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(54) **Title**: METHOD AND DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A SPRAY ASSEMBLY

(57) **Abstract**: A method for separating a feed stream in a distillation tower comprising maintaining a controlled freeze zone (CFZ) section in the distillation tower, receiving a freezing zone liquid stream in a spray nozzle assembly in the CFZ section, wherein the spray nozzle assembly comprises a plurality of outer spray nozzles on an outer periphery of the spray nozzle assembly and at least one inner spray nozzle interior to the outer spray nozzles, wherein each outer spray nozzle is configured to spray the freezing zone liquid stream along a central spray axis, and wherein the central spray axis of at least one of the outer spray nozzles is not parallel to a CFZ wall, and spraying the freezing zone liquid stream through the spray nozzle assembly into the CFZ section to keep a temperature and pressure at which the solid and the hydrocarbon-enriched vapor stream form.

# METHOD AND DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A SPRAY ASSEMBLY

## CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** This application is related to United States Patent Application number 61/912,957 filed December 6, 2013 entitled METHOD AND DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A SPRAY ASSEMBLY, and United States Patent Application number 62/044,770 filed September 2, 2014 entitled METHOD AND DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A SPRAY ASSEMBLY, the entirety of which is incorporated by reference herein.

**[0002]** This application is related to but does not claim priority to U.S. Provisional patent application numbers: 61/912,959 filed on December 6, 2013 entitled METHOD AND SYSTEM OF MAINTAING A LIQUID LEVEL IN A DISTILLATION TOWER; 61/912,964 filed on December 6, 2013 entitled METHOD AND DEVICE FOR SEPARATING A FEED STREAM USING RADIATION DETECTORS; 61/912,970 filed on December 6, 2013 entitled METHOD AND SYSTEM OF DEHYDRATING A FEED STREAM PROCESSED IN A DISTILLATION TOWER; 61/912,975 filed on December 6, 2013 entitled METHOD AND SYSTEM FOR SEPARATING A FEED STREAM WITH A FEED STREAM DISTRIBUTION MECHANISM; 61/912,978 filed on December 6, 2013 entitled METHOD AND SYSTEM FOR PREVENTING ACCUMULATION OF SOLIDS IN A DISTILLATION TOWER; 61/912,983 filed on December 6, 2013 entitled METHOD OF REMOVING SOLDS BY MODIFYING A LIQUID LEVEL IN A DISTILLATION TOWER; 61/912,984 filed on December 6, 2013 entitled METHOD AND SYSTEM OF MODIFYING A LIQUID LEVEL DURING START-UP OPERATIONS; 61/912,986 filed on December 6, 2013 entitled METHOD AND DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A HEATING MECHANISM TO DESTABILIZE AND/OR PREVENT ADHESION OF SOLIDS; 61/912,987 filed on December 6, 2013 entitled METHOD AND DEVICE FOR SEPARATING HYDROCARBONS AND CONTAMINANTS WITH A SURFACE TREATMENT MECHANISM.

# BACKGROUND

Fields of Disclosure

**[0003]** 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.

**[0004]** 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.

**[0005]** 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 ("$CO_2$"), hydrogen sulfide ("$H_2S$"), 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 oftentimes referred to as "sour gas."

**[0006]** 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 the gas stream. Some contaminants, like sulfur-bearing compounds, are noxious and may even be lethal. Additionally, in the presence of water some contaminants can become quite corrosive.

**[0007]** 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% $CO_2$ and ¼ grain $H_2S$ per 100 scf (4 ppmv) or 5 mg/Nm3 $H_2S$. Specifications for lower temperature processes such as natural gas liquefaction plants or nitrogen rejection units typically require less than 50 ppm $CO_2$.

**[0008]** 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.

**[0009]** 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 phases throughout the distillation tower. The separation of $CO_2$ from methane by distillation involves temperature and pressure conditions that result in solidification of $CO_2$ if a pipeline or better quality hydrocarbon product is desired. The required temperatures are cold temperatures typically referred to as cryogenic temperatures.

**[0010]** Certain cryogenic distillations can overcome the above mentioned difficulties. 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 section.

**[0011]** Sometimes solids can adhere to an internal (e.g., controlled freeze zone wall) of the controlled freeze zone section rather than falling to the bottom of the controlled freeze zone section.

**[0012]** The adherence is disadvantageous. The adherence, if uncontrolled, can interfere with the proper operation of the controlled freeze zone section and the effective separation of methane from the contaminants.

**[0013]** A need exists for improved technology to separate a feed stream, containing hydrocarbons and contaminants, while also preventing the adherence of solids on the controlled freeze zone wall.

## SUMMARY

**[0014]** The present disclosure provides a device and method for separating contaminants from hydrocarbons and preventing the adherence of solids on the controlled freeze zone wall, among other things.

**[0015]** A method for separating a feed stream in a distillation tower comprising maintaining a controlled freeze zone section in the distillation tower, receiving a freezing zone liquid stream in a spray nozzle assembly in the controlled freeze zone section, wherein the spray nozzle assembly comprises a plurality of outer spray nozzles on an outer periphery of the spray nozzle assembly and at least one inner spray nozzle interior to the plurality of outer spray nozzles, wherein each outer spray nozzle is configured to spray the freezing zone liquid stream along a central spray axis, and wherein the central spray axis of at least one of the plurality of outer spray nozzles is not parallel to a controlled freeze zone wall, and spraying the freezing zone liquid stream through the spray nozzle assembly into the controlled freeze zone section at a temperature and pressure at which the solid and the hydrocarbon-enriched vapor stream form.

**[0016]** A method for producing hydrocarbons comprising maintaining a controlled freeze zone section in the distillation tower that receives a freezing zone liquid stream to form a solid and a hydrocarbon-enriched vapor stream in the controlled freeze zone section, maintaining a spray assembly in the controlled freeze zone section, wherein the spray assembly comprises a first type of spray nozzle on an outer periphery and a second type of spray nozzle interior to the first type of spray nozzle, and wherein the first type of spray nozzle orients spray at an angle with respect to a controlled freeze zone wall so as to minimize spray liquid impingement on the controlled freeze zone wall, injecting the freezing zone liquid stream into the controlled freeze zone section through the spray assembly at a temperature and pressure at which the solid and the hydrocarbon-enriched vapor stream form, wherein the freezing zone liquid stream comprises a freezing zone liquid stream outermost portion, and producing the hydrocarbon-enriched vapor stream extracted from the distillation tower.

**[0017]** A distillation tower that separates a contaminant in a feed stream from a hydrocarbon in the feed stream may comprise a controlled freeze zone section comprising a controlled freeze zone section comprising a controlled freeze zone wall, a first type of spray nozzle configured to inject a freezing zone liquid stream into the controlled freeze zone section at a temperature and pressure at which a solid forms, and a melt tray assembly below the first type of spray nozzle that configured to melt the solid that comprises the contaminant, wherein the first type of spray nozzle is configured to direct a freezing zone liquid stream outermost portion at an angle to the controlled freeze zone wall with the first type of spray nozzle, and wherein the angle is calculated to minimize or eliminate impingement of the freezing zone liquid stream on the controlled freeze zone wall.

**[0018]** The foregoing has broadly outlined the features of the present disclosure so that the detailed description that follows may be better understood. Additional features will also be described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

**[0019]** 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.

**[0020]** Figure 1 is a schematic diagram of a tower with sections within a single vessel.

**[0021]** Figure 2 is a schematic diagram of a tower with sections within multiple vessels.

**[0022]** Figure 3 is a schematic diagram of a tower with sections within a single vessel.

**[0023]** Figure 4 is a schematic diagram of a tower with sections within multiple vessels.

**[0024]** Figure 5 is a schematic, cross-sectional diagram of a controlled freeze zone section.

**[0025]** Figure 6 is a top view of a spray assembly.

**[0026]** Figure 7 is a flowchart of a method within the scope of the present disclosure.

**[0027]** It should be noted that the figures are merely examples and no limitations on the scope of the present disclosure are intended thereby. Further, the figures are generally not drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of the disclosure.

