

**REDUCING REFRIGERATION AND DEHYDRATION LOAD FOR A FEED
STREAM ENTERING A CRYOGENIC DISTILLATION PROCESS**

CROSS REFERENCE TO RELATED APPLICATIONS

- 5 **[0001]** This application claims the priority benefit of United States Provisional Patent Application 62/126,147 filed February 27, 2015 entitled REDUCING REFRIGERATION AND DEHYDRATION LOAD FOR A FEED STREAM ENTERING A CRYOGENIC DISTILLATION PROCESS, the entirety of which is incorporated by reference herein.

BACKGROUND

10 Fields of Disclosure

[0002] The disclosure relates generally to the field of fluid separation. More specifically, the disclosure relates to the cryogenic separation of contaminants, such as acid gas, from a hydrocarbon.

Description of Related Art

- 15 **[0003]** This section is intended to introduce various aspects of the art, which may be associated with the present disclosure. This discussion is intended to provide a framework to facilitate a better understanding of particular aspects of the present disclosure. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

- 20 **[0004]** The production of natural gas hydrocarbons, such as methane and ethane, from a reservoir oftentimes carries with it the incidental production of non-hydrocarbon gases. Such gases include contaminants, such as at least one of carbon dioxide (“CO₂”), hydrogen sulfide (“H₂S”), carbonyl sulfide, carbon disulfide, and various mercaptans. When a feed stream being produced from a reservoir includes these contaminants mixed with hydrocarbons, the stream is
25 oftentimes referred to as “sour gas.”

[0005] Many natural gas reservoirs have relatively low percentages of hydrocarbons and relatively high percentages of contaminants. Contaminants may act as a diluent and lower the heat content of hydrocarbons. Additionally, some contaminants can become quite corrosive in the presence of water.

- 30 **[0006]** It is usually desirable to remove contaminants from a stream containing

hydrocarbons to produce sweet and concentrated hydrocarbons. Specifications for pipeline quality natural gas may call for a maximum of 2 – 4% CO₂ and ¼ grain H₂S per 100 standard cubic foot (scf) (4 parts per million by volume (ppmv)) or 5 milligrams per normal cubic meter (mg/Nm³) H₂S. Specifications for lower temperature processes such as natural gas liquefaction plants or nitrogen rejection units may require less than 50 parts per million (ppm) CO₂.

[0007] The separation of contaminants from hydrocarbons is difficult and consequently significant work has been applied to the development of hydrocarbon/contaminant separation methods. These methods can be placed into three general classes: absorption by solvents (physical, chemical and hybrids), adsorption by solids, and distillation.

10 [0008] Separation by distillation of some mixtures can be relatively simple and, as such, is widely used in the natural gas industry. However, distillation of mixtures of natural gas hydrocarbons, primarily methane, and one of the most common contaminants in natural gas, carbon dioxide, can present significant difficulties. Conventional distillation principles and conventional distillation equipment assume the presence of only vapor and liquid phases throughout the distillation tower. However, the separation of CO₂ from methane by distillation involves temperature and pressure conditions that result in solidification of CO₂ if a pipeline or better quality hydrocarbon product is desired. The cold temperatures generally required for these distillation techniques are typically referred to as cryogenic temperatures.

[0009] Certain cryogenic distillations provide the appropriate mechanism to handle the formation and subsequent melting of solids during the separation of solid-forming contaminants from hydrocarbons. For example, the formation of solid contaminants in equilibrium with vapor-liquid mixtures of hydrocarbons and contaminants at particular conditions of temperature and pressure can take place in a controlled freeze zone section. Additional and/or alternative cryogenic separation systems are known in the art, e.g., systems solidifying CO₂ outside of a distillation tower, and the disclosure below expressly contemplates and includes such alternate systems.

[0010] Historic cryogenic distillations conditioned feed gas prior to admission to the cryogenic distillation column. The feed gas conditioning generally includes two principal steps: (1) removal of sufficient amounts of moisture, and (2) chilling the feed to an appropriate temperature before introduction into the cryogenic process.

[0011] The water content of feed streams has historically been a matter for concern, as sufficient amounts of moisture may cause hydrate formation in the colder regions of the

cryogenic distillation process. Historic cryogenic distillations feed conditioning configurations first fed wet, sour gas to a dehydration unit, e.g., comprising one or more molecular sieves, in order to remove the bulk of the water from the feed. Dehydration may be important since routing moisture rich liquid streams through cold temperatures in the process risks formation of solid ice or hydrates. However, molecular sieves are typically expensive and heavy, reducing their practicality for many applications, e.g., offshore applications.

[0012] Lowering the temperature of feed streams may also be important. Historically, feed conditioning systems couple a chiller (or a chilling train with cascaded chillers operating in series) between the dehydration unit and the cryogenic distillation column to cool the feed gas prior to reaching the cryogenic distillation column. Chilling the feed gas may minimize the refrigeration load on the reflux generation system in the cryogenic distillation column.

[0013] In the course of chilling the feed stream, some H₂S and CO₂, when in sufficient concentration in the feed gas may condense. Further chilling of the feed gas stream forms additional liquid. The condensed liquids may dissolve a certain amount of water. The condensed liquid stream may also comprise some methane and heavier hydrocarbons, such as, ethane, propane, etc. The feed conditioning configurations may route the liquid stream to the lower portion of the cryogenic distillation column. The lower portion of the cryogenic distillation column may strip out residual methane and may inject the acid liquid stream, which may contain dissolved water, into a spent reservoir via acid gas injection (AGI) or may use the acid liquid stream as a miscible Enhanced Oil Recovery (EOR) fluid. The overhead (treated) gas from the cryogenic distillation system may be sent to a pipeline or a liquefied natural gas (LNG) train for liquefaction.

[0014] The above discussion may indicate that colder feed chilling temperatures are preferable as this increases the amount of fluid condensed during feed conditioning. However, the moisture carrying capacity of a unit of a condensed liquid decreases with decreasing temperature. Therefore, the total moisture dissolved in the liquid may actually be lower at lower temperatures, even though the amount of liquid generated is higher. Further, the moisture bearing capacity of a unit of vapor also decreases with decreasing temperature. Therefore, as the feed gas containing a certain amount of moisture is chilled, the resulting vapor cannot hold as much moisture. Normally, when a low temperature vapor cannot hold as much moisture, the excess moisture may condense and dissolve in the CO₂-rich liquid. However, when the CO₂-rich liquid is saturated with water, additional moisture cannot be dissolved and a solid precipitate (e.g., ice or hydrate) may be formed.

[0015] Consequently, a need exists for a low-cost way to dehydrate and cool a feed stream, and in particular to sufficiently dry and cool the feed stream to avoid forming solid precipitates. In view of the discussion above, a need exists for improved feed conditioning technology that reduces the required level of upstream dehydration. A need exists for a more efficient feed
5 conditioning technology that lowers the capital and operating costs of the present feed conditioning technologies. A need exists for a feed conditioning technique to lower overall energy requirement.

SUMMARY

[0016] The present disclosure provides techniques for reducing the refrigeration load and
10 dehydration requirements for a sour gas feed stream entering a cryogenic distillation column.

[0017] In one embodiment, the disclosure includes a system for conditioning a sour gas feed stream for a cryogenic distillation tower, comprising a dehydration unit configured to separate the sour gas feed stream into a first stream comprising water and a feed stream, and a sequential cooling assembly coupled to both the dehydration unit and the cryogenic distillation
15 tower, wherein the sequential cooling assembly comprises a first stage configured to separate the feed stream into a partially cooled feed stream and a second stream comprising acid gas, a second stage configured to cool the partially cooled feed stream into a cooled feed stream and a third stream comprising acid gas, and a cooled feed stream header coupled to a cryogenic distillation tower feed inlet, wherein the first stage, the second stage, or both are configured to
20 send at least one of the second and third streams to a bottom section of the cryogenic distillation tower.

[0018] In another embodiment, the disclosure includes a method of sequential cooling a sour gas feed stream for a cryogenic distillation tower, comprising receiving the sour gas feed stream, separating the sour gas feed stream into a water stream and a partially dehydrated feed
25 stream, passing the partially dehydrated feed stream to a sequential cooling assembly, cooling the partially dehydrated feed stream to a first temperature, separating the partially dehydrated feed stream into a partially cooled feed stream comprising substantially vapor and a first stream comprising substantially liquid, cooling the partially cooled feed stream to a second temperature, separating the partially cooled feed stream into a cooled feed stream comprising
30 substantially vapor and a second stream comprising substantially liquid, and feeding the cooled feed stream to the cryogenic distillation tower.

