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(54) Title: MIXING AND HEAT INTEGRATION OF MELT TRAY LIQUIDS IN A CRYOGENIC DISTILLATION TOWER

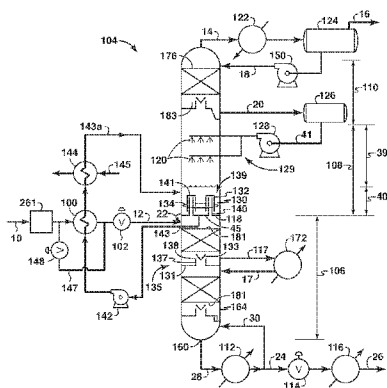


FIG. 1

(57) Abstract: A cryogenic distillation tower for separating a feed stream. The tower includes a distillation section. A controlled freeze zone section is situated above the distillation section and forms a solid from the feed stream. The controlled freeze zone section includes a spray assembly in an upper section and a melt tray assembly in a lower section. The melt tray assembly includes at least one vapor stream riser that directs the vapor from the distillation section into liquid retained by the melt tray assembly, and one or more draw-off openings positioned to permit a portion of the liquid to exit the controlled freeze zone section. The portion of the liquid indirectly exchanges heat with a heating fluid. One or more return inlets return the portion of the liquid to the melt tray assembly after it has been heated in the heat exchanger.

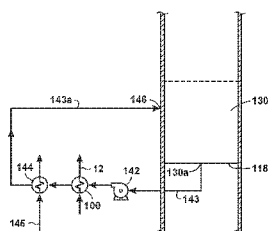


FIG. 5



Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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**MIXING AND HEAT INTEGRATION OF MELT TRAY LIQUIDS IN A
CRYOGENIC DISTILLATION TOWER**

CROSS REFERENCE TO RELATED APPLICATIONS

- 5 **[0001]** This application claims the priority benefit of United States Provisional Patent Application No. 62/691679 filed June 29, 2018, entitled MIXING AND HEAT INTEGRATION OF MELT TRAY LIQUIDS IN A CRYOGENIC DISTILLATION TOWER.
- 10 **[0002]** This application is related to but does not claim priority to U.S. Provisional patent application numbers: 61/912,975 Filed December 6, 2013 and titled METHOD AND
SYSTEM FOR SEPARATING A FEED STREAM WITH A FEED STREAM
DISTRIBUTION MECHANISM; 61/912,957 filed on December 6, 2013 and titled METHOD
AND DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A
SPRAY ASSEMBLY; 62/044,770 filed on September 2, 2014 and titled METHOD AND
DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A
15 SPRAY ASSEMBLY; 61/912,959 filed on December 6, 2013 and titled METHOD AND
SYSTEM OF MAINTANING A LIQUID LEVEL IN A DISTILLATION TOWER;
61/912,964 filed on December 6, 2013 and titled METHOD AND DEVICE FOR
SEPARATING A FEED STREAM USING RADIATION DETECTORS; 61/912,970 filed on
December 6, 2013 and titled METHOD AND SYSTEM OF DEHYDRATING A FEED
20 STREAM PROCESSED IN A DISTILLATION TOWER; 61/912,978 filed on December 6,
2013 and titled METHOD AND SYSTEM FOR PREVENTING ACCUMULATION OF
SOLIDS IN A DISTILLATION TOWER; 61/912,983 filed on December 6, 2013 and titled
METHOD OF REMOVING SOLIDS BY MODIFYING A LIQUID LEVEL IN A
DISTILLATION TOWER; 61/912,984 filed on December 6, 2013 and titled METHOD AND
25 SYSTEM OF MODIFYING A LIQUID LEVEL DURING START-UP OPERATIONS;
61/912,986 filed on December 6, 2013 and titled METHOD AND DEVICE FOR
SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A HEATING
MECHANISM TO DESTABILIZE AND/OR PREVENT ADHESION OF SOLIDS; and
61/912,987 filed on December 6, 2013 and titled METHOD AND DEVICE FOR
30 SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A SURFACE
TREATMENT MECHANISM.
- [0003]** This application is also related to U.S. Application No. 62/691676, titled HYBRID

TRAY FOR INTRODUCING A LOW CO₂ FEED STREAM INTO A DISTILLATION TOWER, having common inventors with this application, and filed on the same date as this application.

BACKGROUND

5 Fields of Disclosure

[0004] 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

10 **[0005]** 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.

15 **[0006]** 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
20 oftentimes referred to as “sour gas.”

[0007] 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. Some contaminants, like sulfur-bearing compounds, are noxious and may even be lethal. Additionally, in the presence of water some contaminants can become
25 quite corrosive.

[0008] It is desirable to remove contaminants from a stream containing hydrocarbons to produce sweet and concentrated hydrocarbons. Specifications for pipeline quality natural gas typically call for a maximum of 2 – 4% CO₂ and ¼ grain H₂S per 100 scf (4 ppmv) or 5 mg/Nm³ H₂S. Specifications for lower temperature processes such as natural gas liquefaction plants or
30 nitrogen rejection units typically require less than 50 ppm CO₂.

[0009] 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.

5 [0010] 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 are predicated on the presence of only vapor and liquid
10 phases throughout the distillation tower. 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 required temperatures are cold temperatures typically referred to as cryogenic temperatures.

[0011] Certain cryogenic distillations can overcome the above mentioned difficulties.
15 These cryogenic distillations provide the appropriate mechanism to handle the formation and subsequent melting of solids during the separation of solid-forming contaminants from hydrocarbons. The formation of solid contaminants in equilibrium with vapor-liquid mixtures of hydrocarbons and contaminants at particular conditions of temperature and pressure takes place in a controlled freeze zone (CFZ) section. A lower section may also help separate the
20 contaminants from the hydrocarbons but the lower section is operated at a temperature and pressure that does not form solids.

[0012] In known cryogenic distillation applications using a CFZ section, a feed stream is dried and precooled to about -60 °F before introduction to the distillation tower below the CFZ section and melt tray. The vapor component of the cooled feed stream combines with the vapor
25 rising from the stripping section of the tower and bubbles through the liquid on the melt tray. This serves several beneficial purposes, including: the rising vapor stream is cooled and a portion of the CO₂ is condensed, resulting in a cooler and cleaner gas stream entering the open portion of the CFZ spray chamber; the rising vapor stream is evenly distributed across the tower cross section as it enters the CFZ spray chamber; most of the required melt tray heat input is
30 provided via sensible heat from cooling the vapor and latent heat from condensing a portion of the CO₂ in the gas stream; and the melt tray liquid is vigorously mixed, which facilitates melting of solid CO₂ particles falling into the melt tray with the bulk liquid temperature only 2 to 3

degrees F above the melting point of CO₂.