DETAILED DESCRIPTION

**[0028]** For the purpose of promoting an understanding of the principles of the disclosure, reference will now be made to the features illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended. Any alterations and further modifications, and any further applications of the principles of the disclosure as described herein are contemplated as would normally occur to one skilled in the art to which the disclosure relates. It will be apparent to those skilled in the relevant art that some features that are not relevant to the present disclosure may not be shown in the drawings for the sake of clarity.

**[0029]** 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.

**[0030]** The disclosure relates to a system and method for separating a feed stream in a distillation tower. The system and method helps prevent the formation of solids that adhere to the wall of the controlled freeze zone section by directing a freezing zone liquid stream outermost portion of a first type of spray nozzle at an outer periphery of the spray assembly so as to eliminate, reduce, and/or minimize spray liquid impingement on the controlled freeze zone wall of the controlled freeze zone section. Figures 1-7 of the disclosure display various aspects of the system and method.

**[0031]** The system and method may separate a feed stream having methane and contaminants. The system may comprise a distillation tower **104**, **204** (Figures 1-4). The distillation tower **104**, **204** may separate the contaminants from the methane.

**[0032]** 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.

**[0033]** The distillation tower **104**, **204** may incorporate only two functional sections when the upper section **110** is not needed and/or desired. When the distillation tower does not include an upper section **110**, a portion of vapor leaving the middle controlled freeze zone section **108** may be condensed in a condenser **122** and returned as a liquid stream via a spray assembly **129**. Moreover, lines **18** and **20** may be eliminated, elements **124** and **126** may be one and the same, and elements **150** and **128** may be one and the same. The stream in line **14**, now taking the vapors leaving the middle controlled freeze section **108**, directs these vapors to the condenser **122**.

**[0034]** 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.

**[0035]** 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**.

**[0036]** 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 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**. 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 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.

**[0037]** 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.

**[0038]** 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**.

**[0039]** 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 **104**, **204**. For example, the valve **102** may comprise a Joule-Thompson (J-T) valve.

**[0040]** 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 of the lines **12** may receive the vapor stream from the feed separator. Another one of the lines **12** may receive the liquid stream from the feed separator. Each of the lines **12** may extend to the same and/or different sections (i.e. middle controlled freeze zone, and lower sections) of the distillation tower **104**, **204**. The expander device **102** may or may not be downstream of the feed separator **103**. The expander device **102** may comprise a plurality of expander devices **102** such that each line **12** has an expander device **102**.

**[0041]** 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 prevent water from later presenting a problem in the heat exchanger **100**, expander device **102**, feed separator **103**, or distillation tower **104**, **204**. The water can present a problem by forming a separate water phase (i.e., ice and/or hydrate) that plugs lines, equipment or negatively affects the distillation process. The dehydration unit **261** dehydrates the feed stream to a dew point sufficiently low to ensure a separate water phase will not form at any point downstream during the rest of the process. The dehydration unit may be any suitable dehydration mechanism, such as a molecular sieve or a glycol dehydration unit.

**[0042]** The system may include a filtering unit (not shown). The feed stream **10** may enter the filtering unit before entering the distillation tower **104**, **204**. The filtering unit may remove undesirable contaminants from the feed stream before the feed stream enters the distillation tower **104**, **204**. Depending on what contaminants are to be removed, the filtering unit may be before or after the dehydration unit **261** and/or before or after the heat exchanger **100**.

**[0043]** The systems may include a line **12** (Figures 1-4). The line may also be referred to as an inlet channel **12**. The feed stream **10** may be introduced into the distillation tower **104**, **204** through the line **12**. The line **12** may extend to the lower section **106** or the middle controlled freeze zone section **108** of the distillation tower **104**, **204**. For example, the line **12** may extend to the lower section **106** such that the feed stream **10** may enter the lower section **106** of the distillation tower **104**, **204** (Figures 1-4). The line **12** may directly or indirectly extend to the lower section **106** or the middle controlled freeze zone section **108**. The line **12** may extend to an outer surface of the distillation tower **104**, **204** before entering the distillation tower **104**, **204**.

**[0044]** 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**.

**[0045]** The lower section **106** is constructed and arranged to separate the feed stream **10** into an enriched contaminant bottom liquid stream (i.e., liquid stream) and a freezing zone vapor stream (i.e., vapor stream). The lower section **106** separates the feed stream at a temperature and pressure at which no solids form. The liquid stream may comprise a greater quantity of contaminants than of methane. The vapor stream may comprise a greater quantity of methane than of contaminants. In any case, the vapor stream is lighter than the liquid stream. As a result, the vapor stream rises from the lower section **106** and the liquid stream falls to the bottom of the lower section **106**.

**[0046]** The lower section **106** may include and/or connect to equipment that separates the feed stream. The equipment may comprise any suitable equipment for separating methane from contaminants, such as one or more packed sections **181**, or one or more distillation trays with perforations, downcomers, and weirs (Figures 1-4).

**[0047]** The equipment may include components that apply heat to the stream to form the vapor stream and the liquid stream. For example, the equipment may comprise a first reboiler **112** that applies heat to the stream. The first reboiler **112** may be located outside of the distillation tower **104**, **204**. The equipment may also comprise a second reboiler **172** that applies heat to the stream. The second reboiler **172** may be located outside of the distillation tower **104**, **204**. Line **117** may lead from the distillation tower to the second reboiler **172**. Line **17** may lead from the second reboiler **172** to the distillation tower. Additional reboilers, set up similarly to the second reboiler described above, may also be used.

**[0048]** 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.

**[0049]** The first reboiler **112** may also apply heat to the stream within the distillation tower **104**, **204**. Specifically, the heat applied by the first reboiler **112** warms up the lower section **106**. This heat travels up the lower section **106** and supplies heat to warm solids entering a melt tray assembly **139** (Figures 1-4) of the middle controlled freeze zone section **108** so that the solids form a liquid and/or slurry mix.

**[0050]** The second reboiler **172** may apply heat to the stream within the lower section **106**. This heat may be 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** may also help with energy integration. Some commercial applications may not have this second reboiler **172**.

**[0051]** 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**.

**[0052]** 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 **106** to supply heat to the middle controlled freeze zone section **106** and/or the melt tray assembly **139**. Unvaporized (or partially vaporized) 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**.

**[0053]** 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**. In the depicted embodiment, 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**.

**[0054]** 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**.

**[0055]** 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**.

**[0056]** 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**.

**[0057]** The system 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.

**[0058]** 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.

**[0059]** The vapor stream in the lower section **106** rises from the lower section **106** to the middle controlled freeze zone section **108**. The middle controlled freeze zone section **108** is maintained to receive a freezing zone liquid stream to form the solid and the vapor stream (i.e., hydrocarbon-enriched vapor stream) in the middle controlled freeze zone section **108**, **501** (Figure 7). The middle controlled freeze zone section **108** is constructed and arranged to separate the feed stream **10** introduced into the middle controlled freeze zone section into a solid and a vapor stream. The solid and the vapor stream are formed in the middle controlled freeze zone section **108** when the freezing zone liquid stream is injected into the middle controlled freeze zone section **108** at a temperature and pressure at which the solid and vapor stream form, **505** (Figure 7). The solid may be comprised more of contaminants than of methane. The vapor stream may comprise more methane than contaminants.

