

METHOD FOR SEPARATING A FEED GAS IN A COLUMN

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of United States patent application
5 number 62/010,664 filed June 11, 2014 entitled METHOD FOR SEPARATING A FEED
GAS IN A COLUMN, the entirety of which is incorporated by reference herein.

FIELD

[0002] The present techniques relate generally to processing of natural gas or similar
10 compounds to remove impurities. More particularly, the present techniques relate to
distillation of natural gas or similar compounds having a relatively low carbon dioxide (CO₂)
concentration to separate and remove the CO₂ from the natural gas.

BACKGROUND

15 [0003] This section is intended to introduce various aspects of the art, which may be
associated with exemplary embodiments of the present techniques. This description is
believed to assist in providing a framework to facilitate a better understanding of particular
aspects of the present techniques. Accordingly, it should be understood that this section
should be read in this light, and not necessarily as admissions of prior art.

20 [0004] Most raw natural gas extracted from the Earth contains primarily methane (CH₄)
and also contains, to varying degrees, low and high molecular weight hydrocarbon
compounds. The primary component methane (CH₄), as a low molecular weight
hydrocarbon, is typically a desirable component within harvested natural gas. Today,
purified CH₄ is viewed as a valuable energy source because it is generally considered as a
25 clean-burning fuel in numerous applications. Compared to other hydrocarbon fuels, the
burning of CH₄ produces less carbon dioxide (CO₂) emissions for each unit of heat released.
Additionally, based on its ratio of heat of combustion to its molecular mass, CH₄ produces
more heat per mass unit than complex hydrocarbons. Furthermore, CH₄ may generally be
transported with ease. Thus, in many cities, CH₄ is piped into homes for domestic heating
30 and cooking purposes as an efficient fuel. In this context, CH₄ is usually known as natural
gas, which has an energy content of ~1,000 BTU per standard cubic foot in certain examples.
In the form of compressed natural gas, CH₄ may be used as a vehicle fuel where it may be
more environmentally friendly than other fossil fuels such as gasoline or diesel.

[0005] Raw natural gas may need to be processed to remove contaminants and impurities such as heavier hydrocarbons including ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}), among others. When brought to the surface and processed along with the CH_4 , such heavier hydrocarbons are collectively referred to as Natural Gas Liquids (NGLs). The raw natural gas may also include acid gas contaminants such as carbon dioxide (CO_2) and hydrogen sulfide (H_2S), and mercaptans, such as methanethiol (CH_3SH) and ethanethiol (C_2H_5SH). Additionally, the raw natural gas may contain contaminants including nitrogen (N_2), helium (He), water vapor, liquid water, mercury, and natural gas condensate.

[0006] The heavier hydrocarbons, NGLs, and contaminants within the raw natural gas may lead to equipment malfunction, production failure, product contamination, among other detrimental production issues. For example, when the acid gas contaminant CO_2 is combined with water, it may create a corrosive form of carbonic acid. Additionally, CO_2 will reduce the BTU value of the natural gas and lower the economic viability of the natural gas, for example, in concentrations of more than 2%. Similarly, H_2S can dissolve in water to create a highly corrosive acid that can attack metal structures. Moreover, water in the form of a vapor or liquid within a raw natural gas may form hydrates, thus, potentially leading to plugging of pipelines. Thus, it may be economically beneficial to remove the contaminants from the natural gas to produce purified CH_4 .

[0007] The separation techniques for purifying raw natural gas may utilize flash drums, separators, and distillation and fractionation towers. In some cases, the separation techniques may embody cryogenic temperatures where CO_2 may solidify and fall out of the natural gas. Other technologies for the removal of CO_2 from natural gas are based on principles that do not involve cryogenic temperatures. For example, some techniques may be solvent-based, such as capturing CO_2 with a chemical, physical, or hybrid solvent, and reversing the process to remove the captured CO_2 .

[0008] U.S. Patent 7,325,415 discloses a process and device for the removal of solid freezable species such as carbon dioxide, water, and heavy hydrocarbons from a natural gas feed stream during liquefaction to produce LNG. The solid freezable species may be removed on a continuous basis following liquefaction of the natural gas feed stream. The solid freezable species may then be liquefied on a continuous basis if required. Continuous removal of the freezable species from the natural gas feed stream is apparently achieved by maintaining both cooling and separation apparatuses at the same working pressure. The

technique provides that at least part of the cooling vessel is constructed from a material having a low thermal conductivity which discourages formation of the solids of the freezable species on the walls of the cooling vessel.

[0009] U.S. Patent 6,755,965 discloses a process for ethane extraction from a gas stream based on turbo-expansion and fractionation with no mechanical refrigeration. The feed gas is sweetened and dehydrated by a conventional amine process followed by a molecular sieve unit to remove carbon dioxide and water. After this pretreatment, the feed gas undergoes a series of cooling steps through a cryogenic brazed aluminum heat exchanger and is fed to a de-methanizer column. A rich-methane stream is recovered from the top of this column and fed to a centrifugal compressor and subsequently routed to a booster/turbo-expander. The temperature of the methane gas is reduced by the expansion allowing the cooled methane stream to be a cooling source for the cryogenic heat exchanger. A feed for a de-ethanizer column comes from the bottom liquids of the de-methanizer column. Thus, ethane is recovered overhead from the de-ethanizer column.

[0010] U.S. Patent 6,516,631 discloses a cryogenic natural gas liquids recovery process, which includes the use of a de-methanizer and a de-ethanizer. The recovery process also includes a step of recycling a portion of the de-ethanizer overhead to the de-methanizer.

[0011] U.S. Patent 6,082,133 discloses an apparatus for separating CO₂ from a mixture of gases having CO₂ and a second gas, where the apparatus includes an active heat exchanger and a regenerating heat exchanger. The mixture of gases is present in the active heat exchanger at a predetermined pressure, which is chosen such that CO₂ freezes on the heat exchanger surface. The heat exchanger surface is cooled by a refrigerant having a temperature below that at which CO₂ freezes at the predetermined pressure. The regenerating heat exchanger includes a heat exchange surface in contact with the refrigerant and also in contact with a layer of frozen CO₂. The refrigerant enters the regenerating heat exchanger at a temperature above that at which the CO₂ in the frozen layer of CO₂ sublimates. The sublimation of the solid CO₂ cools the refrigerant prior to the refrigerant being expanded through an expansion valve, which reduces the temperature of the refrigerant to a point below the freezing point of CO₂ at the predetermined pressure. The refrigerant is re-compressed by a compressor after leaving the active heat exchanger. A second precooling heat exchanger pre-cools the compressed refrigerant by providing thermal contact with the refrigerant leaving the active heat exchanger.

[0012] U.S. Patent 5,819,555 discloses a process to remove CO₂ from a feed stream. The solid forming property of CO₂ and the low vapor phase solubility of carbon dioxide at cold temperatures form the basis for the separation process. The cooled feed stream enters a separation vessel where process means are provided to produce and separate CO₂ solids. The
5 CO₂ is removed from the vessel as a CO₂ rich liquid stream, and a purified cold vapor is removed from the separation vessel as a product stream.

[0013] The aforementioned techniques may provide for purifying a raw gas stream. However, there remains an ongoing need for more efficient separation techniques to purify the raw gas stream by removing CO₂ to produce purified CH₄ for use as a valuable energy
10 source.