[0013] To achieve reliable melting of solids falling into the melt tray liquid, it is important that the melt tray liquid be maintained slightly above the melting point of CO₂ and well mixed. In a standard cryogenic distillation design having a CFZ section, the mixing is achieved via vapor bubbling through the liquid. This vapor also provides the majority of the heat input required for the melt tray. A heating coil immersed in the melt tray liquid is used for fine tune control.

SUMMARY

[0014] The present disclosure provides a device and method for separating contaminants from hydrocarbons, among other things.

[0015] In an aspect, a cryogenic distillation tower is provided for separating a feed stream. A distillation section permits vapor to rise upwardly therefrom. One or more lines direct the feed stream into the distillation tower. A controlled freeze zone section is situated above the distillation section. The controlled freeze zone is constructed and arranged to form a solid from the feed stream. The controlled freeze zone section includes a spray assembly in an upper section of the controlled freeze zone, and a melt tray assembly in a lower section of the controlled freeze zone. The melt tray assembly includes at least one vapor stream riser that directs the vapor from the distillation section into liquid retained by the melt tray assembly, and one or more draw-off openings positioned to permit a portion of the liquid retained by the melt tray assembly to exit the controlled freeze zone section. A heat exchanger heats the portion of the liquid through indirect heat exchange with a heating fluid. One or more return inlets return the portion of the liquid to the melt tray assembly after the portion of the liquid has been heated in the heat exchanger.

[0016] In another aspect, a method is provided for cryogenically separating contaminants from a feed stream in a distillation tower. The feed stream is directed into the distillation tower. Vapor is permitted to rise upwardly from a distillation section of the distillation tower. A solid is formed in a controlled freeze zone section of the distillation tower. The controlled freeze zone section is situated above the distillation section. The solid comprises contaminants in the feed stream. The vapor from the distillation section is directed into liquid retained by a melt tray assembly using at least one vapor stream riser. The solid is melted using the liquid retained by the melt tray assembly. A portion of the liquid retained by the melt tray assembly is permitted to exit the controlled freeze zone section. The portion of the liquid is heated through

indirect heat exchange with a heating fluid in a heat exchanger. The portion of the liquid is returned to the melt tray assembly after the liquid has been heated in the heat exchanger.

[0017] The foregoing has broadly outlined the features of the present disclosure in order that the detailed description that follows may be better understood. Additional features will
5 also be described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] 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.

10 [0019] Figure 1 is a schematic diagram of a tower with sections within a single vessel.

[0020] Figure 2 is a schematic diagram of a tower with sections within multiple vessels.

[0021] Figure 3 is a schematic diagram of a tower with sections within a single vessel.

[0022] Figure 4 is a schematic diagram of a tower with sections within multiple vessels.

[0023] Figure 5 is a side view of a middle controlled freeze zone section of a distillation
15 tower.

[0024] Figure 6 is a top plan view of a melt tray according to disclosed aspects.

[0025] Figure 7 is a flowchart of a method according to disclosed aspects.

[0026] 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
20 drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of the disclosure.

DETAILED DESCRIPTION

[0027] 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
25 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.

5 [0028] As referenced in this application, the terms “stream,” “gas stream,” “vapor stream,” and “liquid stream” 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.

10 [0029] 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 are considered to be within the scope of the disclosure.

20 [0030] The articles “the”, “a” and “an” are not necessarily limited to mean only one, but rather are inclusive and open ended so as to include, optionally, multiple such elements.

25 [0031] The disclosure relates to a system and method for separating a feed stream in a distillation tower. The system and method helps optimally match where the feed stream should enter the distillation tower based on the concentrations of components in the feed stream so as to improve energy efficiency and/or optimally size the distillation tower. The system and method may also help prevent the undesired accumulation of solids in the controlled freeze zone section of the distillation tower. Figures 1-7 of the disclosure display various aspects of the system and method.

30 [0032] The system and method may separate a feed stream having methane and contaminants. The system may comprise a distillation tower **104, 204** (Figures 1-2). The distillation tower **104, 204** may separate the contaminants from the methane.

[0033] 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.

5 [0034] 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
10 vapors leaving the middle controlled freeze section **108**, directs these vapors to the condenser **122**.

[0035] 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.

15 [0036] The sections of the distillation tower **104** may be housed within a single vessel (Figures 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**.

[0037] The sections of the distillation tower **204** may be housed within a plurality of vessels to form a split-tower configuration (Figures 2 and 4). Each of the vessels may be separate from
20 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 Figures 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**.
25 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 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
30 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.

[0038] 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 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 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 a liquid receiver **126** in Figures 1 and 3.

[0039] The system may also include a heat exchanger **100** (Figures 1-4). 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**.

[0040] The system may include an expander device **102** (Figures 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
5 **104, 204**. For example, the valve **102** may comprise a Joule-Thompson (J-T) valve.

[0041] The system may include a feed separator **103** (Figures 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
10 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
15 **102** such that each line **12** has an expander device **102**.

[0042] The system may include a dehydration unit **261** (Figures 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
20 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 does not form at any point downstream during
25 the rest of the process. The dehydration unit may be any suitable dehydration mechanism, such as a molecular sieve or a glycol dehydration unit.

[0043] 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
30 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**.

[0044] The system may include lines **12**. Each of the lines may be referred to as an inlet

channel **12**. The feed stream is introduced into the distillation tower **104, 204** through one of the lines **12**. One or more lines **12** may extend to the lower section **106** or the middle controlled freeze zone section **108** of the distillation tower **104, 204** to another of the lines **12**. 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** (Figures 1-4). Each line **12** may directly or indirectly extend to the lower section **106** or the middle controlled freeze zone section **108**. Each line **12** may extend to an outer surface of the distillation tower **104, 204** before entering the distillation tower.

[0045] If the system includes the feed separator **103** (Figures 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**.

[0046] Before entering the distillation tower **104, 204**, a sample of the feed stream **10** may enter an analyzer (not shown). The sample of the feed stream **10** may be a small sample of the feed stream **10**. The feed stream **10** may comprise feed from multiple feed sources or feed from a single feed source. Each feed source may comprise, for example, a separate reservoir, one or more wellbores within one or more reservoirs, etc. The analyzer may determine the percentage of CO₂ in the sample of the feed stream **10** and, therefore, the content of CO₂ in the feed stream **10**. The analyzer may connect to multiple lines **12** so that the feed stream **10** can be sent to one or more sections **106, 108** of the distillation tower **104, 204** after the sample of the feed stream **10** exits the analyzer. If the analyzer determines that the percentage of CO₂ is greater than about 20% or greater than 20%, the analyzer may direct the feed stream to the line **12** extending from the lower section **106**. If the analyzer determines that the percentage of CO₂ is less than about 20% or less than 20%, the analyzer may direct the feed stream to the line **12** extending from the middle controlled freeze zone section **108**. The analyzer may be any suitable analyzer. For example, the analyzer may be a gas chromatograph or an IR analyzer. The analyzer may be positioned before the feed stream **10** enters the heat exchanger **100**. The feed stream **10** entering the analyzer may be a single phase.