**[0060]** The middle controlled freeze zone section **108** includes a lower section **40** and an upper section **39** (Figure 5). The lower section **40** is below the upper section **39**. The lower section **40** directly abuts the upper section **39**. The lower section **40** is primarily but may not exclusively be a heating section of the middle controlled freeze zone section **108**. The upper section **39** is primarily but may not exclusively be a cooling section of the middle controlled freeze zone section **108**. The temperature and pressure of the upper section **39** are chosen so that the solid can form in the middle controlled freeze zone section **108**.

**[0061]** 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 1-5). The melt tray assembly **139** is within the lower section **40** of the middle controlled freeze zone section **108**. The melt tray assembly **139** is not within the upper section **39** of the middle controlled freeze zone section **108**.

**[0062]** The melt tray assembly **139** is constructed and arranged to melt a solid formed in the middle controlled freeze zone section **108**. When the warm vapor stream rises from the lower section **106** to the middle controlled freeze zone section **108**, the vapor stream immediately encounters the melt tray assembly **139** and supplies heat to melt the solid. The melt tray assembly **139** may comprise at least one of a melt tray **118**, a bubble cap **132**, a liquid **130** and heat mechanism(s) **134**.

**[0063]** 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**.

**[0064]** 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 **140** prevents the liquid **130** from travelling into the riser **140**. The cap **141** helps prevent solids from travelling into the riser **140**. The vapor stream's traversal through the bubble cap **132** allows the vapor stream to transfer heat to the liquid **130** within the melt tray assembly **139**.

**[0065]** 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 the bubble caps **132**. The heat mechanism **134** may be any suitable mechanism, such as a heat coil. The heat source of the heat mechanism **134** may be any suitable heat source.

**[0066]** The liquid **130** in the melt tray assembly is heated by the vapor stream. The liquid **130** may also be heated by the one or more heat mechanisms **134**. The liquid **130** helps melt the solids formed in the middle controlled freeze zone section **108** into a liquid and/or slurry mix. Specifically, the heat transferred by the vapor stream heats up the liquid, thereby enabling the heat to melt the solids. The liquid **130** is at a level sufficient to melt the solids.

**[0067]** 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**.

**[0068]** As shown in Figures 5-6, the spray assembly **129** includes a plurality of spray nozzles **121**, **221**. The plurality of spray nozzles **121**, **221** comprise a plurality of outer spray nozzles on an outer periphery of the spray nozzle assembly, e.g., a first type of spray nozzle **121**, and at least one inner spray nozzle interior to the plurality of outer spray nozzles, e.g., a second type of spray nozzle **221**. The first type of spray nozzle **121** may be maintained in the controlled freeze zone section **108** at a first angle **122**, **502** (Figure 5-7) about its axis **112-112** with a spray distribution **151** (added to figure 5). The second type of spray nozzle **221** may be maintained in the controlled freeze zone section **108** at a second angle **222** about its axis **212-212** with a spray distribution **251** (added to figure 5).

**[0069]** There may be any suitable amount of first type of spray nozzles **121** and/or second type of spray nozzles **221**. For example, as shown in Figure 6, there may be 12 first type of spray nozzles **121** and second type of spray nozzles **221**. The second type of spray nozzles **221** form the inner periphery of nozzles in the spray assembly **129**. The first type of spray nozzles **121** form the outer periphery of the nozzles in the spray assembly **129**.

**[0070]** The first and second types of spray nozzles **121**, **221** spray the freezing zone liquid stream **130**, **230** with a liquid distribution of **151**, **251**, respectively, into the middle controlled freeze zone section **108**. Each liquid distribution **151**, **251** has a central spray axis about which spray is dispersed. The central spray axis is generally coextensive with the axis **112-112** and **212-212**, respectively, when the liquid distribution of **151**, **251** is symmetrical, but may diverge, e.g., when the liquid distribution **151**, **251** is asymmetrical. The freezing zone liquid stream **130**, **230** is injected into the controlled freeze zone section **108** at a temperature and pressure at which the solid and the hydrocarbon-enriched vapor stream form.

**[0071]** The freezing zone liquid stream **130**, **230** comprises a freezing zone liquid stream outermost portion **131**, **231**. The freezing zone liquid stream outermost portion **131** of the freezing zone liquid stream **130** sprayed from the first type of spray nozzle **121** may be directly adjacent to the controlled freeze zone wall **46**. The freezing zone liquid stream outermost portion **131** may be an outermost boundary of the freezing zone liquid stream **130**. In other words, the freezing zone liquid stream outermost portion **131** forms a first part of the outermost perimeter of the freezing zone liquid stream **130** sprayed from the first nozzle **121**. And this first part of the outermost perimeter is closer to the controlled freeze zone wall **46** than any other portion of the outermost perimeter.

**[0072]** The freezing zone liquid stream **130**, **230** may also comprise a freezing zone liquid stream innermost portion **132**, **232**. The freezing zone liquid stream innermost portion **132** of the freezing zone liquid stream sprayed **130** sprayed from the first type of spray nozzle **121** is not directly adjacent to the controlled freeze zone wall **46**. This freezing zone liquid stream innermost portion **132** is farther from the controlled freeze zone wall **46** than the freezing zone liquid stream outermost portion **131**. The freezing zone liquid stream innermost portion **132** may be an innermost boundary of the freezing zone liquid stream **130**. In other words, the freezing zone liquid stream innermost portion **132** forms a second part of the outermost perimeter of the freezing zone liquid stream **130** sprayed from the first nozzle **121**. And this second part of the outermost perimeter is farther from the controlled freeze zone wall **46** than any other portion of the outermost perimeter.

**[0073]** The characteristics such as, but not limited to spray angle and symmetricity, of the liquid stream **130**, **230** from the innermost portion **131**, **231** to the outermost portion **132**, **232** is defined as the liquid distribution **151**, **251**.

**[0074]** The freezing zone liquid stream outermost portion **231** and freezing zone liquid stream innermost portion **232** of the freezing zone liquid stream **230** sprayed from the second type of spray nozzle **221** is farther from the controlled freeze zone wall **46** than the freezing zone liquid stream outermost portion **131** of the freezing zone liquid stream **130** sprayed from the first type of spray nozzle **121**. The freezing zone liquid stream outermost portion **231** and freezing zone liquid stream innermost portion **232** may or may not be farther from the controlled freeze zone wall **46** than the freezing zone liquid stream innermost portion **132** of the freezing zone liquid stream **130** sprayed from the first type of spray nozzle **121**.

**[0075]** The first type of spray nozzle **121** may be directly adjacent to the controlled freeze zone wall **46**. Specifically, the first type of spray nozzle **121** may be directly adjacent to the controlled freeze zone internal surface **31** of the controlled freeze zone wall **46**. The first type of spray nozzle **121** may be at a periphery of the middle controlled freeze zone section

**108**. The first type of spray nozzle **121** may be closer to the controlled freeze zone wall **46** than the second type of spray nozzle **221**. In other words, the second type of spray nozzle **221** may be farther away from the controlled freeze zone wall **46** than the first type of spray nozzle **121**.

**[0076]** The axis of the first type of spray nozzle **121** may be at the first angle **122** to the controlled freeze zone wall **46**. The first angle **122** may be defined by a first longitudinal spray nozzle axis **112-112** and a longitudinal controlled freeze zone wall axis **111-111**. In other words, the bounds of the first angle **122** may be the first longitudinal spray nozzle axis **112-112** and the longitudinal controlled freeze zone wall axis **111-111**. The first angle **122** may be any suitable angle, such as but not limited to, any angle within and including 0 to 60 degrees. For example, the first angle **122** may be 0 degrees, 15 degrees, 30 degrees or 45 degrees.

