurry pump **156** to a screw press **158** or other solids separation device where the solid CO.sub.2 is separated from the contact liquid so that solid CO.sub.2 stream **160** and purified contact liquid stream **162** are formed. Purified contact liquid stream **162** may be combined with a portion of cooled slurry stream **154** and is directed to the direct-contact desublimating heat exchanger **140** as contact liquid stream **142**.

[0046] Alternative solid separation devices including, but not limited to, filtration devices or cyclone separators, may be substituted for the screw press **158**.

[0047] Solid CO.sub.2 stream **160** is directed to a melter, such as indirect-contact heat exchanger **164**, with the resulting CO.sub.2 liquid stream being pumped by melter pump **166** to a multi-stream product heat exchanger **170**, where it is cooled. The resulting cooled CO.sub.2 liquid stream **172** is directed to CO.sub.2 polishing column **174**.

[0048] Additional contact liquid is removed from the CO.sub.2 of stream **172** and exits the CO.sub.2 polishing column **174** as contact liquid stream **176**. Contact liquid stream **176** is cooled in product heat exchanger **170** with the resulting stream being expanded via expansion device **182**. As an example only, the expansion device **182** may be Joule-Thompson (JT) valve. The expanded stream exits expansion device **182** and flows into contact liquid polishing column **184**.

[0049] A carbon dioxide vapor stream **186** exits the top of the contact liquid polishing column **184** and, after passing through heat exchanger **192**, is compressed in compressor **194**. The compressed CO.sub.2 stream exiting the compressor **194** is cooled in heat exchanger **192** (by stream **186**) with the resulting cooled stream **196** being directed to CO.sub.2 stream **198** being directed into CO.sub.2 polishing column **174**.

[0050] A contact liquid stream **202** exits the bottom of contact liquid polishing column **184** and is cooled in product heat exchanger **170** to form cooled contact liquid stream **204**. Cooled contact liquid stream **204** joins the slurry stream exiting slurry pump **146** with the combined stream being directed to first and second heat exchangers **150** and **152** for cooling.

[0051] A CO.sub.2 vapor stream **206** exits the top of the CO.sub.2 polishing column **174** and travels to melter **164** to provide the heat necessary to melt the CO.sub.2 solid stream **160** from screw press **158**. The resulting cooled CO.sub.2 stream is further cooled in LNG vaporizer heat exchanger **212** and then directed to flash drum **214**. A resulting CO.sub.2 vapor stream **216** exits the top of the flash drum **214** and is directed to the desublimating heat exchanger **140**. A CO.sub.2 liquid stream **218** exits the bottom of the flash drum **214** and is directed back to the CO.sub.2 polishing column **174**.