SUMMARY

[0014] An exemplary embodiment provides a method of controlling a temperature in a column. A method includes feeding a feed gas into a port of a sleeve disposed around at least a portion of a periphery of the column. The sleeve includes a space between an outer wall of
15 the column and an inner wall of the column. The sleeve releases the feed gas into the column through an opening disposed at an opposite end of the sleeve from the port.

[0015] Another exemplary embodiment provides a method of separating an acid gas component from a raw natural gas stream in a column. The method includes maintaining a temperature of a zone in the column below the freezing point of an acid gas component in a
20 raw natural gas stream. The method includes feeding the raw natural gas stream at a temperature above the freezing point of the acid gas component into an upper portion of an internal sleeve disposed around a zone of the column. The method includes flowing the raw natural gas stream downward through the internal sleeve to cool the raw natural gas stream and warm an internal wall of the column in the zone, melting accumulated solids from the
25 inner wall. The method also includes releasing the raw natural gas stream into the column at a lower portion of the zone.

[0016] Another exemplary embodiment provides a column for the separation of a feed gas. The column includes an internal sleeve section located around a periphery of a zone of the column. The column includes a feed gas inlet located in an upper region of the internal
30 sleeve, where the internal sleeve is configured to channel the feed gas downward around the periphery of the column. The column includes an inner opening from the internal sleeve, configured to release the feed gas into the zone at a point below the feed gas inlet.

DESCRIPTION OF THE DRAWINGS

[0017] The advantages of the present techniques are better understood by referring to the following detailed description and the attached drawings, in which:

[0018] Fig. 1 is a block diagram of a system to process a feed gas;

5 [0019] Fig. 2 is a drawing of a cryogenic distillation column system configured to receive a feed gas having relatively high CO₂ content;

[0020] Fig. 3 is a simplified process flow diagram of a system for feeding a feed gas above a melt tray and into a controlled freeze zone section of a column;

10 [0021] Fig. 4 is a drawing of feeding a low-CO₂ content feed gas into a controlled freeze zone section of a column as depicted in Fig. 3;

[0022] Fig. 5 is a simplified process flow diagram of a system for feeding a feed gas below a melt tray and into a stripping section of a column;

[0023] Fig. 6 is a drawing of feeding a low-CO₂ content feed gas into a controlled freeze zone section of a column and a feeding a low-CO₂ content feed gas below the controlled
15 freeze zone section of the column;

[0024] Fig. 7 is a graph of a CO₂ / CH₄ temperature-freeze profile; and

[0025] Fig. 8 is a method of processing a feed gas in a column.

DETAILED DESCRIPTION

20 [0026] In the following detailed description section, specific embodiments of the present techniques are described. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the techniques are not limited to the specific embodiments
25 described below, but rather, include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0027] At the outset, for ease of reference, certain terms used in this application and their meanings as used in this context are set forth. To the extent a term used herein is not defined below, it should be given the broadest definition persons in the pertinent art have given that
30 term as reflected in at least one printed publication or issued patent. Further, the present techniques are not limited by the usage of the terms shown below, as all equivalents, synonyms, new developments, and terms or techniques that serve the same or a similar

purpose are considered to be within the scope of the present claims.

[0028] Certain terms are used throughout the following description and claims to refer to particular features or components. As one skilled in the art would appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name only. The figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in schematic form and some details of conventional elements may not be shown in the interest of clarity and conciseness. When referring to the figures described herein, the same reference numerals may be referenced in multiple figures for the sake of simplicity. In the following description and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus, should be interpreted to mean "including, but not limited to."

[0029] The term "acid gas" refers to any gas that dissolves in water to produce an acidic solution. Non-limiting examples of acid gases include hydrogen sulfide (H_2S), carbon dioxide (CO_2), sulfur dioxide (SO_2), or mixtures thereof. The term "trace sulfur compounds" includes carbon disulfide (CS_2), carbonyl sulfide (COS), mercaptans, or mixtures thereof. The term "acid gas injection" (AGI) refers to the disposal of an acid gas stream by compressing it and introducing the pressurized stream into a subterranean reservoir.

[0030] The term "controlled freeze zone process" or "cryogenic distillation" refers to a process that takes advantage of the freezing potential of carbon dioxide in cryogenic distillation, rather than avoiding solidification of carbon dioxide. In the controlled freeze zone process, acid gas components are separated by cryogenic distillation through the controlled freezing and melting of carbon dioxide in a single column, without the use of freeze-suppression additives. The controlled freeze zone process uses a cryogenic distillation column with a special internal section (controlled freeze zone section) to handle the solidification and melting of CO_2 . This controlled freeze zone section (or "CFZ section") does not contain packing or trays like conventional distillation columns, instead it contains one or more spray nozzles and a melting tray. Solid carbon dioxide forms in the vapor space in the CFZ section and falls into the liquid on the melt tray. Substantially all of the solids that form are confined to the controlled freeze zone section. In the rectification section above the CFZ section, methane (CH_4) is enriched to produce an overhead CH_4 -rich stream suitable for sale, while the stripping section below the CFZ section generates a liquid bottoms stream

containing contaminants such as carbon dioxide (CO₂) and hydrogen sulfide (H₂S) with very little residual methane.

[0031] The term “melt tray” refers to a component within a controlled freeze zone of a column where solid contaminants may be warmed and melted to exit the melt tray and flow
5 into a lower stripping section of a column.

[0032] The term “rectification section” refers to a section of a cryogenic distillation column where an overhead CH₄ rich vapor stream may be purified to meet pipeline or liquid natural gas (LNG) feed quality via conventional distillation.

[0033] The term “stripping section” refers to a section of a cryogenic distillation column
10 where a liquid bottoms stream, including containing contaminants such as CO₂ and H₂S, may be processed to recover CO₂ for injection into a well or for use in enhanced oil recovery efforts.

[0034] A sour natural gas produced from a reservoir may contain acid gases, including CO₂ and H₂S, that may render the natural gas as unusable for direct gas sales or household
15 use. Thus, it may be advantageous to use a cryogenic distillation process to separate the acid gases from the natural gas released from the reservoir to generate a clean sales gas, which may include primarily methane (CH₄) gas. One particular cryogenic process that may be utilized includes the Controlled Freeze Zone™ (CFZ™) process, which is a single-step, cryogenic process for the separation of CO₂ and H₂S from natural gas involving the
20 controlled freezing and remelting of CO₂. The CFZ™ process may enable the production of sales-quality gas at lower costs while advantageously handling gases with a wide range of CO₂ and H₂S content. This unconventional cryogenic distillation process may include feeding the raw natural gas into a lower section of a column where lighter vapors may rise upward into a controlled freeze zone and a rectification zone to be purified and to exit the
25 column as a purified CH₄ stream. As the vapor-phase CH₄ is stripped from the raw natural gas, a liquefied acid gas stream, including contaminants such as CO₂ and H₂S, may emerge and may exit the lower stripping section of the column as a liquid for disposal or additional processing.

[0035] When the CO₂ content of the feed gas is about 16 mol% or greater, the feed stream
30 may be introduced to the CFZ™ process below the controlled freeze zone using conventional distillation tower internals. However, when the CO₂ content of the feed gas is lower than about 16 mol%, it is less efficient to introduce the feed stream below the melt tray.