**[0077]** The first angle **122** of the axis of the first type of spray nozzle **121**, **506** may be constructed and arranged to direct the freezing zone liquid stream outermost portion **131** so as to keep the sprayed freezing zone liquid stream away from the controlled freeze zone wall **46**, e.g., to reduce, eliminate, and/or minimize spray liquid impingement on the controlled freeze zone wall **46** (i.e., the longitudinal controlled freeze zone wall axis **111-111**). In some embodiments, reduction and/or minimization of spray liquid impingement on the controlled freeze zone wall **46** may not eliminate spray liquid impingement on the controlled freeze zone wall **46**. The first angle **122** may be constructed and arranged at this position to direct the freezing zone liquid stream away from the controlled freeze zone wall **46**. As shown from a top view in Figure 6, the first angle **122** may lead to an elongated ellipsoid spray projection.

**[0078]** When the innermost portion **131**, **231** of the liquid **130** sprayed from the first type of spray head **121** is angled away from the controlled freeze zone wall **46**, the liquid sprayed may not appreciably impinge on the controlled freeze zone wall **46**, where it could cause possible solid build-up on the controlled freeze zone wall **46**. Consequently, solids such as crystalline solids, fluffy snow and/or slurry like solids, are less likely to build-up on the controlled freeze zone wall **46**. This is in contrast to conventional spray assemblies within distillation towers where sprayed liquid impinges on the distillation tower wall.

**[0079]** The second type of spray nozzle **221** may be at the second angle **222** to the controlled freeze zone wall **46**. The second angle **222** may be defined by a second longitudinal spray nozzle axis **212-212** and a longitudinal controlled freeze zone wall axis **111-111**. In other words, the bounds of the second angle **222** may be the second longitudinal spray nozzle axis **212-212** and the longitudinal controlled freeze zone wall axis **111-111**. The second angle **222** may be any suitable angle, such as but not limited to, any angle within and including 0 to 60 degrees. For example, the second angle **222** may be 0 degrees, 15 degrees, 30 degrees or 45 degrees.

**[0080]** The second angle **222** may or may not be constructed and arranged to direct the freezing zone liquid stream outermost portion **232** at about a 0 degree angle or a 0 degree angle (i.e., substantially parallel) to the controlled freeze zone wall **46** (i.e., the longitudinal controlled freeze zone wall axis **111-111**) with the second type of spray nozzle **221**. Often times the second angle **222** does not have to be constructed and arranged to direct the freezing zone liquid stream outermost portion **232** at about a 0 degree angle or a 0 degree angle (i.e., substantially parallel) to the controlled freeze zone wall **46** (i.e., the longitudinal controlled freeze zone wall axis **111-111**) with the second type of spray nozzle **221** because the second type of spray nozzle **221** is far enough from the controlled freeze zone wall **46** that the trajectory of the freezing zone liquid stream **230** from the second type of spray nozzle **221** does not easily impinge on the controlled freeze zone wall **46**. As shown from a top view in Figure 6, the second angle **122** spray projection may form a circle.

**[0081]** Those skilled in the art will understand that the liquid distribution **151**, **251** of the types of spray nozzles **121**, **221** may be adjusted in a symmetric or asymmetric pattern, as necessary, to optimize the spray coverage across the open space of the cross sectional area of the controlled freeze zone section **108** and still limit spray impingement on the controlled freeze zone tower wall. As discussed above, altering the liquid distribution **151**, **251** of the types of spray nozzles **121**, **221** will change the central spray axis of the spray pattern.

**[0082]** The first type of spray nozzle **121** may comprise a plurality of nozzles **121** and/or the second type of spray nozzle **221** may comprise a plurality of nozzles **221**. Each of the first type of spray nozzles **121** may be at the same angle to another one of the first type of spray nozzles. Each of the first type of spray nozzles **121** may be at a different angle to another one of the first type of spray nozzles. Each of the second type of spray nozzles **221** may be at the same angle to another one of the second type of spray nozzles. Each of the second type of spray nozzles **221** may be at a different angle to another one of the second type of spray nozzles.

**[0083]** The spray assembly **129** may include one or more headers **123** (Figures 5-6). Each header **123** may receive either a single or a plurality of the first and second type of spray nozzles **121**, **221**. Each header may be any suitable header and is not limited to the type of header shown in Figure 6. For example, a header may be a pipe extending from the controlled freeze zone wall **46** such that a longitudinal axis of the header is perpendicular to the longitudinal controlled freeze zone wall axis **111-111** (i.e., the header extends from, for example, the side of the middle controlled freeze zone section). Another example header may enter the controlled freeze zone section from the ellipsoid head at the top of the controlled freeze zone section.

**[0084]** The spray assembly **129** may also include a spray pump **128** (Figures 1-4). The spray pump **128** pumps the liquid to the spray nozzles **121**, **221**. Instead of a spray pump **128**, gravity may induce flow in the liquid.

**[0085]** The solid formed in the middle controlled freeze zone section **108**, falls toward the melt tray assembly **139**. Most, if not all, solids do not fall toward the controlled freeze zone wall **46** because of the above-described arrangement of the spray assembly **120**. To address instances where solids still fall toward and adhere to the controlled freeze zone wall **46**, the middle controlled freeze zone section **108** may also include at least one of (a) a heating mechanism and (b) a surface treated by a treatment mechanism, such as those described in the applications entitled "Method and Device for Separating Hydrocarbons and Contaminants with a Heating Mechanism to Destabilize and/or Prevent Adhesion of Solids" (US Application No. 61/912,986) and "Method and Device for Separating Hydrocarbons and Contaminants with a Surface Treatment Mechanism," (US Application No. 61/912,987) respectively, each by Jaime Valencia, et al. and filed on the same day as the instant application. Using (a) and (b) may minimize the chance of solid build-up more than using less than all three of these mechanisms.

**[0086]** The solid formed in the middle controlled freeze zone section **108** forms the liquid/slurry mix in the melt tray assembly **139**. The liquid/slurry mix flows from the middle controlled freeze zone section **108** to the lower section **106**. The liquid/slurry mix flows from the bottom of the middle controlled freeze zone section **108** to 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 from the lower section **106**. The line **22** may extend from an outer surface of the distillation tower **104**, **204**.

**[0087]** 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**.

**[0088]** The solids form the liquid and/or slurry mix when in the liquid **130**. The liquid and/or slurry mix flows from the middle controlled freeze zone section **108** to the lower distillation section **106**. The liquid and/or slurry mix flows from the bottom of the middle controlled freeze zone section **108** to the top of the lower section **106** via a line **22** (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.

**[0089]** 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**.

**[0090]** 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**.

**[0091]** 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, a section of random or structured packing, etc., to facilitate contact of the vapor and liquid phases.

**[0092]** 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**.

**[0093]** 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.

**[0094]** 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.

**[0095]** 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.

**[0096]** 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).

**[0097]** 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**.

**[0098]** 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 **110**.

**[0099]** 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 before it is sprayed by the nozzle(s). The liquid 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 1-4) 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**.

[0100] The method may include maintaining an upper section **110**. The upper section **110** operates as previously discussed. The method may also include separating the feed stream in the upper section **110** as previously discussed.

[0101] 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. Moreover, Figure 7 may not illustrate all the steps that may be performed. The claims, and only the claims, define the inventive system and methodology.