[0019] In still another embodiment, the disclosure includes a cryogenic distillation system,

comprising a progressive conditioning section for a sour gas feed stream, comprising a first stage assembly configured to separate the sour gas feed stream into a first stream comprising water and a partially dehydrated feed stream, and a second stage assembly coupled to the first stage assembly and configured to separate the partially dehydrated feed stream into a progressively dehydrated feed stream comprising a hydrocarbon and a second stream comprising an acid gas, and further configured to cool the progressively dehydrated feed stream to a first temperature, and a third stage assembly coupled to the second stage assembly and further configured to cool the progressively dehydrated feed stream to a second temperature, wherein the second temperature is colder than the first temperature, and a cryogenic distillation tower comprising a controlled freeze zone, wherein the cryogenic distillation tower is configured to receive the progressively dehydrated feed stream.

[0020] The foregoing has broadly outlined the features of the present disclosure so that the detailed description that follows may be better understood. Additional features will also be described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] These and other features, aspects and advantages of the disclosure will become apparent from the following description, appending claims and the accompanying drawings, which are briefly described below.

[0022] FIG. 1 is a schematic diagram of a tower with sections within a single vessel.

[0023] FIG. 2 is a schematic diagram of a tower with sections in multiple vessels.

[0024] FIG. 3 is a schematic diagram of a tower with sections within a single vessel.

[0025] FIG. 4 is a schematic diagram of a tower with sections in multiple vessels.

[0026] FIG. 5 is a schematic diagram of a feed conditioning configuration.

[0027] FIG. 6 is a schematic diagram of a first embodiment of a feed conditioning configuration.

[0028] FIG. 7 is a schematic diagram of a second embodiment of a feed conditioning configuration.

[0029] FIG. 8 is a schematic diagram of a third embodiment of a feed conditioning configuration.

[0030] FIG. 9 is a schematic diagram of a fourth embodiment of a feed conditioning

configuration.

[0031] It should be noted that the figures are merely examples and no limitations on the scope of the present disclosure are intended thereby. Further, the figures are generally not drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of the disclosure.

DETAILED DESCRIPTION

[0032] For the purpose of promoting an understanding of the principles of the disclosure, reference will now be made to the features illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended. Any alterations and further modifications, and any further applications of the principles of the disclosure as described herein are contemplated as would normally occur to one skilled in the art to which the disclosure relates. It will be apparent to those skilled in the relevant art that some features that are not relevant to the present disclosure may not be shown in the drawings for the sake of clarity.

[0033] As referenced in this application, the terms “gas stream,” “vapor stream,” and “liquid stream” may refer to different stages of a feed stream as the feed stream is processed in a distillation tower that separates methane, the primary hydrocarbon in natural gas, from contaminants. Although the phrases “gas stream,” “vapor stream,” and “liquid stream,” refer to situations where a gas, vapor, and liquid is mainly present in the stream, respectively, there may be other phases also present within the stream. For example, a gas may also be present in a “liquid stream.” In some instances, the terms “gas stream” and “vapor stream” may be used interchangeably.

[0034] As utilized herein, the terms “approximately,” “about,” “substantially,” and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numeral ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and are considered to be within the scope of the disclosure. When used with respect to a subsequent value, the terms may mean plus or minus 10% of the subsequent value unless otherwise indicated.

[0035] The disclosure relates to a system and method for sequentially cooling and/or progressively conditioning the sour gas feed stream prior to a cryogenic distillation column. FIGS. 1-9, and particularly FIGS. 6-9, of the disclosure display various aspects of the system and method. The techniques for sequential cooling and/or progressively conditioning the sour gas feed stream described herein may have a variety of benefits. For example, routing moisture rich liquid streams through warmer temperatures in the process mitigates the risk of hydrate formation. Additionally, removal of feed stream liquids at intermediate temperatures also results in lower chilling loads on subsequent chillers, leading to a variety of feed conditioning efficiencies. For example, as warmer liquid enters the cryogenic distillation tower, the reboiler heat requirement decreases. Further, disclosed feed conditioning configurations may result in the generation of lower amounts of liquid at higher acid gas concentrations. Those of skill in the art will appreciate that use of the disclosed techniques described herein, e.g., sequentially cooling and/or progressively conditioning the sour gas feed stream, may also decrease the reboiler heat requirements, reduce the spray rates in the distillation tower, and, correspondingly, reduce the overhead refrigeration requirement.

[0036] The system and method may separate a feed stream having methane and contaminants. The system may comprise a distillation tower **104, 204** (FIGS. 1-4). The distillation tower **104, 204** may separate the contaminants from the methane.

[0037] In some embodiments not shown in the Figures, the distillation tower **104, 204** may incorporate only two functional sections when the upper section **110** is not needed and/or desired. When the distillation tower does not include an upper section **110**, a portion of vapor leaving the middle controlled freeze zone section **108** may be condensed in a condenser **122** and returned as a liquid stream via a spray assembly **129**. Moreover, lines **18** and **20** may be eliminated, elements **124** and **126** may be one and the same, and elements **150** and **128** may be one and the same. The stream in line **14**, now taking the vapors leaving the middle controlled freeze section **108**, directs these vapors to the condenser **122**.

[0038] In embodiments shown in FIGS. 1-4, the distillation tower **104, 204** may be separated into three functional sections: a lower section **106**, a middle controlled freeze zone section **108** and an upper section **110**. The distillation tower **104, 204** may incorporate three functional sections when the upper section **110** is needed and/or desired.

[0039] The lower section **106** may also be referred to as a stripper section. The middle controlled freeze zone section **108** may also be referred to as a controlled freeze zone section.

The upper section **110** may also be referred to as a rectifier section.

[0040] The sections of the distillation tower **104** may be housed within a single vessel (FIGS. 1 and 3). For example, the lower section **106**, the middle controlled freeze zone section **108**, and the upper section **110** may be housed within a single vessel **164**.

5 [0041] The sections of the distillation tower **204** may be housed within a plurality of vessels to form a split-tower configuration (FIGS. 2 and 4). Each of the vessels may be separate from the other vessels. Piping and/or another suitable mechanism may connect one vessel to another vessel. In this instance, the lower section **106**, middle controlled freeze zone section **108** and upper section **110** may be housed within two or more vessels. For example, as shown in FIGS.
10 2 and 4, the upper section **110** may be housed within a single vessel **254** and the lower and middle controlled freeze zone sections **106**, **108** may be housed within a single vessel **264**. When this is the case, a liquid stream exiting the upper section **110**, may exit through a liquid outlet bottom **260**. The liquid outlet bottom **260** is at the bottom of the upper section **110**. Although not shown, each of the sections may be housed within its own separate vessel, or one
15 or more section may be housed within separate vessels, or the upper and middle controlled freeze zone sections may be housed within a single vessel and the lower section may be housed within a single vessel, etc. When sections of the distillation tower are housed within vessels, the vessels may be side-by-side along a horizontal line and/or above each other along a vertical line.

20 [0042] The split-tower configuration may be beneficial in situations where the height of the distillation tower, motion considerations, and/or transportation issues, such as for remote locations, need to be considered. This split-tower configuration allows for the independent operation of one or more sections. For example, when the upper section is housed within a single vessel and the lower and middle controlled freeze zone sections are housed within a
25 single vessel, independent generation of reflux liquids using a substantially contaminant-free, largely hydrocarbon stream from a packed gas pipeline or an adjacent hydrocarbon line, may occur in the upper section. And the reflux may be used to cool the upper section, establish an appropriate temperature profile in the upper section, and/or build up liquid inventory at the bottom of the upper section to serve as an initial source of spray liquids for the middle
30 controlled freeze zone section. Moreover, the middle controlled freeze zone and lower sections may be independently prepared by chilling the feed stream, feeding it to the optimal location be that in the lower section or in the middle controlled freeze zone section, generating liquids for the lower and the middle controlled freeze zone sections, and disposing the vapors off the

middle controlled freeze zone section while they are off specification with too high a contaminant content. Also, liquid from the upper section may be intermittently or continuously sprayed, building up liquid level in the bottom of the middle controlled freeze zone section and bringing the contaminant content in the middle controlled freeze zone section down and near steady state level so that the two vessels may be connected to send the vapor stream from the middle controlled freeze zone section to the upper section, continuously spraying liquid from the bottom of the upper section into the middle controlled freeze zone section and stabilizing operations into steady state conditions. The split tower configuration may utilize a sump of the upper section as a liquid receiver for the pump **128**, therefore obviating the need for the liquid receiver **126** in FIGS. 1 and 3.

[0043] The system may also include a heat exchanger **100** (FIGS. 1-4), e.g., a shell-and-tube heat exchanger, a packed or trayed column, etc. The feed stream **10** may enter the heat exchanger **100** before entering the distillation tower **104, 204**. The feed stream **10** may be cooled within the heat exchanger **100**. The heat exchanger **100** helps drop the temperature of the feed stream **10** to a level suitable for introduction into the distillation tower **104, 204**. As described at length below, any of the feed conditioning system embodiments shown in FIGS. 6-9 may optionally replace the heat exchanger **100**.