[0036] In embodiments described herein, a feed gas with a lower CO₂ content may be fed at the freezing zone. To prevent freezing of CO₂ on the walls, the feed gas can be injected into an upper region of a hollow area positioned around the perimeter of the freezing zone. An opening in the lower region of the hollow area releases the feed gas above the melt zone.

5 [0037] Fig. 1 is a block diagram of a system **100** to process a feed gas in accordance with embodiments of the present techniques. The feed gas **102** may be a vapor or a multi-phase fluid including methane (CH₄) and at least one acid gas, e.g., CO₂, H₂S. In examples, the feed gas **102** may include a CO₂ concentration range of less than about 16 mol%, or less than about 15 mol%, or less than about 14 mol%, or less than about 13 mol%, or less than about 12 mol%, or less than about 11 mol%, or less than about 10 mol%, or from about 5 to 8 mol%, about 5 to 10 mol%, about 5 to 12 mol%, or about 5 to 14 mol%, along with relatively low concentrations of H₂S and heavier hydrocarbons.

[0038] As shown in Fig. 1, the feed gas **102** may enter a precooler **104**. Within the precooler **104**, the temperature of the feed gas **102** may be lowered to a temperature of about 15 -60 °F (-51.1 °C) to give a cooled feed gas **106**. In one or more embodiments, the precooler **104** may be an indirect heat exchanger, where the cooled feed gas **106** may be expanded through a Joule-Thompson (J-T) valve, for example. The cooled feed gas **106** may be fed to a refrigeration system such as a chiller **108** for additional cooling and refrigeration. A chilled feed gas **110** may emerge from the chiller **108** and may be introduced into a column **112**.

20 [0039] The column **112** may be a distillation column for the condensation, separation, and removal of a CO₂-rich liquid from the feed gas **102**. In embodiments, the column **112** may be a cryogenic distillation column where a CO₂ acid gas component may be separated from the chilled feed gas **110** by a cryogenic process including the controlled freezing and melting of CO₂ without the use of freeze-suppression additives.

25 [0040] Within the column **112**, the chilled feed gas **110** may be stripped and removed of CO₂ and other contaminants to produce a vapor **114**, which may exit overhead or a top outlet of the column **112**. The vapor **114** may primarily include CH₄. The vapor **114** may proceed to a heat exchanger **116** to be cooled to form a condensed liquid (e.g., for reflux) and a vapor CH₄ product, e.g., a clean sales gas. Thus, in embodiments, the heat exchanger **116** is a partial condenser. While product sales gas may be collected directly from the heat exchanger **116**, the embodiment illustrated in Fig. 1 depicts a partially-condensed stream **118** discharging from the heat exchanger **116** and entering a vessel **120** (e.g., accumulator or

30

reflux drum). The vapor CH₄ product may exit the vessel **120** as a sales gas **122** for subsequent sale, or as a feed to a liquid natural gas (LNG) plant, and the like. A liquid **124** may be returned as reflux to the column **112** from the vessel **120**. In the column **112**, the CO₂ and other contaminants removed from the chilled feed gas **110** may embody a liquid **126** that
5 may exit a bottom outlet of the column **112** as liquid bottoms and may include primarily CO₂ along with other contaminants.

[0041] Fig. 2 is a drawing of a cryogenic distillation column system **200** configured to receive a feed having relatively high CO₂ content. Like numbers are as described with respect to Fig. 1. As shown in Fig. 2, a column **112** may be a cryogenic distillation column
10 **112** with an associated reboiler and overhead partial condenser, as will be later discussed in detail. In the illustrated embodiment, the column **112** may include three separate sections, such as an upper distillation section or “rectification section” **202**, a middle distillation section or “controlled freeze zone” **204**, and a lower distillation section or “stripping section” **206**. The controlled freeze zone **204** may include a spray nozzle bank **208**, a freeze zone **210**,
15 and a melt tray **212**.

[0042] A chilled two-phase fluid **110**, e.g., liquid/vapor phase fluid, may be introduced into the stripping section **206** where the two-phase fluid **110** may include a CO₂ concentration and a CH₄ concentration, among other heavier hydrocarbons and contaminants. Within the stripping section **206**, the two-phase fluid **110** may be separated into its liquid and vapor
20 components. If solids are anticipated, the solids may be separated prior to entering the stripping section **206** of the column **112**. The conventional process may include feeding a dry feed gas or a liquid/slurry mixture into the stripping section **206**.

[0043] Within the stripping section **206**, the liquid component may collect on the series of trays **214** and flow into a bottom portion of the stripping section **206** to form a liquid pool
25 **216**. The liquid component may primarily include the liquid CO₂ and dissolved H₂S. The vapor component may leave the stripping section **206** and proceed upward into risers in the melt tray **212**. As the vapor component continues upward, it may enter the controlled freeze zone **204**. The risers of the melt tray **212** may act as a vapor distributor for uniform distribution through the controlled freeze zone **204**. As it continues to rise upward into the
30 controlled freeze zone **204**, the vapor component may contact a spray of cold liquid **217** emitted by the spray nozzle bank **208**. When in contact with the spray of cold liquid **217**, a portion of the CO₂ in the vapor component may solidify within the controlled freeze zone

204. This may act to remove or “freeze out” the CO₂ contaminant within the vapor component. The solidified CO₂ 218 may fall onto the melt tray 212 where it may be heated to form a liquid 220 that may be collected on the melt tray 212. The liquid CO₂ 220 may then flow into the stripping section 206 and into the liquid pool 216, which primarily includes liquid CO₂. The liquid CO₂ 216/220 may exit the stripping section 206 as a sour liquid 222.

[0044] With contaminants removed, the vapor component may continue to flow upward and into the rectification section 202, along with other light gases. The vapor component may include a sweet gas 224, such as methane, CH₄, that may exit overhead of the column 112. The sweet gas 224 may be commercialized or used as an on-site fuel gas. It should be noted that a portion of the sweet gas 224 may be condensed in a heat exchanger 226 to form a partially-condensed stream 228. The partially-condensed stream 228 may enter a reflux drum 230 where a reflux stream, e.g., liquid condensate 232, may be collected and recycled back into the column 112. The liquid condensate 232 may re-enter the column 112 in the form of the spray of cold liquid 217.

[0045] Similarly, a portion of the sour liquid 222 exiting the stripping section 206 may be heated in a reboiler 234 and returned to the liquid pool 216 as a reboiler stream, e.g., a vapor stream 236. The vapor stream 236 may provide energy to the bottom of the cryogenic distillation column 112 to boil off methane and other light components that may be dissolved in the sour liquid 222. A residual reboiled liquid, e.g., a bottoms product 238, may exit the reboiler 234.

[0046] With most distillation-type columns, a raw feed stream may enter a section of a column that has a concentration similar to that of a concentration of species already within the column. For example, in a cryogenic column, a raw feed stream directed into a stripping section may contain a relatively high concentration of CO₂, e.g., at least about 16 mol% or higher, that may match the concentration of the species, e.g., at least about 16 mol% or higher, already within the cryogenic column. In particular, the stripping section may be located below a melt tray, where the melt tray is located in a controlled freeze zone of the column. However, if a raw feed stream with a lower CO₂ concentration, such as less than 16 mol%, or from about 5 mol% to 15 mol%, is injected into the stripping section of the cryogenic column, the lower CO₂ concentration stream may re-vaporize. This re-vaporization may occur in order to match the temperature already within the stripping section, for example, as will be discussed with respect to Fig. 5. To compensate for this effect, the raw

feed stream with the lower CO₂ concentration may need to enter the column at a colder temperature than a raw feed stream with a higher CO₂ concentration. In doing so, extra energy may be expended to remove this additional heat at increased costs. To reduce system power requirements, the present disclosure provides injecting the low-CO₂ raw feed stream into the controlled freeze zone, which may contain a CO₂ concentration similar to that of the raw feed stream.