[0102] Disclosed aspects may be used in hydrocarbon management activities. As used herein, “hydrocarbon management” or “managing hydrocarbons”" includes hydrocarbon extraction, hydrocarbon production, hydrocarbon exploration, identifying potential hydrocarbon resources, identifying well locations, determining well injection and/or extraction rates, identifying reservoir connectivity, acquiring, disposing of and/ or abandoning hydrocarbon resources, reviewing prior hydrocarbon management decisions, and any other hydrocarbon-related acts or activities. The term “hydrocarbon management” is also used for the injection or storage of hydrocarbons or $CO_2$, for example the sequestration of $CO_2$, such as reservoir evaluation, development planning, and reservoir management. The disclosed methodologies and techniques may be used in extracting hydrocarbons from a subsurface region and processing the hydrocarbons. Hydrocarbons and contaminants may be extracted from a reservoir and processed. The hydrocarbons and contaminants may be processed, for example, in the distillation tower previously described. After the hydrocarbons and contaminants are processed, the hydrocarbons may be extracted from the processor, such as the distillation tower, and produced. The contaminants may be discharged into the Earth, etc. For example, as shown in Figure 7, the method for producing hydrocarbons may include producing **509** the hydrocarbon-enriched vapor stream extracted from the distillation tower. The method may also include removing the hydrocarbon-enriched vapor stream from the distillation tower before producing **509** the hydrocarbon-enriched vapor stream. The initial hydrocarbon extraction from the reservoir may be accomplished by drilling a well using hydrocarbon drilling equipment. The equipment and techniques used to drill a well and/or extract these hydrocarbons are well known by those skilled in the relevant art. Other hydrocarbon extraction activities and, more generally, other hydrocarbon management activities, may be performed according to known principles.

[0103] 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.

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

[0105] 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.

CLAIMS

What is claimed is:

1. A method for separating a feed stream in a distillation tower comprising:

maintaining a controlled freeze zone section in the distillation tower;

receiving a freezing zone liquid stream in a spray nozzle assembly in the controlled freeze zone section, wherein the spray nozzle assembly comprises a plurality of outer spray nozzles on an outer periphery of the spray nozzle assembly and at least one inner spray nozzle interior to the plurality of outer spray nozzles, wherein each outer spray nozzle is configured to spray the freezing zone liquid stream along a central spray axis, and wherein the central spray axis of at least one of the plurality of outer spray nozzles is not parallel to a controlled freeze zone wall; and

spraying the freezing zone liquid stream through the spray nozzle assembly into the controlled freeze zone section to keep the controlled freeze zone section at a temperature and pressure at which the solid and the hydrocarbon-enriched vapor stream form.

2. The method of claim 1, wherein an angle of the central spray axis of at least one of the plurality of outer spray nozzles is achieved by angling the outer spray nozzles towards the interior of the tower, varying the distribution of the spray liquid coming out of at least one of the plurality of outer spray nozzles in a pattern to keep the sprayed freezing zone liquid stream away from the controlled freeze zone wall, or both.

3. The method of claims 1-2, wherein the central spray axis of at least one of the plurality of outer spray nozzles is calculated to reduce but not eliminate spray liquid impingement on the controlled freeze zone wall.

4. The method of any one of claims 1-3, wherein the central spray axis angle with respect to the controlled freeze zone wall is the same for each of the plurality of outer spray nozzles.

5. The method of any one of claims 1-4, further comprising:

injecting the freezing zone liquid stream into the controlled freeze zone section using a plurality of inner spray nozzles wherein each inner spray nozzle is configured to spray the freezing zone liquid stream along a central spray axis, and wherein the central spray axis of each inner spray nozzle is parallel to the controlled freeze zone wall.

6. The method of any one of claims 1-5, wherein each of the plurality of outer spray nozzles are directly adjacent to the controlled freeze zone wall.

7. The method of any one of claims 1-6, wherein a central spray axis of at least one of the plurality of outer spray nozzles is calculated to eliminate spray liquid impingement on the controlled freeze zone wall.

8. The method of any one of claims 1-7, wherein the method further comprises flowing the freezing zone liquid spray to the spray nozzle assembly through a top of the controlled freeze zone section.

9. The method of any one of claims 1-8, wherein the method further comprises flowing the freezing zone liquid spray to the spray nozzle assembly through a side of the controlled freeze zone section.

10. A method for producing hydrocarbons comprising:

maintaining a controlled freeze zone section in the distillation tower that receives a freezing zone liquid stream to form a solid and a hydrocarbon-enriched vapor stream in the controlled freeze zone section;

maintaining a spray assembly in the controlled freeze zone section, wherein the spray assembly comprises a first type of spray nozzle on an outer periphery and a second type of spray nozzle interior to the first type of spray nozzle, and wherein the first type of spray nozzle orients spray at an angle with respect to a controlled freeze zone wall so as to minimize spray liquid impingement on the controlled freeze zone wall;

injecting the freezing zone liquid stream into the controlled freeze zone section through the spray assembly at a temperature and pressure at which the solid and the hydrocarbon-enriched vapor stream form, wherein the freezing zone liquid stream comprises a freezing zone liquid stream outermost portion; and

producing the hydrocarbon-enriched vapor stream extracted from the distillation tower.

11. The method of claim 10, wherein the angle is configured such that the outermost portion does not impinge the controlled freeze zone wall.

12. The method of claims 10 or 11, wherein the angle is configured such that the outermost portion impinges the controlled freeze zone wall.

13. The method of any one of claims 10-12, wherein the angle of each of the plurality of first type of spray nozzles is the same.

14. The method of any one of claims 10-13, wherein injecting the freezing zone liquid stream into the controlled freeze zone section through the spray assembly comprises flowing the freezing zone liquid stream through a side of the controlled freeze zone section.

15. The method of any one of claims 10-14, wherein injecting the freezing zone liquid stream into the controlled freeze zone section through the spray assembly comprises flowing the freezing zone liquid stream through a top of the controlled freeze zone section.

16. The method of any one of claims 10-15, wherein the angle is configured by angling at least one of the first type of spray nozzles towards the interior of the tower, varying the distribution of the spray liquid coming out of at least one of the first type of spray nozzles in a pattern to keep the sprayed freezing zone liquid stream away from the controlled freeze zone wall, or both.

17. A distillation tower that separates a contaminant in a feed stream from a hydrocarbon in the feed stream, the distillation tower comprising:

a controlled freeze zone section comprising:

a controlled freeze zone wall;

a first type of spray nozzle configured to inject a freezing zone liquid stream into the controlled freeze zone section at a temperature and pressure at which a solid forms; and

a melt tray assembly below the first type of spray nozzle that configured to melt the solid that comprises the contaminant,