[0052] A CO.sub.2 liquid product stream **222** exits CO.sub.2 polishing column **174** and is directed, via pump **224** through product heat exchanger **170** for cooling. As a result, a cooled CO.sub.2 liquid product stream **226** is formed and directed out of the system.
[0053] As will now be described, in accordance with an embodiment of the disclosure, cooling for the system of FIG. **5** is provided by a liquid natural gas (LNG) stream **232**, which may be pumped via pump **234** or otherwise provided from a tank or other source. LNG stream **232** travels through heat exchangers **150** and **152** to provide cooling therein and form warmed LNG stream **236**. A resulting vaporized (or partially vaporized) natural gas stream **236** exits heat exchanger **170**.
[0054] After leaving heat exchanger **152**, LNG stream **236** is split into LNG streams **238**, **240** and **242**.
[0055] LNG stream **238** travels through product heat exchanger **170** to provide cooling therein. A resulting vaporized (or partially vaporized) natural gas stream **250** exits heat exchanger **170**.
[0056] LNG stream **240** splits into streams **244** and **246** which flow to pre-cool heat exchanger **134**. Stream **246** is warmed in the pre-cool heat exchanger **134** and a resulting warmed LNG stream **248** exits the heat exchanger and joins the LNG stream exiting heat exchanger **150**. LNG stream **244** is also warmed in the pre-cool heat exchanger **134** with the resulting warmed LNG stream **252** exiting the heat exchanger.
[0057] LNG stream **242** travels through heat exchanger **212** and provides cooling therein, with the resulting warmed stream **254** joining streams **250** and **252** to form combined stream **256**. Combined stream **256** may be warmed via heater **260** if the stream still contains liquid or if a warmer natural gas stream is desired. Natural gas stream **258** may then flow out of the system directly or may first be expanded via expansion device **262** which, as an example only, may be a turbine.
[0058] In an alternative embodiment of the system and method of the disclosure presented in FIG. **6**, LNG cooling is not provided in the system pre-cool heat exchanger **302** (which takes the place of pre-cool heat exchanger **134** of FIG. **5**). Instead, the dried process gas stream **118** exiting the desiccant dryer **116** is cooled in the pre-cool heat exchanger **302** solely by a clean light gas stream **304** from the desublimating heat exchanger **140**. More specifically, in the embodiment of FIG. **6**, clean light gas stream **146** exits the top of the heat exchanger **140** and is warmed in heater **306**. The resulting stream **304** then is directed to, and provides cooling within, the pre-cool heat exchanger **302** prior to exiting as further warmed stream **308**.
[0059] Clean light gas stream **308** is split to form streams **310** and **312**. Stream **310** is warmed in heater **149** and then directed to desiccant dryer **116**, as in the system of FIG. **5**. Stream **312** is directed to cooling water cooling tower **126** to provide cooling therein.
[0060] The system of FIG. **6** also differs from the system of FIG. **5** in that only a single contact liquid cooling heat exchanger **150**, which receives LNG stream **232** to provide cooling, is included in the cooling loop that receives slurry from slurry pump **145** and cooled contact liquid stream **204** from the product heat exchanger **170**. The contact liquid cooling heat exchanger **152** of FIG. **5** has been omitted.
[0061] Other than the above exceptions, the system of FIG. **6** is identical to the system in FIG. **5**.
[0062] While the preferred embodiments of the disclosure 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 disclosure, the scope of which is defined by the following claims.

Claims

1. A system for separating carbon dioxide from a process gas comprising: a. a pre-cool heat exchanger configured to receive and cool a process gas stream so that a cooled process gas stream is formed; b. a desublimating heat exchanger including a process gas inlet configured to receive the cooled process gas stream from the pre-cool heat exchanger, said desublimating heat exchanger further including a clean gas outlet, a contact liquid inlet and a slurry outlet; c. a contact liquid heat exchanger in fluid communication with the contact liquid inlet of the desublimating heat exchanger and configured to receive and warm a liquid natural gas stream to provide cooling within the contact liquid heat exchanger; d. said desublimating heat exchanger configured to contact the cooled process gas stream received from the pre-cool heat exchanger with contact liquid cooled by the contact liquid heat exchanger so that carbon dioxide is absorbed within the contact liquid whereby a carbon dioxide laden slurry stream and a carbon dioxide depleted clean process gas stream are formed with the clean process gas stream directed through the clean gas outlet to the pre-cool heat exchanger and the slurry stream directed through the slurry outlet; e. said pre-cool heat exchanger configured to warm the clean process gas stream to provide cooling for the process gas stream; f. a solid separation device in fluid communication with the contact inlet of the desublimating heat exchanger and configured to receive the carbon dioxide laden slurry stream from the slurry outlet of the desublimating heat exchanger and to separate the slurry stream into a condensed carbon dioxide stream and a contact liquid stream.

2. The system of claim 1 wherein the solid separation device is configured to direct the contact liquid stream to the contact liquid heat exchanger, and said contact liquid heat exchanger is configured to cool the contact liquid stream by warming the liquid natural gas stream.

3. The system of claim 1 wherein the contact liquid heat exchanger is configured to receive slurry the slurry stream from the slurry outlet of the desublimating heat exchanger, to cool the slurry stream by warming the liquid natural gas stream and to direct the cooled slurry stream to the solid separation device.

4. The system of claim 1 further comprising a liquid natural gas heater configured to receive a natural gas stream or a partially vaporized liquid natural gas stream from the contact liquid heat exchanger.

5. The system of claim 4 further comprising a liquid natural gas expansion device configured to receive warmed fluid from the liquid natural gas heater.

6. The system of claim 1 further comprising a liquid natural gas expansion device configured to receive a natural gas stream or a partially vaporized liquid natural gas stream from the contact liquid heat exchanger.