[0047] Fig. 3 is a simplified process flow diagram **300** of a system for feeding a feed gas above a melt tray and into a controlled freeze zone section of a column. As shown in Fig. 3, a raw feed stream **302** may be initially precooled against a refrigerant **304** to a temperature of about 50 °F (10 °C) to 65 °F (18.3 °C) in a feed precooler **306**. The raw feed stream **302** may contain CH₄, CO₂, along with H₂S and other heavier hydrocarbons. The raw feed stream **302** is a low-CO₂ concentration feed stream, and may have a CO₂ concentration of less than about 16 mol%, or less than 15 about mol%, or less than about 14 mol%, or less than about 13 mol%, or less than about 12 mol%, or less than about 11 mol%, or less than about 10 mol%, or from about 5 to 8 mol%, about 5 to 10 mol%, about 5 to 12 mol%, or about 5 to 14 mol%.

[0048] After precooling, the pre-cooled feed stream **308** may be further cooled by cross-exchange with stream **310** in reboiler **312** and further cooled by cross-exchange with stream **314** in side-reboiler **316** to form a cooled feed stream **318**. The cooled feed stream **318** may enter a first feed chiller **320** where it may be chilled to a temperature of about -30 °F (-34 °C) to about - 50 °F (-45.6 °C), such as about -40 °F (-40 °C), against the lowest stages of the refrigerant **304** to form chilled feed stream **322**. The chilled feed stream **322** may be further chilled via a second feed chiller **324** to a temperature of about -80 °F (-62.2 °C) to about -90 °F (-67.8 °C), such as -83 °F (-64.9 °C), or as low a temperature as possible so as to not form solid CO₂. A chilled feed stream **326** may enter a controlled freeze zone of a column **328** where it may undergo separation and purification techniques.

[0049] If in a vapor form, the chilled feed stream **326** may be contacted by a spray of cold liquid within the controlled freeze zone of the column **328**. The CO₂ concentration within the chilled feed stream **326** may freeze to produce solid CO₂ that falls onto a melt tray. As described above, the melt tray may act to melt the solid CO₂ to form a liquid stream **330** that may exit a bottom outlet of the column **328**. The liquid stream **330** may include primarily a CO₂ concentration, along with other contaminants, such as H₂S and heavier hydrocarbons. The liquid stream **330** may be disposed of in a number of ways. For example, the liquid

stream **330** may be pumped via pump **332** to a disposal well (AGI) as a CO₂-rich liquid **334**. In other embodiments, the CO₂-rich liquid stream **334** may be marketed, for example, for use in enhanced oil recovery.

[0050] After at least a portion of the CO₂ has been removed from the chilled feed stream **326** within the controlled freeze zone, a vapor stream **336** may continue upward through the column **328**. The vapor stream **336** may primarily include a CH₄ vapor, for example, at a CH₄ concentration of 97 mol% or higher.

[0051] The vapor stream **336** may enter a reflux exchanger **337** where it may be heated to a temperature of from about -140 °F (-95.5 °C) to about 50 °F (10 °C), such as from about -134 °F (-92.2 °C) to about 43.8 °F (6.6 °C), to form a heated vapor stream **338** and later fed to a low-pressure compressor **340**. The low-pressure compressor **340** increases the pressure of the heated vapor stream **338** from a pressure of from about 400 psia to 500 psia, such as about 465 psia, to a pressure of from about 1,000 psia to about 1,100 psia, such as about 1,065 psia, to form a compressed vapor stream **342**. A CH₄ refrigerant stream **344** may also be heated by the reflux exchanger **337** and may have a pressure similar to the compressed vapor stream **342**. Thus, both streams, **342** and **344**, may be combined to produce a consolidated gas stream **346** that may be fed into a high-pressure compressor **348** at a pressure of about 1,000 psia to about 1,100 psia, such as about 1,065 psia, and a temperature of about 150 °F (65.6 °C) to about 160 °F (71.1 °C), such as about 156.6 °F (69.2 °C), for example, to feed a sales gas pipeline. In operation, the pressure of the CH₄ refrigerant **344** may be sufficient as is and thus, may bypass the low-pressure compressor **340** and go directly to the high-pressure compressor **348**, which may conserve compression power.

[0052] The consolidated gas stream **346** may be compressed to provide a compressed consolidated gas **350** at a pressure of about 1,500 psia to about 1,600 psia, such as about 1,525 psia, and a temperature of about 200 °F (93.3 °C) to about 250 °F (121.1 °C), such as 218 °F (103.3 °C). The compressed consolidated gas **350** may thereafter be cooled by a heat exchanger **352** to produce a cooled consolidated gas **354** as a final product stream. The cooled consolidated gas **354** may be split into three separate streams, **356**, **358**, **360**, where each stream may include a CH₄ concentration of about 97 mol% and a CO₂ concentration of about 1.5 mol% or less and where the remaining concentration may include H₂S, heavier hydrocarbons, nitrogen, among other impurities. The first stream **356** may be initially fed into the reflux exchanger **337** to produce a cooled first stream **362**, which may be expanded

through a J-T valve **363** to form a chilled first stream **364**. The chilled first stream **364** may be warmed in the second feed chiller **324** to cool feed stream **322** and to produce the CH₄ refrigerant stream **365**. The second stream **358** may be cooled in the reflux exchanger **337** to produce a cooled second stream **366** and further cooled by a reflux expander **368** to produce a reflux stream **370** that re-enters the column **328**. The third stream **360** may be a final clean sales gas that may be utilized for commercial usage.

[0053] Exemplary process parameters for the various streams with respect to Fig. 3 are provided in Table I. When a raw feed stream **326** with a lower CO₂ concentration is injected into the column **328** at a position above a melt tray and into a controlled freeze zone, the raw feed stream **326** may undergo additional refrigeration via the second feed chiller **324** so that the total required compression power may be about 40,880 horsepower (hp).