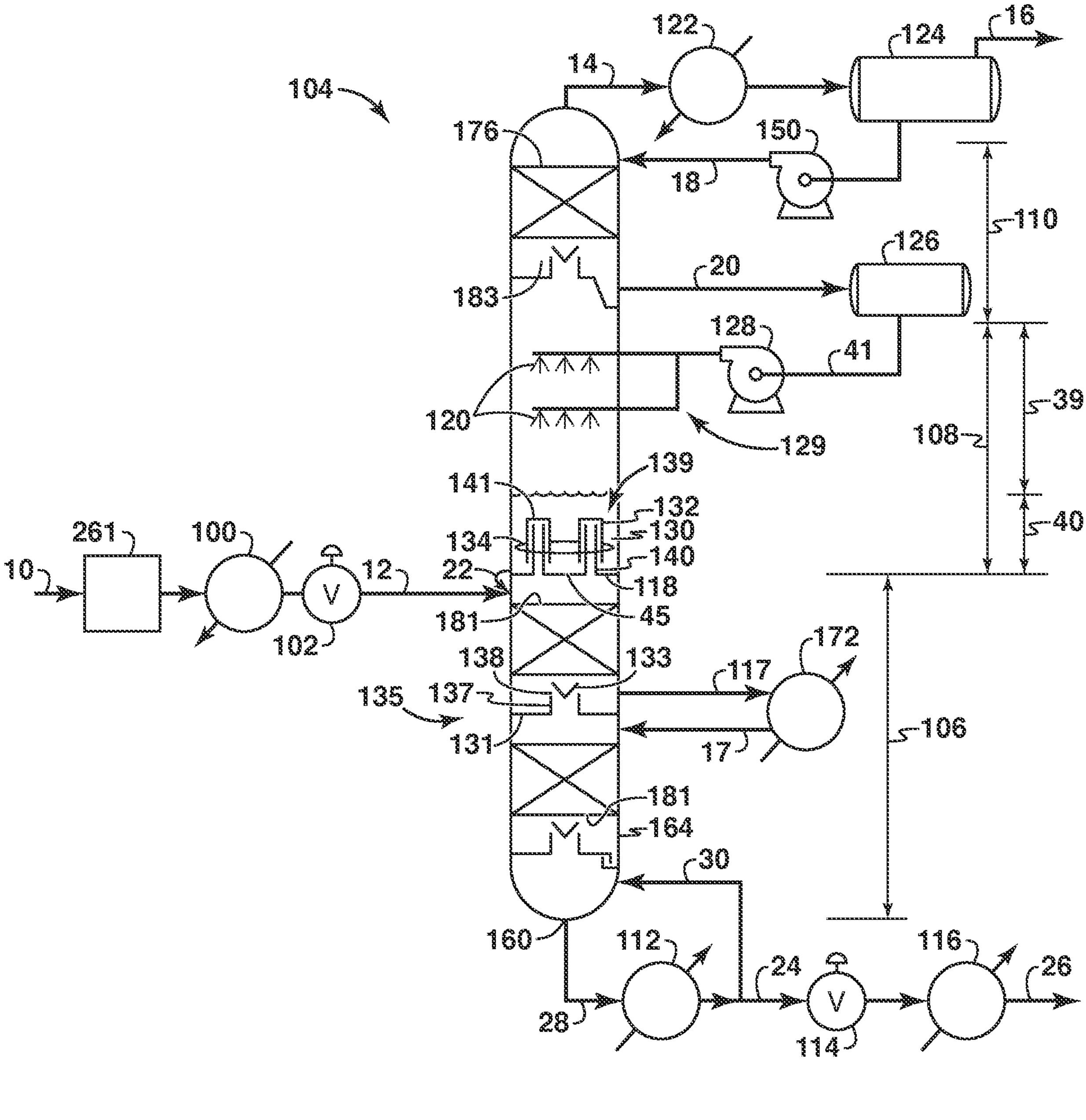
wherein the first type of spray nozzle is configured to direct a freezing zone liquid stream outermost portion at an angle to the controlled freeze zone wall with the first type of spray nozzle, and wherein the angle is calculated to minimize or eliminate impingement of the freezing zone liquid stream on the controlled freeze zone wall.

18. The distillation tower of claim 17, wherein the freezing zone liquid stream outermost portion does not impinge the controlled freeze zone wall.

19. The distillation tower of any one of claims 17-18, wherein the freezing zone liquid stream outermost portion impinges the controlled freeze zone wall.

20. The distillation tower of any one of claims 17-19, wherein the angle is configured by angling at least one of the first type of spray nozzles towards the interior of the tower, varying the distribution of the spray liquid coming out of at least one of the first type of spray nozzles in a pattern to keep the sprayed freezing zone liquid stream away from the controlled freeze zone wall, or both.

21. The distillation tower of any one of claims 17-20, wherein the method further comprises maintaining a second type of spray nozzle in the controlled freeze zone section that is farther from the controlled freeze zone wall than the first type of spray nozzle.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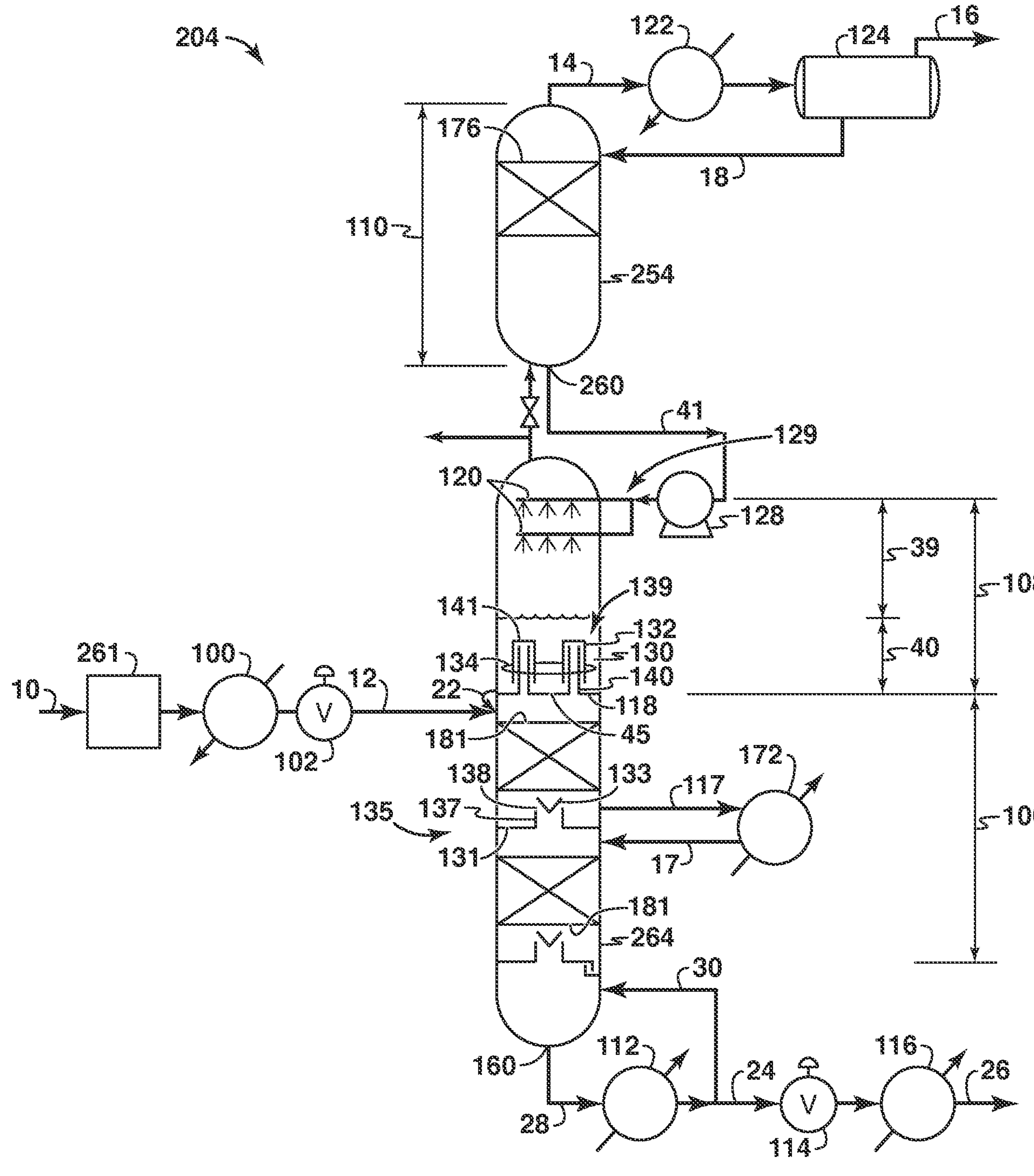
114