[0044] The system may include an expander device **102** (FIGS. 1-4). The feed stream **10** may enter the expander device **102** before entering the distillation tower **104, 204**. The feed stream **10** may be expanded in the expander device **102** after exiting the heat exchanger **100**. The expander device **102** helps drop the temperature of the feed stream **10** to a level suitable for introduction into the distillation tower **104, 204**. The expander device **102** may be any suitable device, such as a valve. If the expander device **102** is a valve, the valve may be any suitable valve that may aid in cooling the feed stream **10** before it enters the distillation tower **104, 204**. For example, the valve **102** may comprise a Joule-Thompson (J-T) valve.

[0045] The system may include a feed separator **103** (FIGS. 3-4). The feed stream may enter the feed separator before entering the distillation tower **104, 204**. The feed separator may separate a feed stream having a mixed liquid and vapor stream into a liquid stream and a vapor stream. Lines **12** may extend from the feed separator to the distillation tower **104, 204**. One of the lines **12** may receive the vapor stream from the feed separator. Another one of the lines **12** may receive the liquid stream from the feed separator. Each of the lines **12** may extend to the same and/or different sections (i.e. middle controlled freeze zone, and lower sections) of the distillation tower **104, 204**. The expander device **102** may or may not be downstream of

the feed separator **103**. The expander device **102** may comprise a plurality of expander devices **102** such that each line **12** has an expander device **102**.

[0046] The system may include a dehydration unit **261** (FIGS. 1-4). The feed stream **10** may enter the dehydration unit **261** before entering the distillation tower **104, 204**. The feed stream **10** enters the dehydration unit **261** before entering the heat exchanger **100** and/or the expander device **102**. The dehydration unit **261** removes water from the feed stream **10** to prevent water from later presenting a problem in the heat exchanger **100**, expander device **102**, feed separator **103**, or distillation tower **104, 204**. The water can present a problem by forming a separate water phase (i.e., ice and/or hydrate) that plugs lines, equipment or negatively affects the distillation process. The dehydration unit **261** dehydrates the feed stream to a dew point sufficiently low to ensure a separate water phase will not form at any point downstream during the rest of the process. The dehydration unit may be any suitable dehydration mechanism, such as a molecular sieve or a glycol dehydration unit. As described below, any of the feed conditioning system embodiments shown in FIGS. 6-9 may optionally replace the dehydration unit **261**.

[0047] The system may include a filtering unit (not shown). The feed stream **10** may enter the filtering unit before entering the distillation tower **104, 204**. The filtering unit may remove undesirable contaminants from the feed stream before the feed stream enters the distillation tower **104, 204**. Depending on what contaminants are to be removed, the filtering unit may be before or after the dehydration unit **261** and/or before or after the heat exchanger **100**.

[0048] The systems may include a line **12** (FIGS. 1-4). The line may also be referred to as an inlet channel **12**. The feed stream **10** may be introduced into the distillation tower **104, 204** through the line **12**. The line **12** may extend to the lower section **106** or the middle controlled freeze zone section **108** of the distillation tower **104, 204**. For example, the line **12** may extend to the lower section **106** such that the feed stream **10** may enter the lower section **106** of the distillation tower **104, 204** (FIGS. 1-4). The line **12** may directly or indirectly extend to the lower section **106** or the middle controlled freeze zone section **108**. The line **12** may extend to an outer surface of the distillation tower **104, 204** before entering the distillation tower **104, 204**.

[0049] If the system includes the feed separator **103** (FIGS. 3-4), the line **12** may comprise a plurality of lines **12**. Each line may be the same line as one of the lines that extends from the feed separator to a specific portion of the distillation tower **104, 204**.

[0050] The lower section **106** is constructed and arranged to separate the feed stream **10** into an enriched contaminant bottom liquid stream (i.e., liquid stream) and a freezing zone vapor stream (i.e., vapor stream). The lower section **106** separates the feed stream at a temperature and pressure at which no solids form. The liquid stream may comprise a greater quantity of contaminants than of methane. The vapor stream may comprise a greater quantity of methane than of contaminants. In any case, the vapor stream is lighter than the liquid stream. As a result, the vapor stream rises from the lower section **106** and the liquid stream falls to the bottom of the lower section **106**.

[0051] The lower section **106** may include and/or connect to equipment that separates the feed stream. The equipment may comprise any suitable equipment for separating methane from contaminants, such as one or more packed sections **181**, or one or more distillation trays with perforations, downcomers, and weirs (FIGS. 1-4).

[0052] The equipment may include components that apply heat to the stream to form the vapor stream and the liquid stream. For example, the equipment may comprise a first reboiler **112** that applies heat to the stream. The first reboiler **112** may be located outside of the distillation tower **104, 204**. The equipment may also comprise a second reboiler **172** that applies heat to the stream. The second reboiler **172** may be located outside of the distillation tower **104, 204**. Line **117** may lead from the distillation tower to the second reboiler **172**. Line **17** may lead from the second reboiler **172** to the distillation tower. Additional reboilers, set up similarly to the second reboiler described above, may also be used.

[0053] The first reboiler **112** may apply heat to the liquid stream that exits the lower section **106** through a liquid outlet **160** of the lower section **106**. The liquid stream may travel from the liquid outlet **160** through line **28** to reach the first reboiler **112** (FIGS. 1-4). The amount of heat applied to the liquid stream by the first reboiler **112** can be increased to separate more methane from contaminants. The more heat applied by the reboiler **112** to the stream, the more methane separated from the liquid contaminants, though more contaminants will also be vaporized.

[0054] The first reboiler **112** may also apply heat to the stream within the distillation tower **104, 204**. Specifically, the heat applied by the first reboiler **112** warms up the lower section **106**. This heat travels up the lower section **106** and supplies heat to warm solids entering a melt tray assembly **139** (FIGS. 1-4) of the middle controlled freeze zone section **108** so that the solids form a liquid and/or slurry mix.

[0055] The second reboiler **172** applies heat to the stream within the lower section **106**. This heat is applied closer to the middle controlled freeze zone section **108** than the heat applied by the first reboiler **112**. As a result, the heat applied by the second reboiler **172** reaches the middle controlled freeze zone section **108** faster than the heat applied by the first reboiler **112**.

5 The second reboiler **172** may also help with energy integration if its heat source is a process stream.

[0056] The equipment may include one or more chimney assemblies **135** (FIGS. 1-4). While falling to the bottom of the lower section **106**, the liquid stream may encounter one or more of the chimney assemblies **135**.

10 [0057] Each chimney assembly **135** includes a chimney tray **131** that collects the liquid stream within the lower section **106**. The liquid stream that collects on the chimney tray **131** may be fed to the second reboiler **172**. After the liquid stream is heated in the second reboiler **172**, the stream may return to the middle controlled freeze zone section **108** to supply heat to the middle controlled freeze zone section **108** and/or the melt tray assembly **139**. Unvaporized
15 stream exiting the second reboiler **172** may be fed back to the distillation tower **104, 204** below the chimney tray **131**. Vapor stream exiting the second reboiler **172** may be routed under or above the chimney tray **131** when the vapor stream enters the distillation tower **104, 204**.

[0058] The chimney tray **131** may include one or more chimneys **137**. The chimney **137** serves as a channel that the vapor stream in the lower section **106** traverses. The vapor stream
20 travels through an opening in the chimney tray **131** at the bottom of the chimney **137** to the top of the chimney **137**. The opening is closer to the bottom of the lower section **106** than it is to the bottom of the middle controlled freeze zone section **108**. The top is closer to the bottom of the middle controlled freeze zone section **108** than it is to the bottom of the lower section **106**.

[0059] Each chimney **137** has attached to it a chimney cap **133**. The chimney cap **133**
25 covers a chimney top opening **138** of the chimney **137**. The chimney cap **133** prevents the liquid stream from entering the chimney **137**. The vapor stream exits the chimney assembly **135** via the chimney top opening **138**.

[0060] After falling to the bottom of the lower section **106**, the liquid stream exits the distillation tower **104, 204** through the liquid outlet **160**. The liquid outlet **160** is within the
30 lower section **106** (FIGS. 1-4). The liquid outlet **160** may be located at the bottom of the lower section **106**.

[0061] After exiting through the liquid outlet **160**, the feed stream may travel via line **28** to

the first reboiler **112**. The feed stream may be heated by the first reboiler **112** and vapor may then re-enter the lower section **106** through line **30**. Unvaporized liquid may continue out of the distillation process via line **24**.

5 **[0062]** The system may include an expander device **114** (FIGS. 1-4). After entering line **24**, the heated liquid stream may be expanded in the expander device **114**. The expander device **114** may be any suitable device, such as a valve. The valve **114** may be any suitable valve, such as a J-T valve.

10 **[0063]** The system may include a heat exchanger **116** (FIGS. 1-4). The liquid stream heated by the first reboiler **112** may be cooled or heated by the heat exchanger **116**. The heat exchanger **116** may be a direct heat exchanger or an indirect heat exchanger. The heat exchanger **116** may comprise any suitable heat exchanger and may output a stream **26**.