Table I: Exemplary Process Parameters for Injection of Raw Feed Stream Above Melt Tray

Stream Number	302	308	318	322	326	370	330	336	338	342	344
Temp - Deg F	94.9	60.0	18.5	-40.0	-84.3	-145.0	22.1	-134.0	43.8	156.6	43.8
Pressure - psia	510.0	500.0	495.0	490.0	475.0	475.0	475.0	470.0	465.0	1065.0	1065.0
Flowrate (MMSCFD)	324.9	324.9	324.9	324.9	324.9	204.5	23.6	505.8	505.8	505.8	82.3
Methane Mole Percent	90.40%	90.40%	90.40%	90.40%	90.40%	97.47%	0.20%	97.47%	97.47%	97.47%	97.47%
Ethane Mole Percent	0.71%	0.71%	0.71%	0.71%	0.71%	0.07%	8.88%	0.07%	0.07%	0.07%	0.07%
CO ₂ Mole Percent	8.00%	8.00%	8.00%	8.00%	8.00%	1.50%	90.92%	1.50%	1.50%	1.50%	1.50%
Nitrogen Mole Percent	0.89%	0.89%	0.89%	0.89%	0.89%	0.96%	0.00%	0.96%	0.96%	0.96%	0.96%

Table I (cont'd): Exemplary Process Parameters for Injection of Raw Feed Stream Above Melt Tray

Stream Number	346	350	354	356	358	362	366	364	365	360	334
Temp - Deg F	156.6	218.7	105.0	105.0	105.0	-106.3	-129.0	-113.0	-45.0	105.0	45.9
Pressure - psia	1065.0	1525.0	1515.0	1515.0	1515.0	1510.0	1510.0	1075.0	1070.0	1515.0	2200.0
Flowrate (MMSCFD)	588.1	588.1	588.1	82.3	204.5	82.3	204.5	82.3	82.3	301.2	23.6
Methane Mole Percent	97.47%	97.47%	97.47%	97.47%	97.47%	97.47%	97.47%	97.47%	97.47%	97.47%	0.20%
Ethane Mole Percent	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	8.88%
CO ₂ Mole Percent	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	90.92%
Nitrogen Mole Percent	0.96%	0.96%	0.96%	0.96%	0.96%	0.96%	0.96%	0.96%	0.96%	0.96%	0.00%

[0054] Fig. 4 is a drawing of feeding a low-CO₂ content feed gas into a controlled freeze zone section of a column **400**, such as column **328** depicted in Fig. 3. In addition to a CO₂ concentration, a low-CO₂ feed stream **402** may include CH₄, other lighter hydrocarbons, and other contaminants, such as H₂S. The low-CO₂ feed stream **402** may have a CO₂ concentration of less than about 16 mol%, or less than about 15 mol%, or less than about 14 mol%, or less than about 13 mol%, or less than about 12 mol%, or less than about 11 mol%, or less than about 10 mol%, or from about 5 to 8 mol%, about 5 to 10 mol%, about 5 to 12 mol%, or about 5 to 14 mol%. In one or more embodiments, the low-CO₂ feed stream **402** may be a two-phase vapor-liquid stream or a dry feed gas.

[0055] As shown in Fig. 4, the low-CO₂ feed stream **402** may be injected into a column **400** via a raw feed nozzle **406** into an internal annular sleeve **407**. The raw feed nozzle **406** may be located in a controlled freeze zone **408** so that the low-CO₂ feed stream **402** may enter the column **400** above a melt tray **410** and within a spray nozzle section **412**. In one or more embodiments, the feed stream **402** may enter the column **400** above the melt tray **410** and above the spray nozzle section **412**. This may be in contrast to conventional configurations where the raw feed nozzle **406** may be located below both the melt tray **410** and in a lower stripping section **414**. The column **400** may also include a rectification section **416** located above the controlled freeze zone **408**.

[0056] The internal annular sleeve **407** may be positioned around a periphery of the controlled freeze zone **408** and a top portion of the internal annular sleeve **407** may be closed off against the wall of column **400**. In one or more embodiments, the internal annular sleeve **407** may be positioned around the entire periphery of the controlled freeze zone **408** or may be located within one or more quadrants related to the periphery of the controlled freeze zone **408**. The low-CO₂ feed stream **402** may enter the column **400** and into the internal annular sleeve **407** so that the incoming low-CO₂ feed stream **402** may be channeled around the periphery and down toward the melt tray **410**. By flowing the low-CO₂ feed stream **402** into the internal annular sleeve **407**, the walls of the column **400** may be warmed, while the low-CO₂ feed stream **402** is chilled to the temperature of the column **400**. In operation, this may mitigate the accumulation of solid CO₂ upon the walls of the column **400**, thus preventing possible CO₂ plugging of the column **400**. The bottom portion of the internal annular sleeve **407** may include a slot **420** located proximate a liquid level **422**, e.g., a CO₂ rich-liquid **422**, on the melt tray **410**, where the slot **420** may project the low-CO₂ feed stream **402** inward and

towards the center of the controlled freeze zone **408**. The internal annular sleeve **407** may be generally cylindrical, generally inverted frusto-conical, generally funnel-shape, or generally tapered, among other shapes. The internal annular sleeve **407** may extend downwards from substantially the top of the control freeze zone **408**, substantially from the middle of the control freeze zone **408**, or substantially from the bottom of the control freeze zone **408**. The internal annular sleeve **407** may terminate substantially in a middle portion of the control freeze zone **408**, substantially in a lower portion of the control freeze zone **408**, in close proximity to a top portion of the melt tray **410**, substantially within an internal section of the melt tray **410**, among others.

[0057] As the low-CO₂ feed stream **402** enters the controlled freeze zone **408**, it may travel downward along the periphery of the walls of the column **400**. The low-CO₂ feed stream **402** may be contacted by a cold liquid spray **424** from the spray nozzle section **412**. In one or more embodiments, the spray nozzle section **412** may direct the cold liquid spray **424** inside of the internal annular sleeve **407**, into a center of the control freeze zone **408**, or a combination of both thereof. The CO₂ concentration in the low-CO₂ feed stream **402** may solidify upon contacting the cold liquid spray **424** to form solid CO₂ **426**. The solid CO₂ **426** may fall and collect on the melt tray **410** where it may melt to form the CO₂ rich-liquid **422**. The CO₂ rich-liquid **422** may flow through a downcomer **427** proximate to the melt tray **410** and into the stripping section **414** to provide a bottoms stream **428**. A portion of the bottoms stream **428** may be heated by a heat exchanger **430** and may re-enter the column **400** in the lower portion of the stripping section **414** as a reboiler stream **432**. The remainder of the bottoms stream **428** may exit the column **400** and may be used for enhanced oil recovery processes or re-injected into an acid-gas well (AGI).

[0058] In the freeze zone **408**, CO₂ and other contaminants are removed from the low-CO₂ feed stream **402**, leaving a vapor **434** that rises upwards into the rectification section **416** of the column. The vapor **434** primarily includes CH₄, but may have small amounts of CO₂ and other contaminants. An overhead vapor stream **436** may exit the column **400** and may enter a heat exchanger **438** to be chilled to produce a chilled hydrocarbon vapor and liquid stream **440**. The chilled hydrocarbon stream **440** may be directed into a reflux vessel **442** to be separated into liquid and gas phases. The liquid phase, as a reflux stream **444**, may be returned to the column **400**, for example, into the rectification section **416**. In the rectification section **416**, the reflux stream **444** may also be used to remove additional

contaminants by sweeping them down into the column **400**.

[0059] The reflux stream **444** may flow downward through a series of mass transfer devices **445** and collect on a collector tray **446**. In one or more embodiments, the mass transfer devices **445** may include trays with cascading weirs and downcomers, as shown in Fig. 4. Alternatively, the mass transfer devices may comprise random packing or structured packing. The liquid collected on the collector tray **446** may be drawn out of the rectification section **416** as a liquid stream **448**, which may flow into a reflux drum **450** from which the aforementioned cold liquid spray **424** may be drawn. Upon exiting the reflux drum **450**, the cold liquid spray **424** is pressurized in a pump **452** for reintroduction into the column **400** to aid in solidifying the CO₂ in the low-CO₂ feed stream **402**.