FIG. 1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124
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172
181
264
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28
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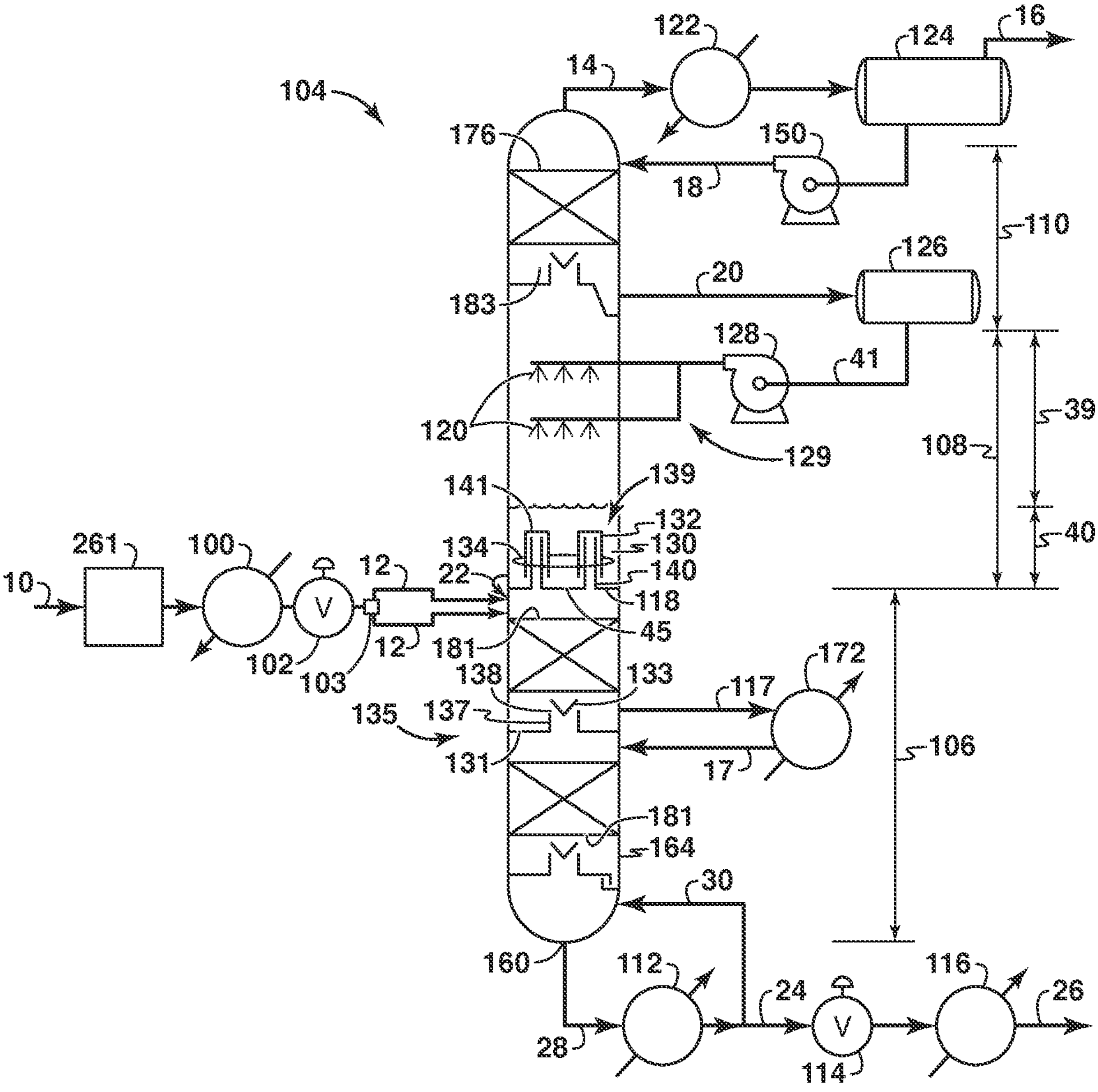
24
114
116
26

*FIG. 2*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114

*FIG. 3*

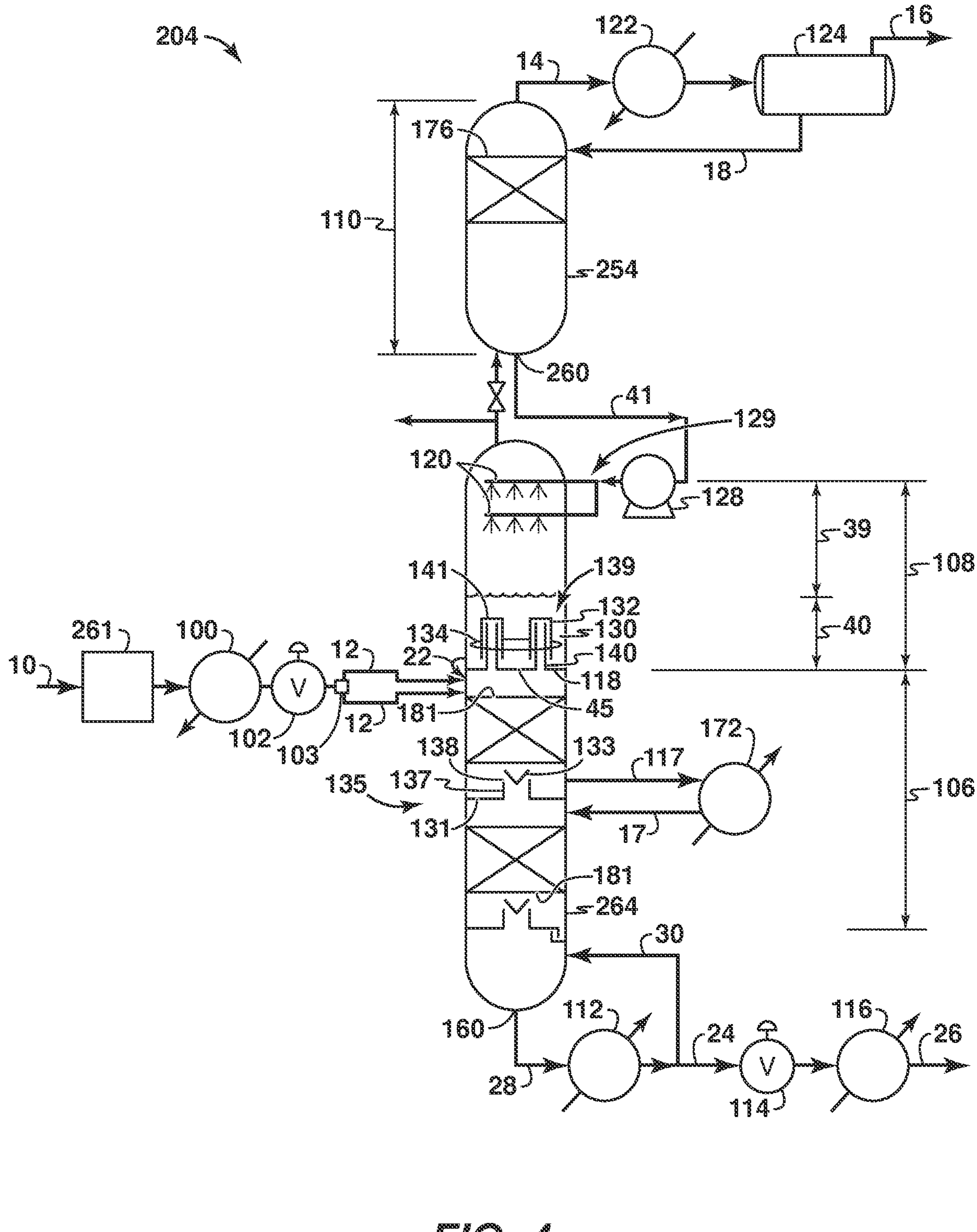
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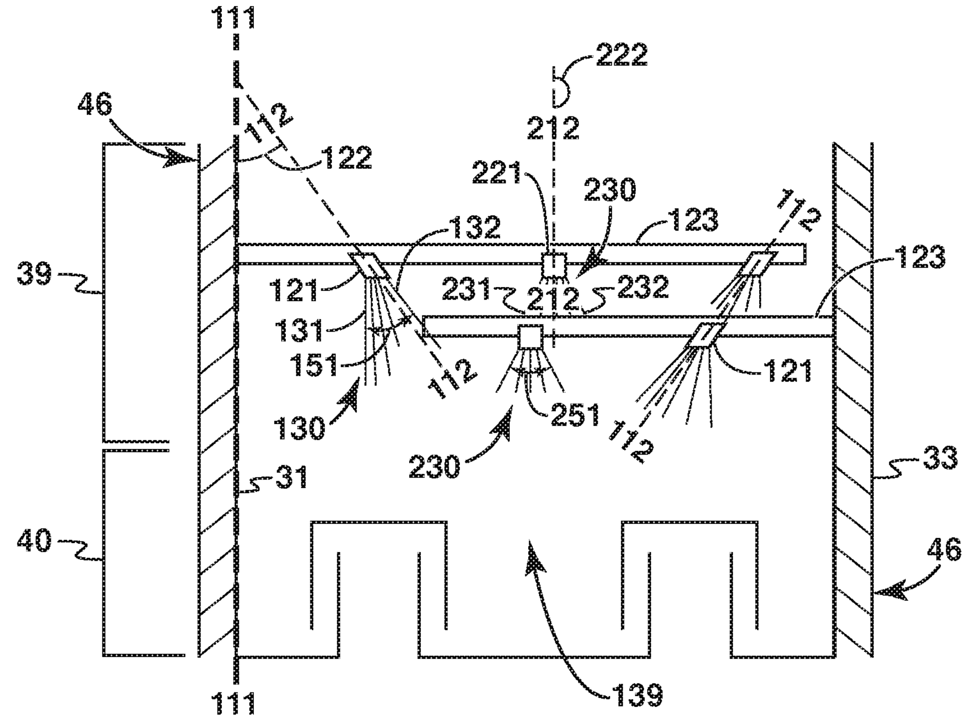
FIG. 4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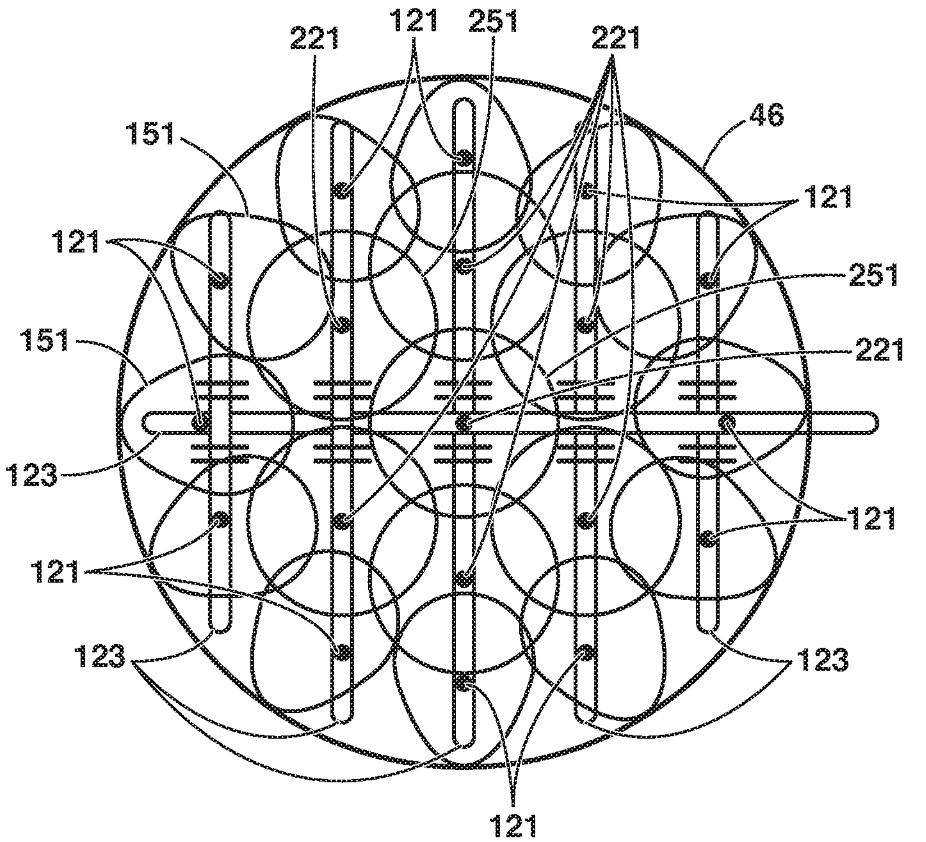
251
112
230
31
33
40
46
139
111