15 **[0064]** The vapor stream in the lower section **106** rises from the lower section **106** to the middle controlled freeze zone section **108**. The middle controlled freeze zone section **108** is maintained to receive a freezing zone liquid stream to form the solid and the vapor stream (i.e., hydrocarbon-enriched vapor stream) in the middle controlled freeze zone section **108**. The middle controlled freeze zone section **108** is constructed and arranged to separate the feed stream **10** introduced into the middle controlled freeze zone section into a solid and a vapor stream. The solid and the vapor stream are formed in the middle controlled freeze zone section **108** when the freezing zone liquid stream is injected into the middle controlled freeze zone section **108** at a temperature and pressure at which the solid and vapor stream form. The solid may be comprised more of contaminants than of methane. The vapor stream may comprise more methane than contaminants.

20 **[0065]** The middle controlled freeze zone section **108** includes a lower section **40** and an upper section **39**. The lower section **40** is below the upper section **39**. The lower section **40** directly abuts the upper section **39**. The lower section **40** is primarily but may not exclusively be a heating section of the middle controlled freeze zone section **108**. The upper section **39** is primarily but may not exclusively be a cooling section of the middle controlled freeze zone section **108**. The temperature and pressure of the upper section **39** are chosen so that the solid can form in the middle controlled freeze zone section **108**.

30 **[0066]** The middle controlled freeze zone section **108** may comprise a melt tray assembly **139** that is maintained in the middle controlled freeze zone section **108** (FIGS. 1-5). The melt tray assembly **139** is within the lower section **40** of the middle controlled freeze zone section

108. The melt tray assembly **139** is not within the upper section **39** of the middle controlled freeze zone section **108**.

[0067] The melt tray assembly **139** is constructed and arranged to melt a solid formed in the middle controlled freeze zone section **108**. When the warm vapor stream rises from the lower section **106** to the middle controlled freeze zone section **108**, the vapor stream immediately encounters the melt tray assembly **139** and supplies heat to melt the solid. The melt tray assembly **139** may comprise at least one of a melt tray **118**, a bubble cap **132**, a liquid **130** and heat mechanism(s) **134**.

[0068] The melt tray **118** may collect a liquid and/or slurry mix. The melt tray **118** divides at least a portion of the middle controlled freeze zone section **108** from the lower section **106**. The melt tray **118** is at the bottom **45** of the middle controlled freeze zone section **108**.

[0069] One or more bubble caps **132** may act as a channel for the vapor stream rising from the lower section **106** to the middle controlled freeze zone section **108**. The bubble cap **132** may provide a path for the vapor stream that forces the vapor stream up the riser **140** and then down and around the riser **140** to the melt tray **118**. The riser **140** is covered by a cap **141**. The cap **141** prevents the liquid **130** from travelling into the riser **140**. The cap **141** helps prevent solids from travelling into the riser **140**. The vapor stream's traversal through the bubble cap **132** allows the vapor stream to transfer heat to the liquid **130** within the melt tray assembly **139**.

[0070] One or more heat mechanisms **134** may further heat up the liquid **130** to facilitate melting of the solids into a liquid and/or slurry mix. The heat mechanism(s) **134** may be located anywhere within the melt tray assembly **139**. For example, as shown in FIGS. 1-4, a heat mechanism **134** may be located around the bubble caps **132**. The heat mechanism **134** may be any suitable mechanism, such as a heat coil. The heat source of the heat mechanism **134** may be any suitable heat source.

[0071] The liquid **130** in the melt tray assembly is heated by the vapor stream. The liquid **130** may also be heated by the one or more heat mechanisms **134**. The liquid **130** helps melt the solids formed in the middle controlled freeze zone section **108** into a liquid and/or slurry mix. Specifically, the heat transferred by the vapor stream heats up the liquid, thereby enabling the heat to melt the solids. The liquid **130** is at a level sufficient to melt the solids.

[0072] The middle controlled freeze zone section **108** may also comprise a spray assembly **129**. The spray assembly **129** cools the vapor stream that rises from the lower section **40**. The

spray assembly **129** sprays liquid, which is cooler than the vapor stream, on the vapor stream to cool the vapor stream. The spray assembly **129** is within the upper section **39**. The spray assembly **129** is not within the lower section **40**. The spray assembly **129** is above the melt tray assembly **139**. In other words, the melt tray assembly **139** is below the spray assembly **129**.

[0073] The temperature in the middle controlled freeze zone section **108** cools down as the vapor stream travels from the bottom of the middle controlled freeze zone section **108** to the top of the middle controlled freeze zone section **108**. The methane in the vapor stream rises from the middle controlled freeze zone section **108** to the upper section **110**. Some contaminants may remain in the methane and also rise. The contaminants in the vapor stream tend to condense or solidify with the colder temperatures and fall to the bottom of the middle controlled freeze zone section **108**.

[0074] The solids form the liquid and/or slurry mix when in the liquid **130**. The liquid and/or slurry mix flows from the middle controlled freeze zone section **108** to the lower distillation section **106**. The liquid and/or slurry mix flows from the bottom of the middle controlled freeze zone section **108** to the top of the lower section **106** via a line **22** (FIGS. 1-4). The line **22** may be an exterior line. The line **22** may extend from the distillation tower **104, 204**. The line **22** may extend from the middle controlled freeze zone section **108**. The line may extend to the lower section **106**.

[0075] The vapor stream that rises in the middle controlled freeze zone section **108** and does not form solids or otherwise fall to the bottom of the middle controlled freeze zone section **108**, rises to the upper section **110**. The upper section **110** operates at a temperature and pressure and contaminant concentration at which no solid forms. The upper section **110** is constructed and arranged to cool the vapor stream to separate the methane from the contaminants. Reflux in the upper section **110** cools the vapor stream. The reflux is introduced into the upper section **110** via line **18**. Line **18** may extend to the upper section **110**. Line **18** may extend from an outer surface of the distillation tower **104, 204**.

[0076] After contacting the reflux in the upper section **110**, the feed stream forms a vapor stream and a liquid stream. The vapor stream mainly comprises methane. The liquid stream comprises relatively more contaminants. The vapor stream rises in the upper section **110** and the liquid falls to a bottom of the upper section **110**.

[0077] To facilitate separation of the methane from the contaminants when the stream

contacts the reflux, the upper section **110** may include one or more mass transfer devices **176**. Each mass transfer device **176** helps separate the methane from the contaminants. Each mass transfer device **176** may comprise any suitable separation device, such as a tray with perforations, or a section of random or structured packing **176** to facilitate contact of the vapor and liquid phases.

[0078] After rising, the vapor stream may exit the distillation tower **104, 204** through line **14**. The line **14** may emanate from an upper part of the upper section **110**. The line **14** may extend from an outer surface of the upper section **110**.

[0079] From line **14**, the vapor stream may enter a condenser **122**. The condenser **122** cools the vapor stream to form a cooled stream. The condenser **122** at least partially condenses the stream.

[0080] After exiting the condenser **122**, the cooled stream may enter a separator **124**. The separator **124** separates the vapor stream into liquid and vapor streams. The separator may be any suitable separator that can separate a stream into liquid and vapor streams, such as a reflux drum.

[0081] Once separated, the vapor stream may exit the separator **124** as sales product. The sales product may travel through line **16** for subsequent sale to a pipeline and/or condensation to be liquefied natural gas.

[0082] Once separated, the liquid stream may return to the upper section **110** through line **18** as the reflux. The reflux may travel to the upper section **110** via any suitable mechanism, such as a reflux pump **150** (FIGS. 1 and 3) or gravity (FIGS. 2 and 4).

[0083] The liquid stream (i.e., freezing zone liquid stream) that falls to the bottom of the upper section **110** collects at the bottom of the upper section **110**. The liquid may collect on tray **183** (FIGS. 1 and 3) or at the bottommost portion of the upper section **110** (FIGS. 2 and 4). The collected liquid may exit the distillation tower **104, 204** through line **20** (FIGS. 1 and 3) or outlet **260** (FIGS. 2 and 4). The line **20** may emanate from the upper section **110**. The line **20** may emanate from a bottom end of the upper section **110**. The line **20** may extend from an outer surface of the upper section **110**.

[0084] The line **20** and/or outlet **260** connect to a line **41**. The line **41** leads to the spray assembly **129** in the middle controlled freeze zone section **108**. The line **41** emanates from the holding vessel **126**. The line **41** may extend to an outer surface of the middle controlled freeze zone section **108**.