[0047] While the feed stream **10** may be introduced into any section of the distillation tower **104, 204** regardless of the percentage of CO₂ in the feed stream **10**, it is more efficient to introduce the feed stream **10** into the section of the distillation tower **104, 204** that will employ the best use of energy. For this reason, it is preferable to introduce the feed stream to the lower section **106** when the percentage of CO₂ in the feed stream is greater than any percentage about

20% or greater than 20% and to the middle controlled freeze zone section **108** when the percentage of CO₂ in the feed stream is any percentage less than about 20% or less than 20%.

[0048] The feed stream may be directly or indirectly fed to one of the sections **106, 108**. Thus, for the best use of energy it is best to introduce the feed stream into the distillation tower
5 **104, 204** at the point in the distillation process of the distillation tower **104, 204** that matches the relevant percentage or content of CO₂ in the feed stream.

[0049] The feed stream **10** may enter a feed separator **103**. The feed separator **103** separates a feed stream vapor portion from a feed stream liquid portion before the feed stream is introduced into the distillation tower **104, 204**. The feed stream vapor portion may be fed to
10 a different section or portion within a section of the distillation tower **104, 204** than the feed stream liquid portion. For example, the feed stream vapor portion may be fed to an upper controlled freeze zone section **39** of the middle controlled freeze zone section **108** and/or the feed stream liquid portion may be fed to a lower controlled freeze zone section **40** of the middle controlled freeze zone section **108** or to the lower section **106** of the distillation tower.

[0050] The lower section **106** is constructed and arranged to separate the feed stream **10**
15 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
20 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
25 from contaminants, such as one or more packed sections **181**, or one or more distillation trays with perforations downcomers and weirs (Figures 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
30 **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** (Figures 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 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** (Figures 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**. The second reboiler **172** also helps with energy integration.

[0056] The equipment may include one or more chimney assemblies **135** (Figures 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**.

[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 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 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** 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 lower section **106** (Figures 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**.

[0062] The systems may include an expander device **114** (Figures 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.

[0063] The system may include a heat exchanger **116** (Figures 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. After exiting the heat exchanger **116**, the liquid stream exits the distillation process via line **26**.

[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 constructed and arranged to separate the feed stream **10** introduced into the middle controlled freeze zone section, or into the top of lower section **106**, into a solid and a vapor stream. The middle controlled freeze zone section **108** forms a solid, which may comprise more of

contaminants than of methane. The vapor stream (i.e., methane-enriched vapor stream) may comprise more methane than contaminants.

5 [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 not exclusively a heating section of the middle controlled freeze zone section **108**. The upper section **39** is primarily but not exclusively 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**.

10 [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** (Figures 1-4). 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**.

15 [0067] The melt tray assembly **139** is constructed and arranged to melt solids 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 solids. As shown in Figures 1-4 and more particularly in Figures 5-6, the melt tray assembly **139** may comprise at least one
20 of a melt tray **118**, a bubble cap **132**, a liquid **130**, one or more draw-off openings **130a**, one or more return inlets **146**, and optionally may include a 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**.

25 [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 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 and it also helps prevent solids from travelling into the riser
30 **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 Figures 1-4, a heat mechanism **134** may be located around bubble caps **132**. The heat mechanism **134** may be any
5 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
10 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] According to an aspect of the disclosure, the liquid **130** may also be heated by drawing off part of the liquid, heating the liquid through heat exchange with one or more heat sources external to the controlled freeze zone section **108**, and returning the heated liquid to
15 the remainder of the liquid retained by the melt tray assembly **139**. As shown in Figure 5, one or more draw-off openings **130a** may be included to draw off part of the liquid **130**. The draw-off openings **130a** may be positioned at or near the bottom of the melt tray **118**. At least part of the liquid retained by the melt tray exits the draw-off openings **130a** and is pumped, using pump **142**, to one or more heat exchangers to heat or warm the liquid **130**. The heat exchangers
20 may include heat exchanger **100**, which operates to drop the temperature of the feed stream **10** as previously described. The drawn-off liquid **143** may alternatively or additionally pass through one or more additional heat exchangers (depicted and described herein as additional heat exchanger **144**) and be heated by a heating fluid **145**. The heating fluid may be ethane, propane, or another suitable fluid, and is returned to heating source (not shown) after passing
25 through the additional heat exchanger **144**. Once heated by the heat exchanger **100** and/or the additional heat exchanger **144**, the heated liquid **143a** is returned to the melt tray assembly **139** through the one or more return inlets **146**. The heated liquid **143a** mixes with the liquid **130** and provides additional heat to melt solids retained in the liquid **130**.

[0073] The use of heat exchanger **100** to heat liquid **130** may eliminate the necessity of
30 heating element **134**. Such elimination of the heating element **134** may significantly reduce the congestion and complexity of the melt tray assembly **139**. Also, heating the liquid **130** in the heat exchanger **100**, combined with recycling the heated liquid **143a** back to the melt tray

assembly **139**, provides a more even heating operation to the liquid **130** across a wide range of operating conditions. In contrast, the heating element **134** could provide undesirable non-uniform heating, particularly at turn-down conditions where the temperature pinches out well before the end of the heating element.

5 **[0074]** The heat exchanger **100** and/or the additional heat exchanger **144** may be advantageously used with applications in which low CO₂ feed gas (i.e., feed gas having a composition of less than 30 mol% CO₂, or less than 25 mol% CO₂, or less than 22 mol% CO₂, or less than 20 mol% CO₂) is introduced above the melt tray assembly **139**, as is described, for example, in United States Patent Application titled “Hybrid Tray for Introducing a Low CO₂
10 Feed Stream into a Distillation Tower,” being commonly owned and filed on an even date herewith, the disclosure of which is incorporated herein by reference in its entirety. In such a situation, the heat exchangers may provide beneficial heat integration between the relatively warmer feed gas (about -60 °F, which is the lowest achievable temperature using a conventional propane-based refrigeration system plus Joule-Thompson cooling via valve **102**) and the
15 relatively colder melt tray liquid (about -75 °F to -80 °F). This would provide a means to cool the feed gas while maintaining its low CO₂ content. The heated liquid **143a** provides a portion of the heat required to melt solids in the melt tray assembly **139**, while the additional cooling of the feed gas reduces the load on the condenser **122** and associated equipment while the additional heating of the melt tray liquid reduces the heat input needed from other sources –
20 such as the heating element **134**.