[0060] A portion of the chilled hydrocarbon vapor stream **436** that may not have condensed but remained in the vapor phase may exit the reflux vessel **442** as a final product stream **454**. The final product stream **454** may include lighter hydrocarbons gases, primarily CH₄, that may be ultimately sold commercially. In one or more embodiments, the final product stream **454** may also include a concentration of ethane, nitrogen, CO₂, and helium.

[0061] In one or more embodiments, the low-CO₂ feed stream **402**, as shown in Fig. 4, may include a H₂S concentration. The concentration of the H₂S may encompass a low range of less than about 8%, or from about 5% to about 8%. Any H₂S present may have a slight preference towards being in a liquid form versus a gas form at particular processing temperatures. For example, if a larger volume of cold spray liquid **424** contacts the low-CO₂ feed stream **402**, including the H₂S concentration, the column **400** may drive the H₂S concentration downward to within a parts-per-million (ppm) limit, such as a 4 ppm limit. As the H₂S concentration comes into contact with the cold spray liquid **424**, the H₂S can be pulled out of the low-CO₂ feed stream **402** as H₂S liquid. The liquid H₂S may flow downward through the controlled freeze zone **408** and collect on the melt tray **410** along with the CO₂ rich-liquid **422**. A mixture of CO₂/H₂S liquid may flow downward into the stripping section **414** where it may ultimately exit the column **400** as a part of a CO₂-rich liquid bottoms stream **428** with a H₂S concentration.

[0062] Fig. 5 is a simplified process flow diagram **500** of a system for feeding a feed gas below a melt tray and into a stripping section of a column. With most distillation-type columns, a raw feed stream may enter a section of a column that has a concentration similar to that of a concentration of species already within the column. For example, in a cryogenic

column, the raw feed stream directed into a stripping section of a column may contain a high concentration of CO₂ (e.g., at least about 16% or higher) that may match the concentration of the species (e.g., at least about 16% or higher) already within the cryogenic column. However, if a raw feed stream with a lower CO₂ concentration (e.g., at least about 5% to 16%) is injected into a stripping section of the cryogenic column, the lower CO₂ concentration gas may pass through the melt tray to match the CO₂ concentration in the spray section, as will be described with respect to Fig. 5. Thus, as shown in Fig. 5, a low-CO₂ feed stream **502** that is fed below a melt tray may be cooled once by a single feed chiller, as described above with respect to Fig. 3. In operation, the warmer low-CO₂ feed stream **502** does not require the use of a second feed chiller, as depicted in Fig. 3. However, while the warmer low-CO₂ feed stream **502** prevents the adherence of solid CO₂ on the walls of a column and a melt tray, the load on the cryogenic column may be increased. In particular, the incremental heat load can be removed via the cryogenic column, which may increase the net power requirement of the cryogenic column.

[0063] As shown in Fig. 5, the low-CO₂ feed stream **502** may be initially precooled against a refrigerant **504** in a feed precooler **506**. The low-CO₂ feed stream **502** may contain CH₄, CO₂, along with H₂S and other heavier hydrocarbons. With respect to Fig. 5, the concentration of CO₂ in the low-CO₂ feed stream **502** may be less than about 16 mol%, or less than about 15 mol%, or less than about 14 mol%, or less than about 13 mol%, or less than about 12 mol%, or less than about 11 mol%, or less than about 10 mol%, or from about 5 to 8 mol%, about 5 to 10 mol%, about 5 to 12 mol%, or about 5 to 14 mol%.

[0064] After precooling, a pre-cooled feed stream **508** may be generated to heat a cooling loop **510** for a reboiler **512** and a cooling loop **514** for a side-reboiler **516**, while being further cooled to form a cooled feed stream **518**. The cooled feed stream **518** may enter a feed chiller **520** where it may be cooled to -30 °F (-34.4 °C) to form a cooled feed stream **522**. The pressure of the cooled feed stream **522** may be lowered to provide a colder, low-pressure feed **523**. The low-pressure cooled feed **523** may enter a column **524** where it may undergo separation techniques to recover the CH₄ from the low-CO₂ feed stream **502** to generate purified CH₄.

[0065] Since the low-CO₂ feed stream **502** includes a low-CO₂ concentration (e.g., 5 to 8%) that may be injected into a section, e.g., stripping section, of the column **524** that may normally have a CO₂ concentration above 16%, the feed stream **502** may try to compensate

for the concentration deficiency by fully vaporizing. Thus, any CO₂-rich liquid in the low-CO₂ feed stream **502** may re-vaporize to chill the CO₂-rich fluids in the stripper and to increase the CO₂ vapor concentration (e.g. to about 16% or greater). It is preferred to more closely match the feed temperature to the normal temperature at that location in the distillation column. Therefore, the second feed chiller **324**, as described with respect to Fig. 3, may not be included with respect to Fig. 5. Thus, the low-CO₂ feed stream **502** that may enter the column may be warmer, e.g., -31.4 °F (-35.2 °C), than the low-CO₂ feed stream **302** of Fig. 3, e.g., -84.3 °F (-64.6 °C).

[0066] Within the column **524**, the low-pressure cooled feed **523** may separate to provide a vapor stream **526** and a liquid acid gas stream **528**. The vapor stream **526** may include a CH₄ concentration of 97% or higher so as to include primarily CH₄ vapor. The liquid acid gas stream **528** may include CO₂, along with other contaminants such as H₂S and heavier hydrocarbon components. The liquid acid gas stream **528** may be pumped via pump **530** to a reinjection pressure for later disposal as a CO₂ liquid **531**.

[0067] The vapor stream **526** may enter an overhead exchanger **532** where it may be heated to a temperature of from about -140 °F (-95.5 °C) to about 50 °F (-45.6 °C), such as from about -133 °F (-91.7 °C) to about 49.5 °F (9.7 °C), to form a heated vapor stream **534** at a pressure of from about 400 psia to 500 psia, such as about 465 psia. The heated vapor stream **534** may be fed to a sales gas compressor **536** to increase its pressure to a pressure of from about 1500 psia to about 1600 psia, such as about 1525 psia, to form a compressed vapor stream **538** at a temperature of about 200 °F (93.3 °C) to about 275 °F (135 °C), such as about 245 °F (118.3 °C). The compressed vapor stream **538** may flow into a heat exchanger **540** where it may be cooled to a temperature of from about 90 °F (32.2 °C) to about 120 °F (48.9 °C), such as about 105 °F (40.6 °C). A cooled vapor stream **542** may exit the heat exchanger **540** and may be split into two streams. In one or more embodiments, the number of streams that the cooled vapor stream **542** may be split into may vary depending on usage and need. Each stream may include a CH₄ concentration of about 97% and a CO₂ concentration of about 1.5% or less where the remaining concentration may include heavier hydrocarbons such as ethane (C₂H₆) concentration and nitrogen gas. A first stream **544** may be initially fed into the overhead exchanger **532** to form a cooled stream **546**. The cooled stream **546** may flow into a reflux expander **548** to generate a cooled reflux stream **550** that may be fed into back into the column **524**. A second stream **552** may be a final clean sales

gas that may be utilized for commercial usage.