[0085] The line **20** and/or outlet **260** may directly or indirectly (FIGS. 1-4) connect to the line **41**. When the line **20** and/or outlet **260** directly connect to the line **41**, the liquid spray may be pumped to the spray nozzle(s) **120** via any suitable mechanism, such as the spray pump **128** or gravity. When the line **20** and/or outlet **260** indirectly connect to the line **41**, the lines **20**,
5 **41** and/or outlet **260** and line **41** may directly connect to a holding vessel **126** (FIGS. 1 and 3). The holding vessel **126** may house at least some of the liquid spray before it is sprayed by the nozzle(s). The liquid spray may be pumped from the holding vessel **126** to the spray nozzle(s) **120** via any suitable mechanism, such as the spray pump **128** (FIGS. 1-4) or gravity. The holding vessel **126** may be needed when there is not a sufficient amount of liquid stream at the
10 bottom of the upper section **110** to feed the spray nozzles **120**.

[0086] The method may include maintaining an upper section **110**. The upper section **110** operates as previously discussed. The method may also include separating the feed stream in the upper section **110** as previously discussed. Various lineups, systems, methods, and/or processes using open-loop refrigeration to provide cooling to a distillation system operating
15 under solids forming conditions for at least one of the components in a stream to the distillation system are known in the art, e.g., U.S. Patent Number 6,053,007, and may optionally be utilized in conjunction with the disclosed techniques as would be understood by those of skill in the art.

[0087] FIG. 5 is a schematic diagram of a feed conditioning configuration **500** prior to a
20 distillation tower **502**, e.g., the tower **104**, **204** of FIGS. 1-4, or any other cryogenic distillation tower suitably employable herewith as would be understood by those of skill in the art. The feed conditioning configuration **500** is configured to receive a sour gas feed **504** via a sour gas feed stream header, e.g., the feed stream **10** of FIGS. 1-4. The sour gas feed stream **504** is passed to a dehydration unit **506**, e.g., a glycol unit or the dehydration unit **261** of FIGS. 1-4.
25 The dehydration unit **506** may separate the sour gas feed stream **504** into a first stream **508**, e.g., a liquid stream and/or a waste stream comprising substantially water, and a partially dehydrated feed stream **510**, comprising the feed gas stream having at least a portion of the initial water content removed. The partially dehydrated feed stream **510** is passed to a chiller **512**, comprising a heat exchanger **100** of FIG. 1-4. The chiller **512** may separate and/or
30 condense additional contaminants, e.g., some water, carbon dioxide, and/or heavier hydrocarbons (e.g., ethane) if present in sufficient concentration in the feed gas stream, to form a second stream **514**, e.g., a condensate stream comprising water. The chiller **512** may feed the second stream **514** to a bottom section of the distillation tower **502**, e.g., the lower section **106**

of FIGS. 1-4. The chiller **512** may feed any non-condensed stream feed gas **520** to a section of the tower **502**, e.g., the middle controlled freeze zone section **108** of FIGS. 1-4. Some embodiments of the configuration **500** may include an expander device, e.g., the expander device **102** of FIGS. 1-4, prior to introducing the feed gas to the tower **502**. As discussed above
5 with respect to the expander device **102**, the expander device may aid in cooling the feed gas before it enters the distillation tower **502**. The tower **502** may separate the conditioned feed stream into an overhead stream **516** comprising methane and/or nitrogen and a stream **518** comprising liquids, e.g., water, carbon dioxide, and/or heavy hydrocarbons.

[0088] In operation, the feed conditioning configuration **500** conditions the sour gas feed stream **504** prior to introduction into the tower **502**. This may include two general steps: (1) removal of sufficient amounts of moisture to mitigate any concerns of hydrate formation in the colder regions of the process, and (2) chilling the feed to an appropriate temperature before introduction into the process, which minimizes the refrigeration load on the reflux generation system. The bulk of the moisture may be removed at the dehydration unit **506** via the first stream **508**. Chilling of the partially dehydrated feed stream **510** may be accomplished at the
15 chiller **512**, which may pass the second stream **514** to a bottom section of the distillation tower **502**, e.g., the lower section **106** of FIGS. 1-4. Chilling the feed gas stream further forms more liquid condensate. While a higher amount of liquid may be able to dissolve more moisture, lower liquid temperature diminishes the water-carrying capacity of the colder liquid.
20 Additionally, colder liquids have a lower vapor pressure of water above it, so the resulting gas will be drier, but reducing the feed gas stream to the saturation temperature risks forming hydrates. For these reasons, a particular feed conditioning configuration may be chosen based on the costs and benefits in relation to the desired performance metric. Consequently, some embodiments of the present disclosure use a multistage feed chilling train to cool and condition
25 the feed in stages (e.g., FIG. 6). The chiller **512** may feed any non-condensate stream feed gas to a section of the tower **502**, e.g., the middle controlled freeze zone section **108** of FIGS. 1-4. Once separated in the tower **502**, the overhead stream **516** of treated gas may be sent, e.g., to a pipeline or a LNG train for liquefaction, while the bottom section of the distillation tower **502** may strip out any residual methane and send the resulting acid gas stream **518**, e.g., to a spent
30 reservoir for AGI or for use as a miscible EOR fluid.

[0089] FIG. 6 is a schematic diagram of a first embodiment of a feed conditioning configuration **600** prior to a distillation tower **502**. The components of FIG. 6 may be the same as the identically numbered components of FIG. 5 except as otherwise noted. The feed

conditioning configuration **600** includes a two-stage progressive chilling process or a sequential cooling assembly. The feed conditioning configuration **600** is configured to receive a sour gas via a sour gas feed stream **504**. The sour gas feed stream **504** is passed to a dehydration unit **506**. The dehydration unit **506** may separate the sour gas feed stream **504** into a first stream **508** comprising substantially water and a partially dehydrated feed stream **510** having the bulk of water removed. The partially dehydrated feed stream **510** is passed to a chiller **602a**, e.g., via a receiving header configured to receive the partially dehydrated feed stream **510** from the dehydration unit **506**. The chiller **602a** may cool the partially dehydrated feed stream **510** to a first temperature and condense at least a portion of the dehydrated feed stream **510**. The first temperature may be less than about +30 °C, or less than about +25 °C, or less than about +20 °C, or less than about +15 °C, or less than about +10 °C and may be greater than about -40 °C, or greater than about -35 °C, or greater than about -30 °C, or greater than about -25 °C, or greater than about -20 °C. In some embodiments, the first temperature may be between about +30 °C and about -40 °C, or between about +10 °C and -20 °C. The partially chilled feed stream **610** may be sent to a separator **604a** where it is separated into a methane-rich stream **606** comprising vapor and an acid-gas-rich stream **608a**, e.g., a stream comprising liquid or substantially liquid, such as water and/or acid gas. The separator **604a** may send the acid-gas-rich stream **608a** to a bottom section of the distillation tower **502**, e.g., the lower section **106** of FIGS. 1-4, and may send the methane-rich stream **606** to a second stage chiller **602b**. The chiller **602b** may cool the methane-rich stream **606** to a second temperature and condense at least a portion of the methane-rich stream **606**. The second temperature may be less than about -10 °C, or less than about -15 °C, or less than about -20 °C, and may be greater than about -80 °C, or greater than about -75 °C, or greater than about -70 °C, or greater than about -65 °C, or greater than about -60 °C. In some embodiments, the second temperature may be between about -20 °C and about -80 °C, or between about -20 °C and about -60 °C. The partially chilled feed stream **610** may be sent to a separator **604b** where it is separated into a progressively dehydrated feed stream, i.e., a methane-rich stream **612** comprising vapor or substantially vapor, and an acid-gas-rich stream **608b** comprising liquid or substantially liquid. The separator **604b** may send the acid-gas-rich stream **608b** to a lower section of the distillation tower **502** and may send the methane-rich stream **612** to a section of the tower **502**, e.g., the middle controlled freeze zone section **108** of FIGS. 1-4. Some embodiments of the configuration **600** may include an expander device, e.g., the expander device **102** of FIGS. 1-4, prior to introducing one or more of the methane-rich stream **612**, the acid-gas-rich stream **608a**, or the acid-gas-rich stream **608b** to the tower **502**. As discussed

above with respect to the expander device **102**, the expander device may aid in cooling the feed gas before it enters the distillation tower **502**. The tower **502** may separate the conditioned feed stream, e.g., the methane-rich stream **612**, into an overhead stream **516** comprising methane and/or nitrogen and a stream **518** comprising water, carbon dioxide, and/or heavy hydrocarbons.

[0090] As described above, a two-phase stream may be introduced into a separator **604a** and/or **604b**, e.g., to separate the methane-rich vapor from the acid-gas-rich liquid. Due to the ability of acid gasses (e.g., CO₂) to dissolve significant amounts of water at these intermediate temperatures, an appreciable amount of water may be removed along with the liquids in this separator. This process may be repeated with the moisture-lean vapor (e.g., a partially dehydrated feed gas stream) to further remove water from the vapor stream before introduction into the tower **502**. The liquid streams coming from the one or more intermediate separators may be combined and introduced into the tower **502** at a different point from the conditioned gas, e.g., at a section of the tower **502**, e.g., the lower section **106** of FIGS. 1-4, or into one or more bottom or side reboilers, e.g., the reboilers **112**, **172** of FIG. 1-4, which operate at warmer temperature.