[0075] According to aspects of the disclosure, the pumping rate of pump **142** may advantageously be established based on design parameters of the distillation tower **104**, **204**, such as tower size, sizes and locations of draw-off openings **130a** and return inlets **146**, and the like. In an aspect there should be no need to throttle or control the pumping rate during
25 operation. Additionally, heat input to the additional heat exchanger **144**, if present, should be controlled on the side of the heating fluid **145**. In a preferred aspect the heat input may be adjusted to maintain a target temperature for the heated liquid **143a**, drawn-off liquid, the liquid **130**, or another location.

[0076] The duty for heat exchanger **100** should be maximized to provide the most efficient
30 operation. As a precaution, a feed gas bypass line **147** and a bypass valve **148** may be used to permit the feed gas **10** to bypass the heat exchanger **100**, thereby increasing the temperature of the feed gas. This option may be used if feed gas risers, which introduce feed gas above the

liquid level of liquid **130**, experience fouling from solid CO₂ in a low CO₂ environment.

[0077] 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**.

[0078] The spray assembly **129** includes one or more spray nozzles **120** (Figures 1-4). Each spray nozzle **120** sprays liquid on the vapor stream. The spray assembly **129** may also include a spray pump **128** (Figures 1-4) that pumps the liquid. Instead of a spray pump **128**, gravity may induce flow in the liquid.

[0079] The liquid sprayed by the spray assembly **129** contacts the vapor stream at a temperature and pressure at which solids form. Solids, containing mainly contaminants, form when the sprayed liquid contacts the vapor stream. The solids fall toward the melt tray assembly **139**.

[0080] 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**.

[0081] 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**. At least part of 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** (Figures 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**. The line **22** may extend from an outer surface of the distillation tower **104**, **204**.

[0082] As shown in Figures 1-2, 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**.

[0083] 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**.

[0084] 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 to facilitate contact of the vapor and liquid phases.

[0085] 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**. 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. 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. 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. 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** (Figures 1 and 3) or gravity (Figures 2 and 4).

[0086] 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** (Figures 1 and 3) or at the bottommost portion of the upper section **110** (Figures 2 and 4). The collected liquid may exit the distillation tower **104, 204** through line **20** (Figures 1 and 3) or outlet **260** (Figures 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**.

[0087] 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**.

[0088] The line **20** and/or outlet **260** may directly or indirectly (Figures 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, 41** and/or outlet **260** and line **41** may directly connect to a holding vessel **126** (Figures 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** (Figures 1-2) or gravity. The holding vessel **126** may be needed when there is not a sufficient amount of liquid stream at the bottom of the upper section **110** to feed the spray nozzles **120**.

[0089] Figure 7 is a flowchart depicting a method **700** of cryogenically separating contaminants from a feed stream in a distillation tower according to disclosed aspects. At block **702** the feed stream is directed into the distillation tower. At block **704** vapor is permitted to rise upwardly from a distillation section of the distillation tower. At block **706** a solid is formed in a controlled freeze zone section of the distillation tower. The controlled freeze zone section is situated above the distillation section. The solid comprises contaminants in the feed stream. At block **708** the vapor from the distillation section into is directed into liquid retained by a melt tray assembly using at least one vapor stream riser. At block **710** the solid is melted using the liquid retained by the melt tray assembly. At block **712** a portion of the liquid retained by the melt tray assembly is permitted to exit the controlled freeze zone section. At block **714** the portion of the liquid is heated through indirect heat exchange with a heating fluid in a heat exchanger. At block **716** the portion of the liquid is returned to the melt tray assembly after

the liquid has been heated in the heat exchanger.

[0090] It is important to note that the steps depicted in Figure 7 are provided for illustrative purposes only and a particular step may not be required to perform the inventive methodology. The claims, and only the claims, define the inventive system and methodology.

5 **[0091]** 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
10 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 to produce hydrocarbons in a feed stream extracted
15 from, for example, a subsurface region. The feed stream extracted may be processed in the distillation tower **104, 204** and separated into hydrocarbons and contaminants. The separated hydrocarbons exit the middle controlled freeze zone section **108** or the upper section **110** of the distillation tower. Some or all of the hydrocarbons that exit are produced. Hydrocarbon extraction may be conducted to remove the feed stream from for example, the subsurface
20 region, which may be accomplished by drilling a well using oil well drilling equipment. The equipment and techniques used to drill a well and/or extract the 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.

[0092] Aspects of the disclosure may include any combinations of the methods and systems
25 shown in the following numbered paragraphs. This is not to be considered a complete listing of all possible aspects, as any number of variations can be envisioned from the description above.

1. A cryogenic distillation tower for separating a feed stream, the distillation tower comprising:

- 30 a distillation section permitting vapor to rise upwardly therefrom;
one or more lines for directing the feed stream into the distillation tower;

a controlled freeze zone section situated above the distillation section, the controlled freeze zone constructed and arranged to form a solid from the feed stream, the controlled freeze zone section including

a spray assembly in an upper section of the controlled freeze zone, and

5 a melt tray assembly in a lower section of the controlled freeze zone, wherein the melt tray assembly includes

at least one vapor stream riser that directs the vapor from the distillation section into liquid retained by the melt tray assembly, and

10 one or more draw-off openings positioned to permit a portion of the liquid retained by the melt tray assembly to exit the controlled freeze zone section;

a heat exchanger arranged to heat the portion of the liquid through indirect heat exchange with a heating fluid; and

15 one or more return inlets that return the portion of the liquid to the melt tray assembly after the portion of the liquid has been heated in the heat exchanger.

2. The cryogenic distillation tower of claim 1, wherein the heating fluid is the feed stream prior to the feed stream being directed into the distillation tower.

3. The cryogenic distillation tower of claim 1 or claim 2, wherein the heat exchanger is a first heat exchanger and the heating fluid is a first heating fluid, and further comprising a second
20 heat exchanger arranged to heat the portion of the liquid through indirect heat exchange with a second heating fluid.

4. The cryogenic distillation tower of paragraph 3, wherein the second heating fluid comprises one or more of ethane and propane.

5. The cryogenic distillation tower of any one of paragraphs 1-4, further comprising a
25 pump for pumping the portion of the liquid exiting the one or more draw-off openings.

6. The cryogenic distillation tower of any one of paragraphs 1-5, further comprising a bypass line configured to selectively permit the feed stream to bypass the heat exchanger.

7. The cryogenic distillation tower of any one of paragraphs 1-6, wherein the one or more return inlets comprise two or more return inlets that are evenly distributed about a perimeter of
30 the cryogenic distillation tower.