[0068] Exemplary process parameters for the various streams with respect to Fig. 5 are provided in Table II. By feeding the low-pressure, cooled feed **523**, which contains a low-CO₂ concentration, into the lower stripping section of the column **524** at a warmer temperature, extra energy may be needed to remove the additional heat. Additionally, with less cooling of the low-CO₂ feed stream **502**, extra cooling may be supplied via the overhead exchanger **532**. As stated above, the total required compression power for Fig. 3 may be about 40,800 horsepower (hp). However, due to the additional energy needed to remove the additional heat, the total required compression power with respect to Fig. 5 may be about 44,900 hp. Thus, to conserve energy and limit cost, it may be appropriate to inject a low-CO₂ raw feed stream into an area of a column that may match the CO₂ concentration and temperature of the species previously existing in the column, as discussed with respect to Fig. 3 and Fig. 4.

Table II: Exemplary Process Parameters for Injection of Raw Feed Stream Below a Melt Tray

	502	508	518	522	523	550	528	526
Temperature - Deg F	94.9	63.4	8.3	-30.0	-31.4	-144.7	22.6	-133.7
Pressure - psia	510.0	500.0	495.0	490.0	475.0	475.0	475.0	470.0
Flowrate (MMSCFD)	324.9	324.9	324.9	324.9	324.9	319.0	23.4	620.4
Methane Mole Percent	90.40%	90.40%	90.40%	90.40%	90.40%	97.41%	0.14%	97.41%
Ethane Mole Percent	0.71%	0.71%	0.71%	0.71%	0.71%	0.13%	8.16%	0.13%
CO ₂ Mole Percent	8.00%	8.00%	8.00%	8.00%	8.00%	1.50%	91.70%	1.50%
Nitrogen Mole Percent	0.89%	0.89%	0.89%	0.89%	0.89%	0.96%	0.00%	0.96%

Table II (cont'd): Exemplary Process Parameters for Injection of Raw Feed Stream Below a Melt Tray

	534	538	542	544	546	552	531
Temperature - Deg F	49.5	245.3	105.0	105.0	-128.7	105.0	46.4
Pressure - psia	465.0	1525.0	1515.0	1515.0	1510.0	1515.0	2200.0
Flowrate (MMSCFD)	620.4	620.4	620.4	319.0	319.0	301.4	23.4
Methane Mole Percent	97.41%	97.41%	97.41%	97.41%	97.41%	97.41%	0.14%
Ethane Mole Percent	0.13%	0.13%	0.13%	0.13%	0.13%	0.13%	8.16%
CO2 Mole Percent	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	91.70%
Nitrogen Mole Percent	0.96%	0.96%	0.96%	0.96%	0.96%	0.96%	0.00%

[0069] Fig. 6 is a drawing of feeding a low-CO₂ content feed gas into a controlled freeze zone section of a column **600** and feeding a low-CO₂ content feed gas below the controlled freeze zone section of the column. Like numbers are as described with respect to Fig. 4. The low-CO₂ feed stream **402** and the low-CO₂ feed stream **604** may include CH₄, other light hydrocarbons, and certain contaminants including CO₂.

[0070] The low-CO₂ feed stream **402** may be injected into the column **600** via a raw feed nozzle **406** as a vapor. In one or more embodiments, the low-CO₂ feed stream **402** may be a vapor-liquid fluid or a vapor-liquid-solid slurry. As described above with respect to Fig. 4, the low-CO₂ feed **402** may flow into an internal annular sleeve **407** so that the incoming low-CO₂ feed stream **402** may be channeled around the periphery of the column **600**. The flowing of the low-CO₂ feed stream **402** into the internal annular sleeve **407** may create a “warming” wall for the column **600**, thereby mitigating the accumulation of solid CO₂ upon the walls or plugging of the column **600** by the solid CO₂ in the slurry.

[0071] The low-CO₂ feed **402** may travel downward along the periphery of the walls of the column **600** in a controlled freeze zone **408** and collect on a melt tray **410**. The low-CO₂ feed **402** may be contacted by a liquid spray **424** to form solid CO₂ **426**. The solid CO₂ **426** may collect and melt on the melt tray **410** to form a CO₂ rich-liquid **422**. The CO₂ rich-liquid **422** may cascade across the melt tray **410** and downward through stripping section **414** to accumulate as a pool of CO₂ rich-liquid **602** at the bottom of the stripping section **414**. The pool of CO₂ rich-liquid **602** may exit the column **600** as a bottoms CO₂ rich-liquid **428** to be heated by a heat exchanger **430**. A vapor reboiler stream **432** may re-enter the column **600** while a portion of the bottoms CO₂ rich-liquid **428** may exit the column **600** for other

intended uses like EOR.

[0072] A vapor component may separate out of the low-CO₂ feed **402** to form hydrocarbon vapors **434**, which may include a rich CH₄ vapor concentration. The hydrocarbon vapors **434** may continue to rise upward and out of the controlled freeze zone
5 **408** and into a rectification section **416**. A hydrocarbon vapor stream **436** may exit the column **600** and may enter a heat exchanger **438** to be chilled to produce a chilled hydrocarbon stream **440**. The chilled hydrocarbon stream **440** may be directed into a reflux vessel **442** to be separated into liquid and gas phases. The liquid phase, as a reflux fluid stream **444**, may enter the column **600** to flow downward through a series of mass transfer
10 devices **445** through the rectification section **416** and collect on a collector tray **446** to be drawn off as a liquid stream **448**, which may flow into a reflux drum **450** where the aforementioned liquid for spray **424** is collected. Upon exiting the reflux drum **450**, the liquid for spray **424** may be pressurized in a pump **452** for reintroduction into the column **600** as a spray to aid in solidifying the CO₂ concentration in the low-CO₂ feed stream **402**.

15 [0073] A portion of the chilled hydrocarbon vapors **440** that may not have condensed but remained in the vapor phase may exit the reflux vessel **442** as a final product stream **454**. The final product stream **454** may include light hydrocarbon gases, primarily CH₄, that may be ultimately sold commercially.

[0074] The low-CO₂ feed stream **604** may enter a section of the column **600** where a
20 high-CO₂ feed stream may typically enter, e.g., the stripping section **414**. The CO₂ concentration in the high-CO₂ feed gas may include a concentration range of about 16 to 20%, about 16% to 24%, about 16% to 28%, or about 16% to 30%, or even about 16% to 40%. However, as previously discussed, the low-CO₂ feed stream **604** may have a CO₂ concentration of less than about 16 mol%, or less than 15 about mol%, or less than about 14
25 mol%, or less than about 13 mol%, or less than about 12 mol%, or less than about 11 mol%, or less than about 10 mol%, or from about 5 to 8 mol%, about 5 to 10 mol%, about 5 to 12 mol%, or about 5 to 14 mol%.

[0075] In one or more embodiments, the low-CO₂ feed stream **604** may enter a flash drum **606** prior to feeding into the column **600**. It may be desirable to separate the low-CO₂
30 feed stream **604** in the flash drum **606** instead of feeding directly into the stripping section **414** if liquid/slurry formation is expected. After separation in the flash drum **606**, a vapor stream **608** may be fed below the melt tray **410** and into the stripping section **414** and a

liquid/slurry stream **610** may be fed into the controlled freeze zone **408**. The fluid stream **610** may include a liquid-solid mixture of acid gas and heavier hydrocarbons that may fall upon the melt tray **410** to be warmed. The warmed liquids of the fluid stream **610** may flow downward into the stripping section **414** to mix with the CO₂ rich-liquid **422** that exits the column **600** as a bottoms CO₂-rich liquid **428**, as previously discussed. Any light vapors, including CH₄, associated with the fluid stream **610** may rise into the controlled freeze zone **408** and may mix with the vapor **434** that rises upwards into the rectification section **416** of the column, as previously discussed.