[0091] The benefits of using a two-stage progressive chilling process or a sequential cooling assembly are many, and include (1) reduction in feed chilling energy requirements due to the reduction in the amount of fluid being chilled, (2) minimizing the risk of heavy hydrocarbons, e.g., benzene, toluene, xylene, etc., freezing during the feed conditioning process, and (3) minimizing the risk of glycol or other material carried over from a dehydration unit freezing during the feed conditioning process.

[0092] The above benefits may be due, at least in part, to the ability of acid gasses (particularly carbon dioxide) to hold significant amounts of water at these intermediate temperatures. Because of this ability, a significant amount of water may be removed along with the liquids using the two-stage progressive chilling process or a sequential cooling assembly, e.g., in the separators **604a** and/or **604b**. Repeating the separation process of separator **604a** using the separator **604b** may remove more water from the vapor stream than conventional approaches to feed conditioning, which in turn may allow for colder methane-rich stream **612** temperatures, and may reduce the overall cooling load on the feed conditioning configuration **600**, e.g., by reducing the stream volume needed to be cooled. Various embodiments of the feed conditioning configurations disclosed herein, e.g., the feed conditioning configurations **600**, **700**, **800**, and/or **900**, may remove sufficient moisture to

prevent the formation of ice, hydrates, or a combination thereof downstream of the sequential cooling assembly, e.g., in any of the disparate pressure and/or temperature conditions of the cryogenic distillation processes known in the art. In alternate embodiments, the acid-gas-rich streams **608a** and/or **608b** are combined and introduced into the distillation tower **502** at an intermediate section or side/bottom reboilers.

[0093] Further, as described above, routing moisture rich liquid streams, e.g., acid-gas-rich streams **608a** and/or **608b**, through warmer temperatures in the process may mitigate the risk of hydrate formation or the freezing of heavy hydrocarbons and/or glycol. Additionally, removal of liquid at intermediate temperatures may also result in lower chilling loads on subsequent chillers, leading to improved efficiencies.

[0094] As a result of the above benefits, the feed conditioning configurations described herein may yield less dissolved methane and higher acid gas concentrations in the liquid streams entering the tower **502**, resulting in higher water carrying capacities, lower reboiler loads, and, correspondingly, lower distillation tower **502** spray rates. Preliminary calculations indicate that the feed conditioning configuration shown in FIG. 6 has the ability to handle higher moisture content in the feed stream **504**, when compared to the feed conditioning configuration shown in FIG. 5, e.g., 1.8 times higher moisture content for some feed compositions. Additionally, the configuration shown in FIG. 6 reduced the feed refrigeration requirements when compared to the configuration shows in FIG. 5, e.g., a potential savings of nearly 10% in chilling train refrigeration duty for some feed compositions. The ability to process higher moisture content flows, requiring lower chilling capacities, and options for heat integration are particular benefits of this embodiment. In alternate embodiments, static mixers or “turbulators” may be used in the chillers to facilitate water vapor absorption into the acid gas liquid.

[0095] FIG. 7 is a schematic diagram of a second embodiment of a feed conditioning configuration **700** prior to a distillation tower **502**. The components of FIG. 7 may be the same as the identically numbered components of FIGS. 5-6 except as otherwise noted. The feed conditioning configuration **700** includes a direct-contact recycle dehydration process. The feed conditioning configuration **700** is configured to receive a sour gas via a sour gas feed stream **504**. The sour gas feed stream **504** is passed to a dehydration unit **506**. The dehydration unit **506** may separate the sour gas feed stream **504** into a first stream **508** comprising substantially water and a partially dehydrated feed stream **510** having the bulk of water removed. The partially dehydrated feed stream **510** is passed to a scrubber **702**. A chiller (not shown) may

cool the stream before entering the scrubber **702**. For example, the chiller may cool the stream to a temperature that is less than about +30 °C, or less than about +25 °C, or less than about +20 °C, and that is greater than about -10 °C, or greater than about -5 °C, or greater than 0 °C. In some embodiments, the chiller may cool the stream to a temperature between about +30 °C and about -10 °C, or between about +20 °C and about 0 °C. In the scrubber **702** moisture is removed from the partially dehydrated feed stream **510** to create a first stream **704**, e.g., a wet liquid stream, which may contain a significant amount of water, some heavy hydrocarbons, e.g., ethane, propane, etc., or acid gas components, or any combination thereof. The scrubber **702** may also create a partially dehydrated stream **706** having at least a portion of the moisture removed. The scrubber **702** may pass the first stream **704** to a bottom section of the distillation tower **502**, e.g., the lower section **106** of FIGS. 1-4, and may send the partially dehydrated stream **706** to a chiller **602a**. The chiller **602a** may chill the partially dehydrated stream **706** to a first intermediate temperature, thereby condensing at least a portion of the partially dehydrated stream **706** and creating a two-phase stream **708**. The first intermediate temperature may be less than about +30 °C, or less than about +25 °C, or less than about +20 °C, or less than about +15 °C, or less than about +10 °C and may be greater than about -40 °C, or greater than about -35 °C, or greater than about -30 °C, or greater than about -25 °C, or greater than about -20 °C. In some embodiments, the first intermediate temperature may be between about +30 °C and about -40 °C, or between about +10 °C and -20 °C. The chiller **602a** may send the two-phase stream **708** to a separator **604a**. The separator **604a** separates the two-phase stream **708** into a methane-rich stream **606** and an acid-gas-rich stream **608a**. The separator **604a** may return the acid-gas-rich stream **608a** as a recycle stream to the scrubber **702**, e.g., to facilitate dehydration, and may send the methane-rich stream **606** to a second stage chiller **602b**. The chiller **602b** may cool the methane-rich stream **606** to a second intermediate temperature, creating a two-phase stream **710**. The second intermediate temperature may be less than about -10 °C, or less than about -15 °C, or less than about -20 °C, and may be greater than about -80 °C, or greater than about -75 °C, or greater than about -70 °C, or greater than about -65 °C, or greater than about -60 °C. In some embodiments, the second intermediate temperature may be between about -20 °C and about -80 °C, or between about -20 °C and about -60 °C. The two-phase stream **710** may be separated into a substantially vapor and substantially liquid stream in a separator (not shown) and introduced to a section of the tower **502**, e.g., the middle controlled freeze zone section **108** of FIGS. 1-4. Alternatively, the liquid stream may be recycled back to the scrubber **702**, or another scrubber in the feed conditioning train. Some embodiments of the configuration **700** may include an expander device, e.g., the expander

device **102** of FIGS. 1-4, prior to introducing the chilled stream **710**, the first stream **704**, or both to the tower **502**. As discussed above with respect to the expander device **102**, the expander device may aid in cooling the feed gas before it enters the distillation tower **502**. The tower **502** may separate the conditioned feed stream, e.g., the chilled methane-rich stream **710**,
5 into an overhead stream **516** comprising methane and/or nitrogen and a stream **518** comprising water, carbon dioxide, and/or heavy hydrocarbons.

[0096] The feed conditioning configuration **700** may utilize a direct-contact process, e.g., a packed or trayed column, in the scrubber **702**. Utilizing a direct-contact process may allow additional moisture to be removed from the sour gas stream over certain prior art processes.
10 Unlike certain prior art processes, the sour gas feed stream **504** in the present embodiment may contain non-negligible amounts of hydrocarbons. The post-scrub process liquid exiting the scrubber **702** may be combined with the first stream **704**, e.g., the wet liquid stream, and introduced into the bottoms of the tower **502**.

[0097] FIG. 8 is a schematic diagram of a third embodiment of a feed conditioning
15 configuration **800** prior to a distillation tower **502**. The components of FIG. 8 may be the same as the identically numbered components of FIGS. 5-7 except as otherwise noted. The feed conditioning configuration **800** includes a side-draw recycle dehydration process. The feed conditioning configuration **800** is configured to receive a sour gas via a sour gas feed stream **504**. The sour gas feed stream **504** is passed to a dehydration unit **506**. The dehydration unit
20 **506** may separate the sour gas feed stream **504** into a first stream **508** comprising substantially water and a partially dehydrated feed stream **510** having at least a portion of the water removed. The partially dehydrated feed stream **510** is passed to a chiller **602a**. The chiller **602a** may cool the partially dehydrated feed stream **510** to a first intermediate temperature, which may condense at least a portion of the dehydrated feed stream **510** when CO₂ concentration is
25 sufficient, creating a partially chilled feed stream **610**. The first intermediate temperature may be less than about +30 °C, or less than about +25 °C, or less than about +20 °C, or less than about +15 °C, or less than about +10 °C and may be greater than about -40 °C, or greater than about -35 °C, or greater than about -30 °C, or greater than about -25 °C, or greater than about -20 °C. In some embodiments, the first intermediate temperature may be between about +30
30 °C and about -40 °C, or between about +10 °C and -20 °C. The partially chilled feed stream **610** may be sent to a scrubber **702**, where moisture may be removed from the partially dehydrated feed stream **610** to create a first stream **704**, e.g., a wet liquid stream, and a partially dehydrated stream **706** having additional moisture removed. The scrubber **702** may pass the