8. The cryogenic distillation tower of any one of paragraphs 1-7, wherein the melt tray assembly includes a heating element to heat the liquid retained in the melt tray assembly.
9. The cryogenic distillation tower of any one of paragraphs 1-8, wherein the feed gas comprises less than 30 mol% carbon dioxide.
- 5 10. The cryogenic distillation tower of any one of paragraphs 1-9, wherein the solid comprises carbon dioxide.
11. A method of cryogenically separating contaminants from a feed stream in a distillation tower, the method comprising:
- directing the feed stream into the distillation tower;
 - 10 permitting vapor to rise upwardly from a distillation section of the distillation tower;
 - forming a solid in a controlled freeze zone section of the distillation tower, the controlled freeze zone section being situated above the distillation section, wherein the solid comprises contaminants in the feed stream;
 - directing the vapor from the distillation section into liquid retained by a melt tray
 - 15 assembly using at least one vapor stream riser;
 - melting the solid using the liquid retained by the melt tray assembly;
 - permitting a portion of the liquid retained by the melt tray assembly to exit the controlled freeze zone section;
 - heating the portion of the liquid through indirect heat exchange with a heating fluid in
 - 20 a heat exchanger; and
 - returning the portion of the liquid to the melt tray assembly after the liquid has been heated in the heat exchanger.
12. The cryogenic distillation tower of paragraph 11, wherein the heating fluid is the feed stream prior to the feed stream being directed into the distillation tower.
- 25 13. The cryogenic distillation tower of paragraph 11 or paragraph 12, wherein the heat exchanger is a first heat exchanger and the heating fluid is a first heating fluid, and further comprising:
- heating the portion of the liquid through indirect heat exchange with a second heating fluid in a second heat exchanger.

14. The cryogenic distillation tower of paragraph 13, wherein the second heating fluid comprises one or more of ethane and propane.
15. The cryogenic distillation tower of any one of paragraphs 11-14, further comprising: pumping the portion of the liquid exiting the one or more draw-off openings.
- 5 16. The cryogenic distillation tower of any one of paragraphs 11-15, further comprising: selectively permitting the feed stream to bypass the heat exchanger.
17. The cryogenic distillation tower of any one of paragraphs 11-16, wherein the one or more return inlets comprise two or more return inlets that are evenly distributed about a perimeter of the tower.
- 10 18. The cryogenic distillation tower of any one of paragraphs 11-17, further comprising: heating the liquid retained in the melt tray assembly using a heating element.
19. The cryogenic distillation tower of any one of paragraphs 11-18, wherein the feed gas comprises less than 30 mol% carbon dioxide.
20. The cryogenic distillation tower of any one of paragraphs 11-19, wherein the solid
15 comprises carbon dioxide.
- [0093]** It should be understood that 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.
- 20 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

What is claimed is:

1. A cryogenic distillation tower for separating a feed stream, the distillation tower comprising:
 - 5 a distillation section permitting vapor to rise upwardly therefrom;
 - one or more lines for directing the feed stream into the distillation tower;
 - a controlled freeze zone section situated above the distillation section, the controlled freeze zone constructed and arranged to form a solid from the feed stream, the controlled freeze zone section including
 - 10 a spray assembly in an upper section of the controlled freeze zone, and
 - a melt tray assembly in a lower section of the controlled freeze zone, wherein the melt tray assembly includes
 - at least one vapor stream riser that directs the vapor from the distillation section into liquid retained by the melt tray assembly, and
 - 15 one or more draw-off openings positioned to permit a portion of the liquid retained by the melt tray assembly to exit the controlled freeze zone section;
 - a heat exchanger arranged to heat the portion of the liquid through indirect heat exchange with a heating fluid; and
 - 20 one or more return inlets that return the portion of the liquid to the melt tray assembly after the portion of the liquid has been heated in the heat exchanger.
2. The cryogenic distillation tower of claim 1, wherein the heating fluid is the feed stream prior to the feed stream being directed into the distillation tower.
- 25 3. The cryogenic distillation tower of claim 1 or claim 2, wherein the heat exchanger is a first heat exchanger and the heating fluid is a first heating fluid, and further comprising a second heat exchanger arranged to heat the portion of the liquid through indirect heat exchange with a second heating fluid.
- 30 4. The cryogenic distillation tower of claim 3, wherein the second heating fluid comprises one or more of ethane and propane.
5. The cryogenic distillation tower of any one of claims 1-4, further comprising a pump

for pumping the portion of the liquid exiting the one or more draw-off openings.

6. The cryogenic distillation tower of any one of claims 1-5, further comprising a bypass line configured to selectively permit the feed stream to bypass the heat exchanger.

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7. The cryogenic distillation tower of any one of claims 1-6, wherein the one or more return inlets comprise two or more return inlets that are evenly distributed about a perimeter of the cryogenic distillation tower.

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8. The cryogenic distillation tower of any one of claims 1-7, wherein the melt tray assembly includes a heating element to heat the liquid retained in the melt tray assembly.

9. The cryogenic distillation tower of any one of claims 1-8, wherein the feed gas comprises less than 30 mol% carbon dioxide.

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10. The cryogenic distillation tower of any one of claims 1-9, wherein the solid comprises carbon dioxide.

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11. A method of cryogenically separating contaminants from a feed stream in a distillation tower, the method comprising:

directing the feed stream into the distillation tower;

permitting vapor to rise upwardly from a distillation section of the distillation tower;

forming a solid in a controlled freeze zone section of the distillation tower, the controlled freeze zone section being situated above the distillation section, wherein the solid comprises contaminants in the feed stream;

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directing the vapor from the distillation section into liquid retained by a melt tray assembly using at least one vapor stream riser;

melting the solid using the liquid retained by the melt tray assembly;

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permitting a portion of the liquid retained by the melt tray assembly to exit the controlled freeze zone section;

heating the portion of the liquid through indirect heat exchange with a heating fluid in a heat exchanger; and

returning the portion of the liquid to the melt tray assembly after the liquid has been heated in the heat exchanger.

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12. The method of claim 11, wherein the heating fluid is the feed stream prior to the feed

stream being directed into the distillation tower.

13. The method of claim 11 or claim 12, wherein the heat exchanger is a first heat exchanger and the heating fluid is a first heating fluid, and further comprising:

5 heating the portion of the liquid through indirect heat exchange with a second heating fluid in a second heat exchanger.

14. The method of claim 13, wherein the second heating fluid comprises one or more of ethane and propane.

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15. The method of any one of claims 11-14, further comprising:
pumping the portion of the liquid exiting the one or more draw-off openings.