*FIG. 5*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221
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121
121
123
123
121

*FIG. 6*

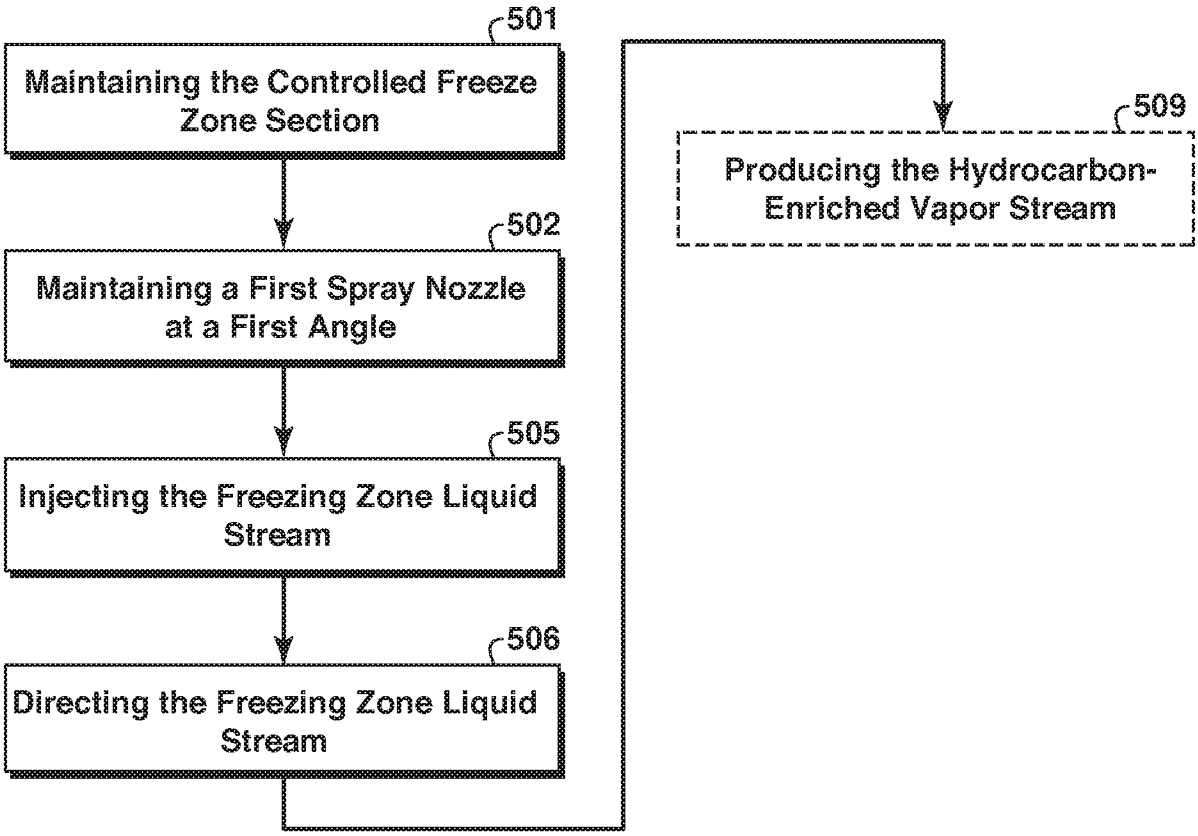
501
Maintaining the Controlled Freeze Zone Section
502
Maintaining a First Spray Nozzle at a First Angle
505
Injecting the Freezing Zone Liquid Stream
506
Directing the Freezing Zone Liquid Stream
509
Producing the Hydrocarbon-Enriched Vapor Stream

FIG. 7