first stream **704** to a bottom section of the distillation tower **502**, e.g., the lower section **106** of FIGS. 1-4, and may send the partially dehydrated stream **706** to a chiller **602b**. The chiller **602b** may cool the partially dehydrated stream **706** to a second intermediate temperature, creating a two-phase stream **710**, and may send the two-phase stream **710** to a section of the tower **502**, e.g., the middle controlled freeze zone section **108** of FIGS. 1-4. The second intermediate temperature may be less than about -10 °C, or less than about -15 °C, or less than about -20 °C, and may be greater than about -80 °C, or greater than about -75 °C, or greater than about -70 °C, or greater than about -65 °C, or greater than about -60 °C. In some embodiments, the second intermediate temperature may be between about -20 °C and about -80 °C, or between about -20 °C and about -60 °C. Some embodiments of the configuration **800** may include an expander device, e.g., the expander device **102** of FIGS. 1-4, prior to introducing the chilled stream **710**, the first stream **704**, or both to the tower **502**. As discussed above with respect to the expander device **102**, the expander device may aid in cooling the feed gas before it enters the distillation tower **502**. The tower **502** may separate the conditioned feed stream, e.g., the methane-rich stream **710**, into an overhead stream **516** comprising methane and/or nitrogen and a stream **518** comprising water, carbon dioxide, and/or heavy hydrocarbons.

[0098] The configuration **800** further includes a side-draw recycle system that may take a liquid stream **802** from an intermediate location in the tower **502** bottoms section, and may pass the liquid stream **802** through a heat exchanger **804** to the scrubber **702**. In some embodiments, a stream comprising significant amounts of acid gas, e.g., the liquid stream **802**, the stream **518**, or both, may be recycled and/or recirculated and mixed with the feed entering the feed conditioning system, e.g., via the sour gas feed stream **504**, as indicated by the dashed lines **806** and **808**, respectively. Alternate mixing sites in the configuration **800** may be optionally selected depending on the desired operating characteristics of the configuration **800**. Mixing the comparatively high CO₂ and/or H₂S slip stream with the feed stream may increase the concentration of these components as the stream passes through the feed conditioning configuration **800**. This increase in acid gas concentrations in the feed conditioning configuration **800**, and particularly in the chilling train, may result in a greater amount of liquid to condense, resulting in a greater amount of moisture removed from the conditioned stream and ultimately the chilled stream **710** entering the tower **502**. Those of skill in the art will appreciate that while the slip stream, side-draw, and/or other recycle embodiments may increase the feed refrigeration load experienced by the feed conditioning configuration **800**, it

may nonetheless be desirable in some contexts, e.g., when the increase in feed refrigeration load is offset by the energy and/or capital savings due to relaxation of the feed moisture specification. Thus, the internal heat exchange between the side-draw and the “wet” liquid, i.e., the partially chilled feed stream **610**, may increase the efficiency of the configuration **800** in some low feed acid gas situations where less liquid may be generated during the feed chilling process.

[0099] Additionally, in embodiments having a side-draw, slip stream, or other feature for recycling downstream fluids e.g., the acid-gas-rich stream **608a** of the feed conditioning configuration **600** of FIG. 6, the stream **518** of FIG. 9, etc., incorporated into the feed conditioning configuration, the recycle stream may function as a tool for upset recovery. When there are indications of an upset condition, e.g., temporary ice and/or hydrate formation, as may happen near the coldest region of the feed conditioning configuration, the upset recovery technique may be optionally and/or temporarily employed. Specifically, a stream containing a comparatively greater amounts of acid gas, e.g., CO₂ and/or H₂S, may be recycled and introduced or contacted upstream in the feed conditioning configuration, thereby introducing a dryer and/or warmer stream for dislodging any accumulated hydrates. Once the upset has been recovered and/or eliminated, the upset recovery tool may be secured.

[0100] FIG. 9 is a schematic diagram of a fourth embodiment of a feed conditioning configuration **900** prior to a distillation tower **502**. The components of FIG. 9 may be the same as the identically numbered components of FIGS. 5-8 except as otherwise noted. The feed conditioning configuration **900** includes a heavy hydrocarbon removal and dehydration process. The feed conditioning configuration **900** is configured to receive a sour gas via a sour gas feed stream **504**. The sour gas feed stream **504** is passed to a dehydration unit **506**. The dehydration unit **506** may separate the sour gas feed stream **504** into a first stream **508** comprising substantially water and a partially dehydrated feed stream **510** having the bulk of water removed. The partially dehydrated feed stream **510** is passed to a chiller **602a**. The chiller **602a** may cool the partially dehydrated feed stream **510** to a first intermediate temperature, e.g., condensing at least a portion of the dehydrated feed stream **510** and creating a partially chilled feed stream **610**. The first intermediate temperature may be less than about +30 °C, or less than about +25 °C, or less than about +20 °C, or less than about +15 °C, or less than about +10 °C and may be greater than about -40 °C, or greater than about -35 °C, or greater than about -30 °C, or greater than about -25 °C, or greater than about -20 °C. In some embodiments, the first intermediate temperature may be between about +30 °C and about -40

°C, or between about +10 °C and -20 °C. The partially chilled feed stream **610** may be sent to a heavy hydrocarbon recovery column **904** where moisture may be removed from the partially dehydrated feed stream **610**. The heavy hydrocarbon recovery column **904** may create a first stream **704**, e.g., a wet liquid stream, which may contain a significant amount of moisture, some heavy hydrocarbons, e.g., propane, and/or acid gas components, or any combination thereof. The heavy hydrocarbon recovery column **904** may also create a partially dehydrated stream **706** having additional moisture removed. The heavy hydrocarbon recovery column **904** may send the first stream **704** out of the configuration **900** and may send the partially dehydrated stream **706** to a chiller **602b**. The chiller **602b** may further chill the partially dehydrated stream **706** to a second intermediate temperature, condensing at least a portion of the partially dehydrated stream **706** and creating a two-phase stream **708**. The second intermediate temperature may be less than about +30 °C, or less than about +25 °C, or less than about +20 °C, or less than about +15 °C, or less than about +10 °C and may be greater than about -40 °C, or greater than about -35 °C, or greater than about -30 °C, or greater than about -25 °C, or greater than about -20 °C. In some embodiments, the second intermediate temperature may be between about +30 °C and about -40 °C, or between about +10 °C and -20 °C. The chiller **602b** may send a two-phase stream **708** to a separator **604a** where the two-phase stream **708** may be separated into a methane-rich stream **612** comprising substantially vapor and an acid-gas-rich stream **608a** comprising substantially liquid. The separator **604a** may send the acid-gas-rich stream **608a** to a bottom section of the distillation tower **502** and may send the methane-rich stream **612** to a second stage chiller **602c**, e.g., a chiller **602a** or **602b** of FIG. 6. The chiller **602c** may cool the methane-rich stream **612** to a third intermediate temperature, creating a chilled methane-rich stream **710**, and may send the chilled methane-rich stream **710** to a section of the tower **502**, e.g., the middle controlled freeze zone section **108** of FIGS. 1-4. The third intermediate temperature may be less than about -10 °C, or less than about -15 °C, or less than about -20 °C, and may be greater than about -80 °C, or greater than about -75 °C, or greater than about -70 °C, or greater than about -65 °C, or greater than about -60 °C. In some embodiments, the third intermediate temperature may be between about -20 °C and about -80 °C, or between about -20 °C and about -60 °C. Some embodiments of the configuration **900** may include an expander device, e.g., the expander device **102** of FIGS. 1-4, prior to introducing the methane-rich stream **710**, the acid-gas-rich stream **608a**, or both to the tower **502**. As discussed above with respect to the expander device **102**, the expander device may aid in cooling the feed gas before it enters the distillation tower **502**. The tower **502** may separate the conditioned feed stream, e.g., the chilled methane-rich stream **710**, into

an overhead stream **516** comprising methane and/or nitrogen and a stream **518** comprising water, carbon dioxide, and/or heavy hydrocarbons. The stream **518** may be cooled using a heat exchanger **902**, e.g., a heat exchanger **100** of FIGS. 1-4, and introduced into the heavy hydrocarbon recovery column **904** to further remove moisture. In an alternative embodiment, liquid stream **518**, comprising significant amounts of acid gas, e.g., CO₂ and/or H₂S, may be passed from the tower **502** and recycled and/or recirculated and mixed with the feed entering the feed conditioning system, e.g., via the sour gas feed stream **504**. Mixing the comparatively high CO₂ and/or H₂S slip stream with the feed stream may increase the concentration of these components as the stream passes through the feed conditioning configuration **900**. This increase in acid gas concentrations in the feed conditioning configuration **900**, and particularly in the chilling train, may result in a greater amount of liquid to condense, resulting in a greater amount of moisture removed from the conditioned stream and ultimately the chilled stream **710** entering the tower **502**. Those of skill in the art will appreciate that while the slip stream, side-draw, and/or other recycle embodiments may increase the feed refrigeration load experienced by the feed conditioning configuration **900**, it may nonetheless be desirable in some contexts, e.g., when the increase in feed refrigeration load is offset by the energy and/or capital savings due to relaxation of the feed moisture specification.