[0076] The vapor **608** component of the low-CO₂ feed stream **604** may be separated to form a vapor stream and a liquid stream. The liquid stream may mix with the CO₂ rich-liquid **422** that exits the column **600** as a bottoms CO₂ rich-liquid **428**, as previously discussed. The vapor stream may rise upward past the melt tray **410** and into the controlled freeze zone **408** to be contacted with the cold liquid spray **424** to freeze out any CO₂ and to form a CH₄ rich vapor stream. As previously stated, the solid CO₂ may melt upon the melt tray **410** to mix with the CO₂ rich-liquid **422**. The CH₄ rich vapor stream may continue upward into the rectification section **416** and may mix with the vapors **434**, as previously discussed.

[0077] Fig. 7 is a graph **700** of a CO₂/CH₄ temperature-freeze profile **702**. A CO₂ saturation concentration **704** as a function of temperature **706** within the cryogenic liquid may be illustrated in the graph **700**. Solid CO₂ is present for conditions to the right of curve **702**. As described herein, different sections of a cryogenic column may include a rectifying section **708**, a controlled freeze zone (CFZ) section **710** including a melt tray **712**, and a stripping section **714**.

[0078] Within the range of CO₂ saturation concentrations **704** of the CFZ section **710**, a CO₂ freezing curve **716** may occur between a 2 mol% and 12 mol% CO₂ concentration in the vapor phase. As shown in Fig. 7, the CO₂ freezing curve **716** includes a feed with a 2 mol% and 12 mol% CO₂ concentration in the vapor phase that may be introduced below the melt tray **712**. When introduced below the melt tray **712**, the CO₂ liquid may re-vaporize until the concentration has risen to about a 16% mol concentration. Thus, additional reflux refrigeration and power may be needed to re-condense the CO₂ and purify the vapor in an effort to produce a sales gas.

[0079] However, as described with respect to Fig. 3 and Fig. 4, it may be advantageous to introduce a feed gas with a CO₂ concentration in the range of 2 mol% to 12 mol% into a

section of the column where the CO₂ content of the feed and the CO₂ content of the vapor within the column are approximately the same. As shown in Fig. 7, feed gas conditions **718** introduced into the CFZ section **710** may contain a 8% mol concentration of CO₂ at a process pressure of 471 psia and may be introduced above the melt tray **712**. As discussed with
5 respect to Figs. 3 and 4, by introducing the feed gas above the melt tray **712** in the CFZ section **710**, the possibility of re-vaporizing the CO₂ may be reduced, thus, improving power efficiency and minimizing power consumption.

[0080] Fig. 8 is a method **800** of processing a feed gas in a column in accordance with embodiments of the present techniques. At block **802**, a feed gas may be fed into an
10 intermediate zone of a column. The feed gas may flow through an internal sleeve and into a bottom portion of a controlled freeze zone of the column. At block **804**, the feed gas may come into contact with a cold liquid to form a vapor stream and solid CO₂ in the intermediate zone, where the vapor stream may be rich in methane (CH₄). At block **806**, the solid CO₂ may be warmed and liquefied on a melt tray located in the intermediate zone of the column,
15 where the feed gas flowing in the internal sleeve of the column contributes to melting CO₂ solid accumulation. At block **808**, the liquefied CO₂ may be removed from a lower section of the column.

[0081] While the present techniques may be susceptible to various modifications and alternative forms, the embodiments discussed above have been shown only by way of
20 example. However, it should again be understood that the techniques are not intended to be limited to the particular embodiments disclosed herein. Indeed, the present techniques include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

CLAIMS

1. A method of controlling a temperature in a column, the method comprising feeding a feed gas into a port of a sleeve disposed around at least a portion of a periphery of the column, wherein:

the sleeve comprises a space between an outer wall of the column and an inner wall of the column;

the sleeve is disposed around a zone of the column that is configured to freeze at least one component of the feed gas;

the port is disposed in an upper region of the sleeve;

the sleeve is configured to channel the feed gas downward around the periphery of the column; and

the sleeve is configured to release the feed gas into the column through an opening disposed at a point below the port where the feed gas is fed into the sleeve.

2. The method of claim 1, wherein the feed gas comprises a CO₂ concentration of less than about 16%.

3. The method of claim 1, wherein the flow of the feed gas in the sleeve is configured to melt a solid that has accumulated on the inner wall of the column.

4. The method of claim 1, wherein the feed gas is fed into the sleeve at a temperature above a freezing temperature for at least one component in the feed gas.

5. The method of claim 1, wherein a concentration of CO₂ in the feed gas that is fed into the sleeve matches a concentration of CO₂ in a zone of the column that is configured to freeze at least one component of the feed gas.

6. A method of separating an acid gas component from a raw natural gas stream in a column, the method comprising:
maintaining a temperature of a zone in the column below the freezing point of an acid gas component in the raw natural gas stream;

feeding the raw natural gas stream at a temperature above the freezing point of the acid gas component into an upper portion of an internal sleeve disposed around a zone of the column;

flowing the raw natural gas stream downward through the internal sleeve to cool the raw natural gas stream and warm an internal wall of the column in the zone, melting accumulated solids from the inner wall; and
releasing the raw natural gas stream into the column at a lower portion of the zone.

7. The method of claim 6, wherein the raw natural gas stream includes methane (CH₄) and acid gas.

8. The method of claim 6, wherein the acid gas is hydrogen sulfide (H₂S), carbon dioxide (CO₂), or sulfur dioxide (SO₂), or a combination thereof.

9. The method of claim 6, comprising feeding the raw natural gas stream at a temperature above the freezing temperature for CO₂ in the zone.

10. A column for the separation of a feed gas, the column comprising:

an internal sleeve located around a periphery of a zone of the column; and

a feed gas inlet located in an upper region of the internal sleeve, wherein the internal sleeve is configured to channel the feed gas downward around the periphery of the column; and

an inner opening from the internal sleeve, configured to release the feed gas into the zone at a point below the feed gas inlet.

11. The column of claim 10, wherein the feed gas comprises methane (CH₄) and carbon dioxide (CO₂).

12. The column of claim 10, wherein the feed gas comprises a concentration of CO₂ that is lower than about 7%.

13. The column of claim 10, wherein a concentration of CO₂ in the feed gas that is fed into the internal sleeve matches a concentration of CO₂ in a zone of the column that is configured to freeze at least one component of the feed gas.

14. The column of claim 10, wherein the internal sleeve is positioned around the entire periphery of the zone or located within one or more quadrants related to the periphery of the zone.

15. The column of claim 10, comprising a slot in the internal sleeve, wherein the slot projects the feed gas toward a center of the column.

16. The column of claim 10, wherein the internal sleeve is generally cylindrical, generally frustoconical, generally funnel-shape, generally tapered, or a combination thereof.

17. The column of claim 10, wherein the internal sleeve extends downwards from substantially the top of the zone, substantially from the middle of the zone, or substantially from the bottom of the zone.

18. The column of claim 10, wherein the internal sleeve terminates substantially in a middle portion of the zone, substantially in a lower portion of the zone, in close proximity to a top portion of a melt tray, or substantially within an internal section of the melt tray.

19. The column of claim 10, wherein a spray nozzle section is directed to spray a liquid inside of the internal sleeve, into a center of the zone, or a combination thereof.