7. The system of claim 1 further comprising a source of liquid natural gas in fluid communication with the contact liquid heat exchanger.

8. The system of claim 7 further comprising a liquid natural gas pump configured to direct liquid natural gas from the source of liquid natural gas to the contact liquid heat exchanger.

9. The system of claim 7 further comprising an upstream liquid natural gas heater configured to warm liquid natural gas at it is transferred from the source of liquid natural gas to the contact heat exchanger.

10. The system of claim 1 wherein the contact liquid heat exchanger includes a first contact liquid heat exchanger and a second contact liquid heat exchanger.

11. The system of claim 10 wherein the first contact liquid heat exchanger is upstream from the second contact liquid heat exchanger and the first contact heat exchanger include ceramic insulation configured to insulate contact liquid from liquid natural gas.

12. The system of claim 1 wherein the pre-cool heat exchanger is also configured to receive and warm a liquid natural gas stream to provide cooling for the process gas stream.

13. The system of claim 12 wherein the contact liquid heat exchanger and the pre-cool heat exchanger receive liquid natural gas streams from a shared source.

14. A system for separating carbon dioxide from a process gas comprising: a. a pre-cool heat exchanger configured to receive and cool a process gas stream so that a cooled process gas stream is formed; b. a desublimating heat exchanger including a process gas inlet configured to receive the cooled process gas stream from the pre-cool heat exchanger, said desublimating heat exchanger further including a clean gas outlet, a contact liquid inlet and a slurry outlet; c. a contact liquid heat exchanger; d. a solid separation device configured to direct a contact liquid to the contact liquid inlet of the desublimating heat exchanger; e. said desublimating heat exchanger configured to contact the cooled process gas stream received from the pre-cool heat exchanger with contact liquid from the solid separation device so that carbon dioxide is absorbed within the contact liquid whereby a carbon dioxide laden slurry stream and a carbon dioxide depleted clean process gas stream are formed with the clean process gas stream directed through the clean gas outlet to the pre-cool heat exchanger and the slurry stream directed through the slurry outlet to the contact liquid heat exchanger; f. said pre-cool heat exchanger configured to warm the clean process gas stream to provide cooling for the process gas stream; g. said contact liquid heat exchanger configured to receive and warm a liquid natural gas stream to cool the slurry stream, said contact liquid heat exchanger also configured to direct the cooled slurry stream to the solid separation device; h. said solid separation device configured to separate the carbon dioxide laden slurry stream into a condensed carbon dioxide stream and a contact liquid stream.

15. The system of claim 14 wherein the pre-cool heat exchanger is also configured to receive and warm a liquid natural gas stream to provide cooling for the process gas stream.

16. The system of claim 15 wherein the contact liquid heat exchanger and the pre-cool heat exchanger receive liquid natural gas streams from a shared source.

17. The system of claim 14 wherein the separation device is a screw press.

18. The system of claim 14 further comprising a product heat exchanger in fluid communication with the solid separation device and configured to receive a carbon dioxide stream, said product heat exchanger also configured to receive and warm a liquid natural gas stream to cool the received carbon dioxide stream.

19. The system of claim 18 further comprising a melter configured to receive and melt a solid carbon dioxide stream from the solid separation device and to direct a resulting carbon dioxide liquid stream to the product heat exchanger.

20. A method for separating carbon dioxide from a process gas comprising: a. pre-cooling a process gas stream by warming a clean process gas stream so that a cooled process gas stream is formed; b. cooling a contact liquid by warming a liquid natural gas stream so that a cooled contact liquid stream is formed; c. contacting the cooled process gas stream with the cooled contact liquid stream so that carbon dioxide is absorbed within the contact liquid whereby a carbon dioxide laden slurry stream and a carbon dioxide depleted clean process gas stream are formed, where the clean process gas stream is warmed in step a.; d. separating the slurry stream into a condensed carbon dioxide stream and a contact liquid stream.

21. The method of claim 20 wherein the contact liquid stream of step d. is cooled in step b.

22. The method of claim 20 wherein step a. includes warming a liquid natural gas stream.

23. The method of claim 22 wherein the liquid natural gas streams of steps a. and b. are from a shard source.

24. The method of claim 20 wherein step b. includes cooling the slurry stream of step c.