[0101] Those of skill in the art will appreciate that a two-stage progressive chilling process or a sequential cooling assembly described above may not be available in certain contexts, and, consequently, only one stage of refrigeration may be available. In such cases, alternate embodiments of the feed conditioning configurations **600**, **700**, **800**, and/or **900** may still be achieved using a multi-pass heat exchanger, e.g., a brazed aluminum heat exchanger, to obtain the desired heat exchange between the feed gas and the feed refrigerant. Using a multi-pass heat exchanger in this manner, the feed gas may be drawn out of the heat exchanger during conditioning at an intermediate temperature and separated into a liquid stream and a vapor stream. The vapor stream produced in this manner may be returned for further chilling. The liquid stream produced in this manner may be introduced either into the tower **502** either directly, as in feed conditioning configurations **600** and **900**, or indirectly, as in feed conditioning configurations **700** and **800**. These and other variations will be apparent to those of skill in the art.

[0102] It is important to note that the steps described above in connection with FIGS. 5-9 are provided for illustrative purposes only and a particular step may not be required to perform the inventive methodology. Moreover, FIGS. 5-9 may not illustrate all the steps that may be

performed. The claims, and only the claims, define the inventive system and methodology.

[0103] Disclosed aspects may be used in hydrocarbon management activities. As used herein, “hydrocarbon management” or “managing hydrocarbons” includes hydrocarbon extraction, hydrocarbon production, hydrocarbon exploration, identifying potential hydrocarbon resources, identifying well locations, determining well injection and/or extraction rates, identifying reservoir connectivity, acquiring, disposing of and/or abandoning hydrocarbon resources, reviewing prior hydrocarbon management decisions, and any other hydrocarbon-related acts or activities. The term “hydrocarbon management” is also used for the injection or storage of hydrocarbons or CO₂, for example the sequestration of CO₂, such as reservoir evaluation, development planning, and reservoir management. The disclosed methodologies and techniques may be used in extracting hydrocarbons from a subsurface region and processing the hydrocarbons. Hydrocarbons and contaminants may be extracted from a reservoir and processed. The hydrocarbons and contaminants may be processed, for example, in the distillation tower previously described. After the hydrocarbons and contaminants are processed, the hydrocarbons may be extracted from the processor, such as the distillation tower, and produced. The contaminants may be discharged into the Earth, etc. For example, as shown in FIGS. 5-9, the method for producing hydrocarbons may include producing the hydrocarbon-enriched vapor stream extracted from the distillation tower. The method may also include removing the hydrocarbon-enriched vapor stream from the distillation tower before producing the hydrocarbon-enriched vapor stream. The initial hydrocarbon extraction from the reservoir may be accomplished by drilling a well using hydrocarbon drilling equipment. The equipment and techniques used to drill a well and/or extract these hydrocarbons are well known by those skilled in the relevant art. Other hydrocarbon extraction activities and, more generally, other hydrocarbon management activities, may be performed according to known principles.

[0104] It should be understood that the numerous changes, modifications, and alternatives to the preceding disclosure can be made without departing from the scope of the disclosure. The preceding description, therefore, is not meant to limit the scope of the disclosure. Rather, the scope of the disclosure is to be determined only by the appended claims and their equivalents. It is also contemplated that structures and features in the present examples can be altered, rearranged, substituted, deleted, duplicated, combined, or added to each other.

CLAIMS

1. A system for conditioning a sour gas feed stream for a cryogenic distillation tower, comprising:
 - a dehydration unit configured to separate the sour gas feed stream into a first stream comprising water and a feed stream; and
 - a sequential cooling assembly coupled to both the dehydration unit and the cryogenic distillation tower, wherein the sequential cooling assembly is connected by a cooled feed stream header to a cryogenic distillation tower feed inlet and comprises:
 - a first stage configured to separate the feed stream into a partially cooled feed stream and a second stream comprising acid gas;
 - a second stage configured to cool the partially cooled feed stream into a cooled feed stream and a third stream comprising acid gas;
 - a scrubber for removing moisture;
 - wherein the scrubber is configured to receive an acid-gas rich recycle stream, comprising
 - a stream from an outlet of a bottom section of the cryogenic distillation tower, or
 - a slip stream from an intermediate location in the distillation tower bottom section,
 - as part of an upset event recovery technique to recover from or eliminate an upset condition in which ice and/or hydrates have formed in the sequential cooling assembly;
 - wherein the first stage, the second stage, or both are configured to send at least one of the second and third streams to a bottom section of the cryogenic distillation tower.
2. The system of claim 1, wherein the scrubber is coupled to a stream outlet from the second stage.
3. The system of any one of claims 1-2, further comprising a heat exchanger between the cryogenic distillation tower bottom section outlet and the scrubber.
4. The system of any one of claims 1-3, wherein the temperature of the partially cooled feed stream is between about +10 °C to about -60 °C and the temperature of the cooled feed stream is between about -10 °C to about -60 °C.

5. The system of any one of claims 1-4, wherein the second stage is further configured to separate the partially cooled feed stream into a cooled feed stream and a third stream comprising water and acid gas, and wherein the second stage comprises a second separator coupled to a second cryogenic distillation tower bottom section inlet.
6. The system of any one of claims 1-5, wherein the cryogenic distillation tower comprises a controlled freeze zone section.
7. A method of sequentially cooling a sour gas feed stream for a cryogenic distillation tower, comprising:
 - receiving the sour gas feed stream;
 - separating the sour gas feed stream into a water stream and a partially dehydrated feed stream;
 - passing the partially dehydrated feed stream to a sequential cooling assembly;
 - cooling the partially dehydrated feed stream to a first temperature;
 - separating the partially dehydrated feed stream into a partially cooled feed stream comprising vapor and a first stream comprising liquid;
 - cooling the partially cooled feed stream to a second temperature;
 - separating the partially cooled feed stream into a cooled feed stream comprising vapor and a second stream comprising liquid;
 - feeding the cooled feed stream to the cryogenic distillation tower; and
 - mixing an acid-gas-rich liquid stream into a scrubber of the sequential cooling assembly, the scrubber for removing moisture, wherein the acid-gas-rich liquid stream originates at least in part from a bottom section of the cryogenic distillation tower;wherein the mixing step is part of an upset recovery technique, further comprising temporarily employing the upset recovery technique to recover from or eliminate an upset condition in which ice and/or hydrates have formed in the sequential cooling assembly.
8. The method of claim 7, wherein the first stream comprises carbon dioxide.
9. The method of claim 7 or 8, further comprising cooling the cooled feed stream to a third temperature prior to feeding the cooled feed stream to the cryogenic distillation tower.
10. The method of any one of claims 7-9, wherein the first stream, the second stream, or both are sent to a bottom section of the cryogenic distillation tower.
11. A cryogenic distillation system, comprising:

a progressive conditioning section for a sour gas feed stream, comprising:

a first stage assembly configured to separate the sour gas feed stream into a first stream comprising water and a partially dehydrated feed stream;

a second stage assembly coupled to the first stage assembly and configured to separate the partially dehydrated feed stream into a progressively dehydrated feed stream comprising a hydrocarbon and a second stream comprising an acid gas, and further configured to cool the progressively dehydrated feed stream to a first temperature, wherein the second stage assembly includes a scrubber for removing moisture, and wherein the scrubber is configured to receive an acid-gas-rich recycle stream as part of an upset recovery technique that is temporarily employed to recover from or eliminate an upset condition in which ice and/or hydrates have formed in the progressive conditioning section; and

a third stage assembly coupled to the second stage assembly and further configured to cool the progressively dehydrated feed stream to a second temperature, wherein the second temperature is colder than the first temperature; and

a cryogenic distillation tower comprising a controlled freeze zone, wherein the cryogenic distillation tower is configured to receive the progressively dehydrated feed stream;

wherein the acid-gas-rich recycle stream originates from a bottom section of the cryogenic distillation tower.

12. The system of claim 11, wherein the third stage assembly is further configured to split the progressively dehydrated feed stream into a cooled feed stream comprising a hydrocarbon and a third stream comprising an acid gas, and wherein the second stage assembly, the third stage assembly, or both are coupled to a bottom section of the cryogenic distillation tower.

13. The system of claim 11 or 12, further comprising a fourth stage assembly configured to cool the cooled feed stream to a third temperature, wherein the third temperature is colder than the second temperature.