16. The method of any one of claims 11-15, further comprising:

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selectively permitting the feed stream to bypass the heat exchanger.

17. The method of any one of claims 11-16, wherein the one or more return inlets comprise two or more return inlets that are evenly distributed about a perimeter of the tower.

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18. The method of any one of claims 11-17, further comprising: heating the liquid retained in the melt tray assembly using a heating element.

19. The method of any one of claims 11-18, wherein the feed gas comprises less than 30 mol% carbon dioxide.

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20. The method of any one of claims 11-19, wherein the solid comprises carbon dioxide.

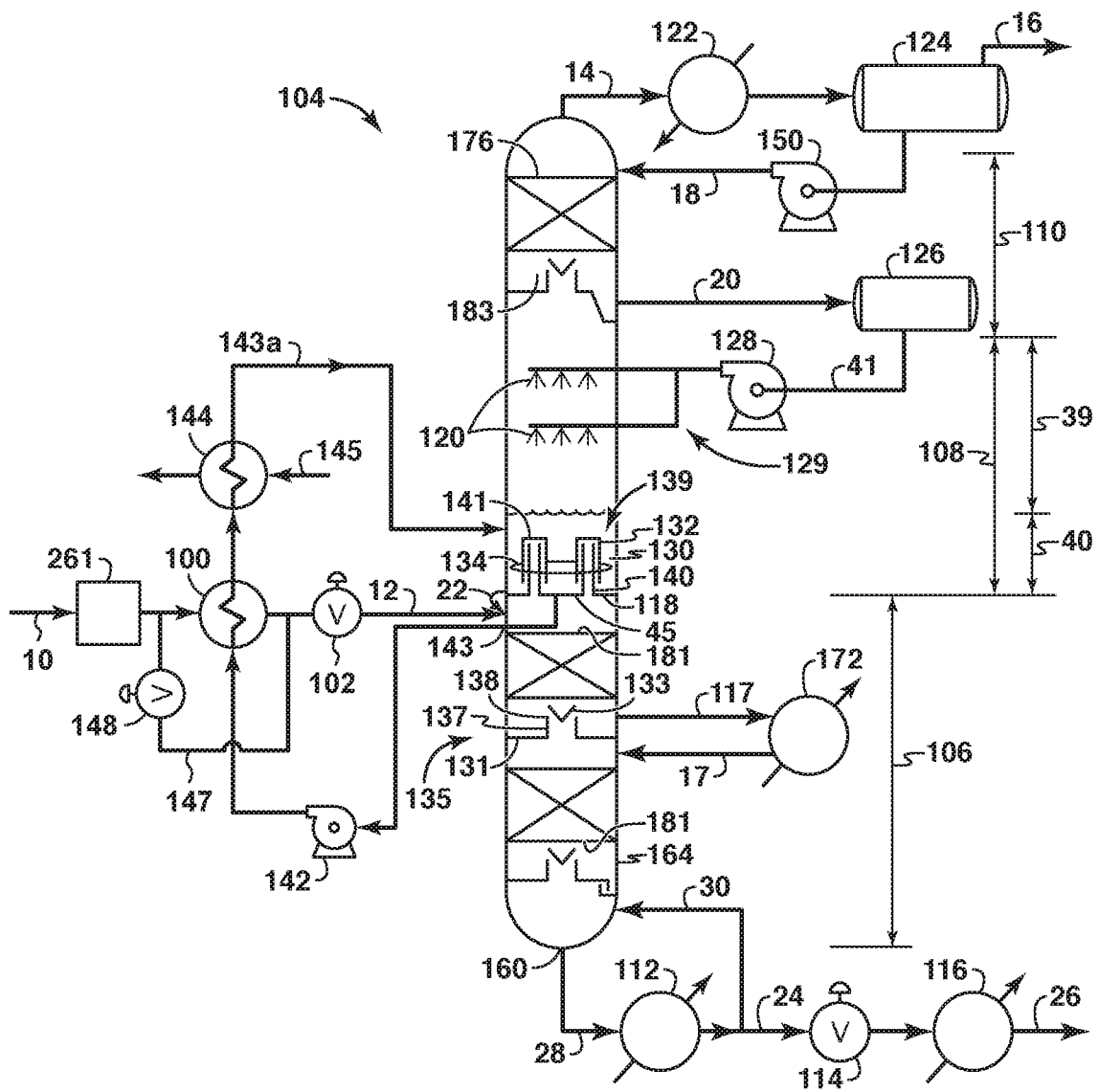


FIG. 1

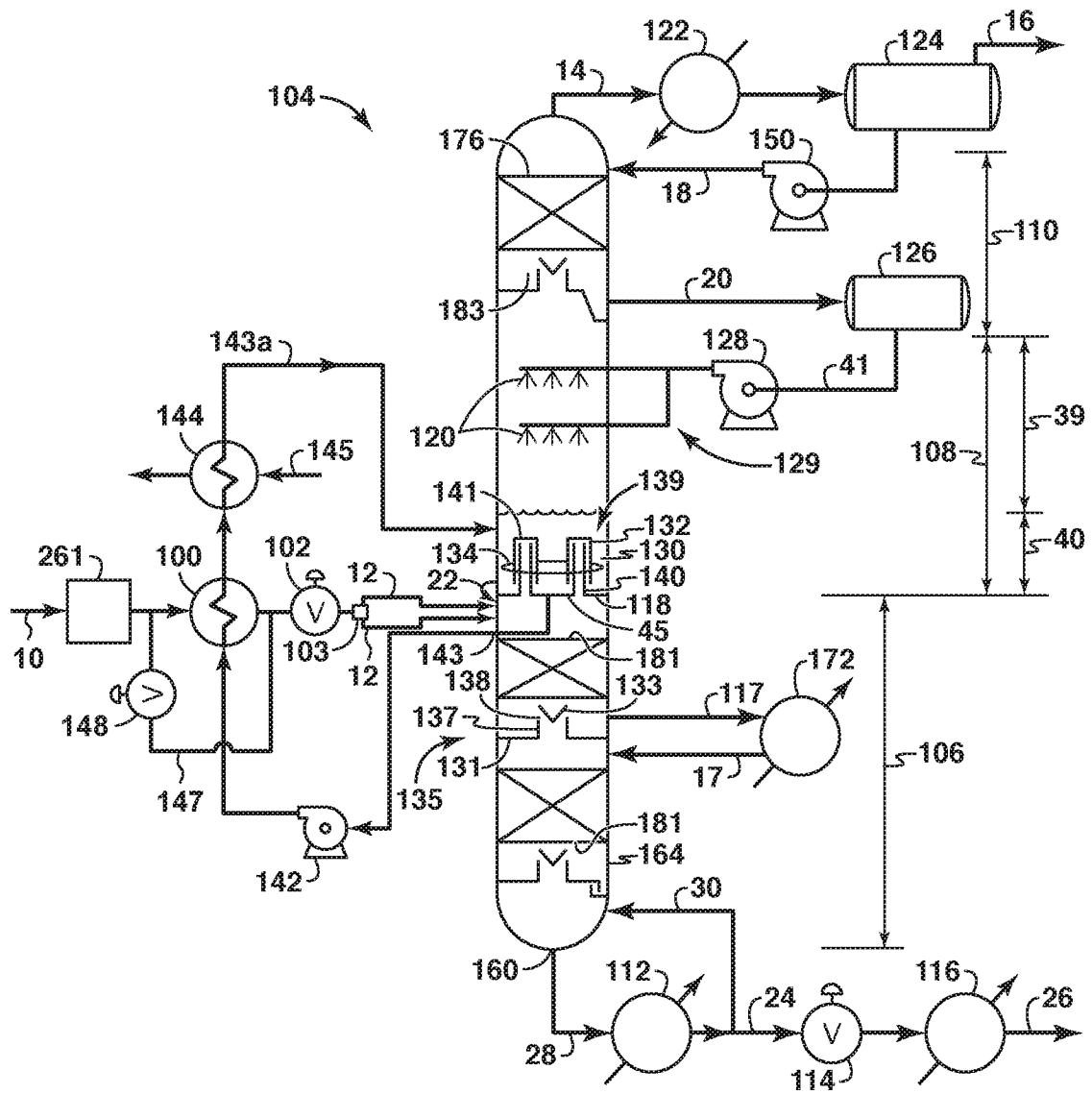


FIG. 3

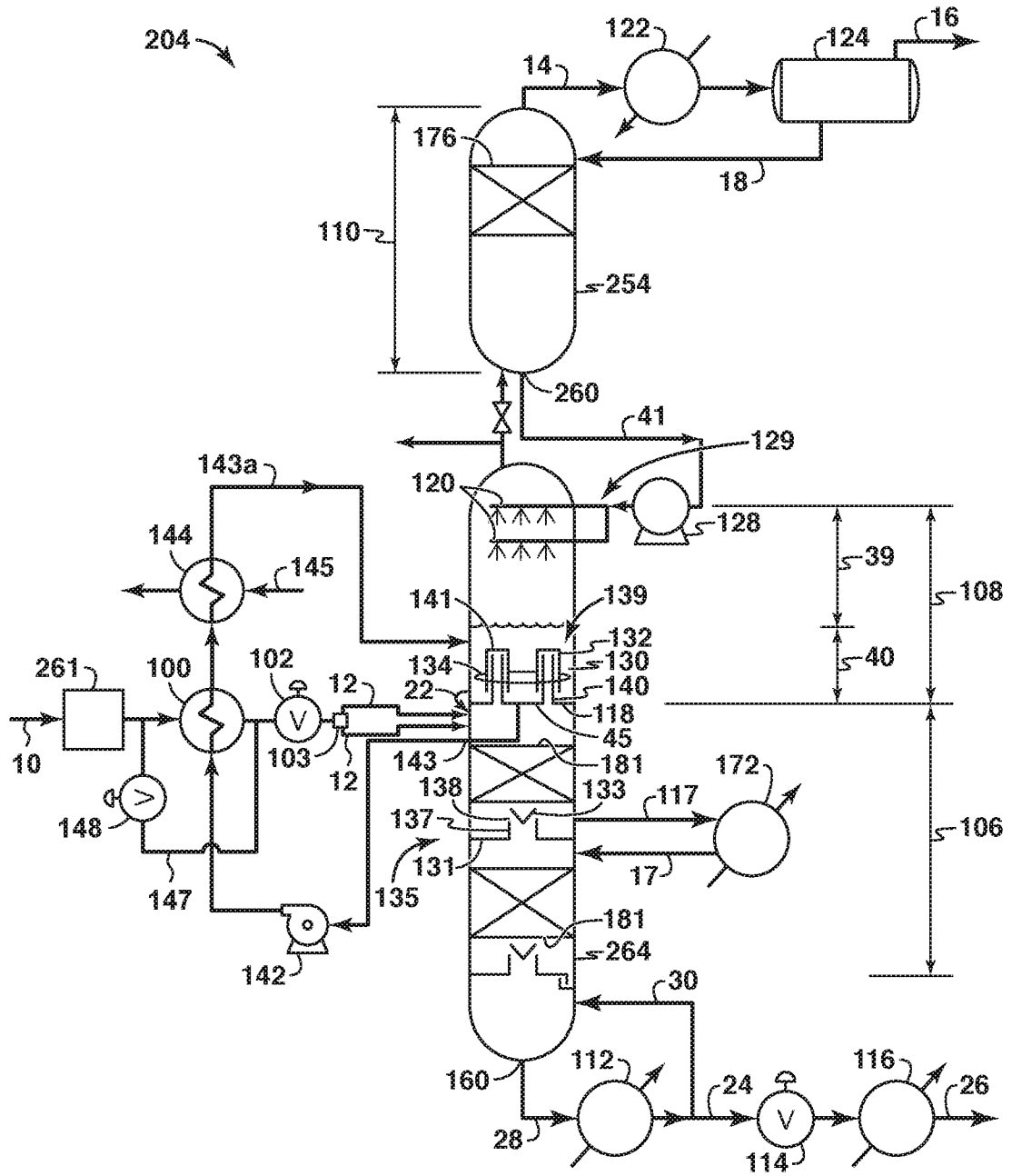


FIG. 4

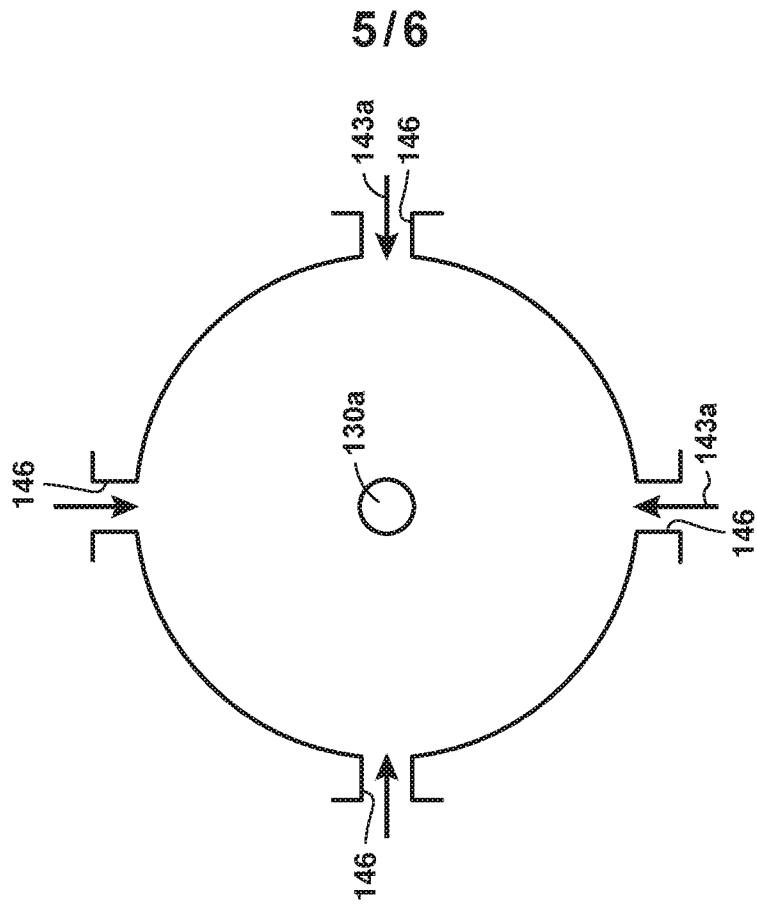


FIG. 6

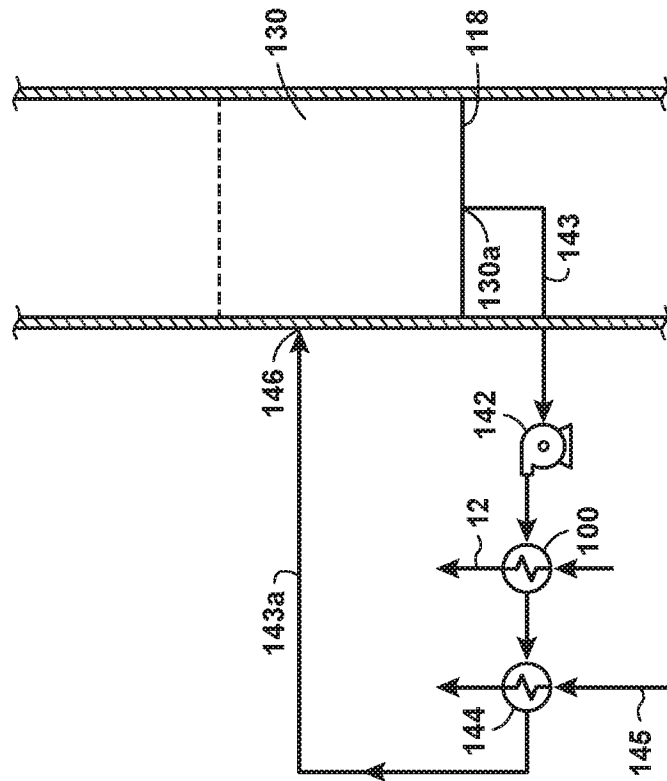


FIG. 5

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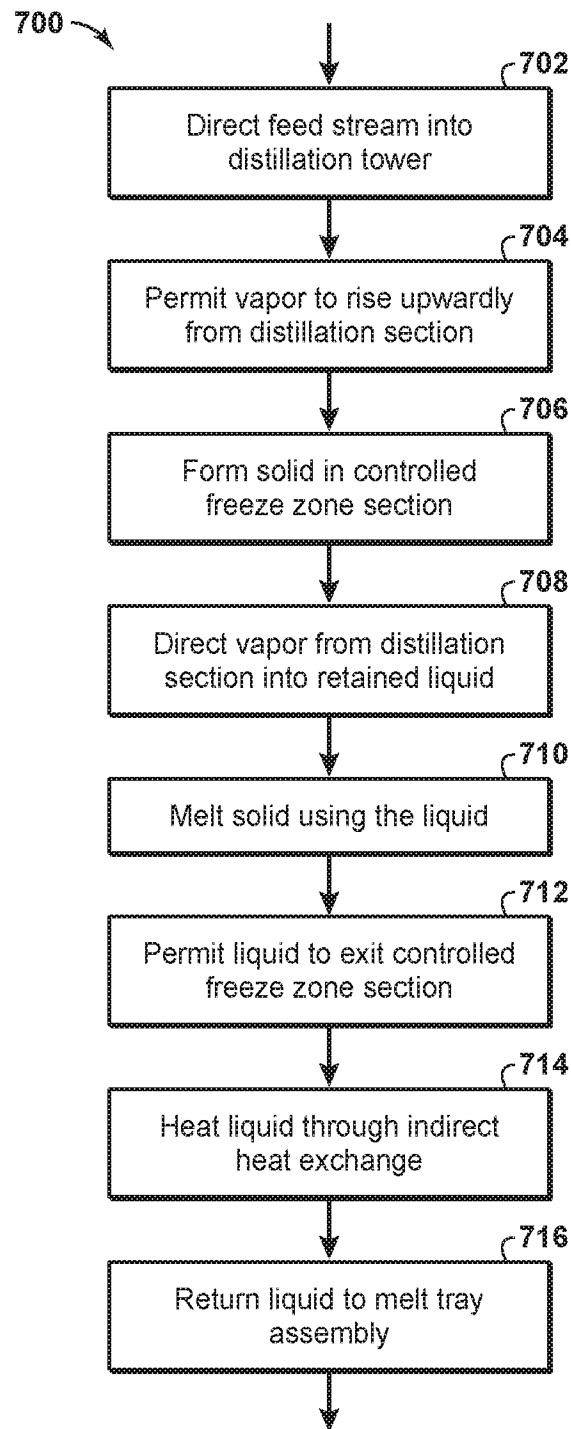


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/036918

A. CLASSIFICATION OF SUBJECT MATTER
 INV. B01D1/16 B01D3/16 B01D3/20
 ADD.
 According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
 Minimum documentation searched (classification system followed by classification symbols)
 B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/031144 A1 (NORTHROP PAUL SCOTT [US] ET AL) 9 February 2012 (2012-02-09) fig.1-2, par.55-112 -----	1-20
X	US 2015/159946 A1 (VALENCIA JAIME A [US]) 11 June 2015 (2015-06-11) fig.1,5, par.33-105 -----	1-4,6-20
X	US 2016/206970 A1 (ALZNER GERHARD [DE] ET AL) 21 July 2016 (2016-07-21) fig.22, par.97-99 -----	1-4,7,9,10
X	US 2016/010917 A1 (NORTHROP P SCOTT [US] ET AL) 14 January 2016 (2016-01-14) fig.1, 48-127 -----	1-20

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search 25 July 2019	Date of mailing of the international search report 31/07/2019
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Weber, Christian
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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