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(54) CONTROLLED FREEZE ZONE TOWER

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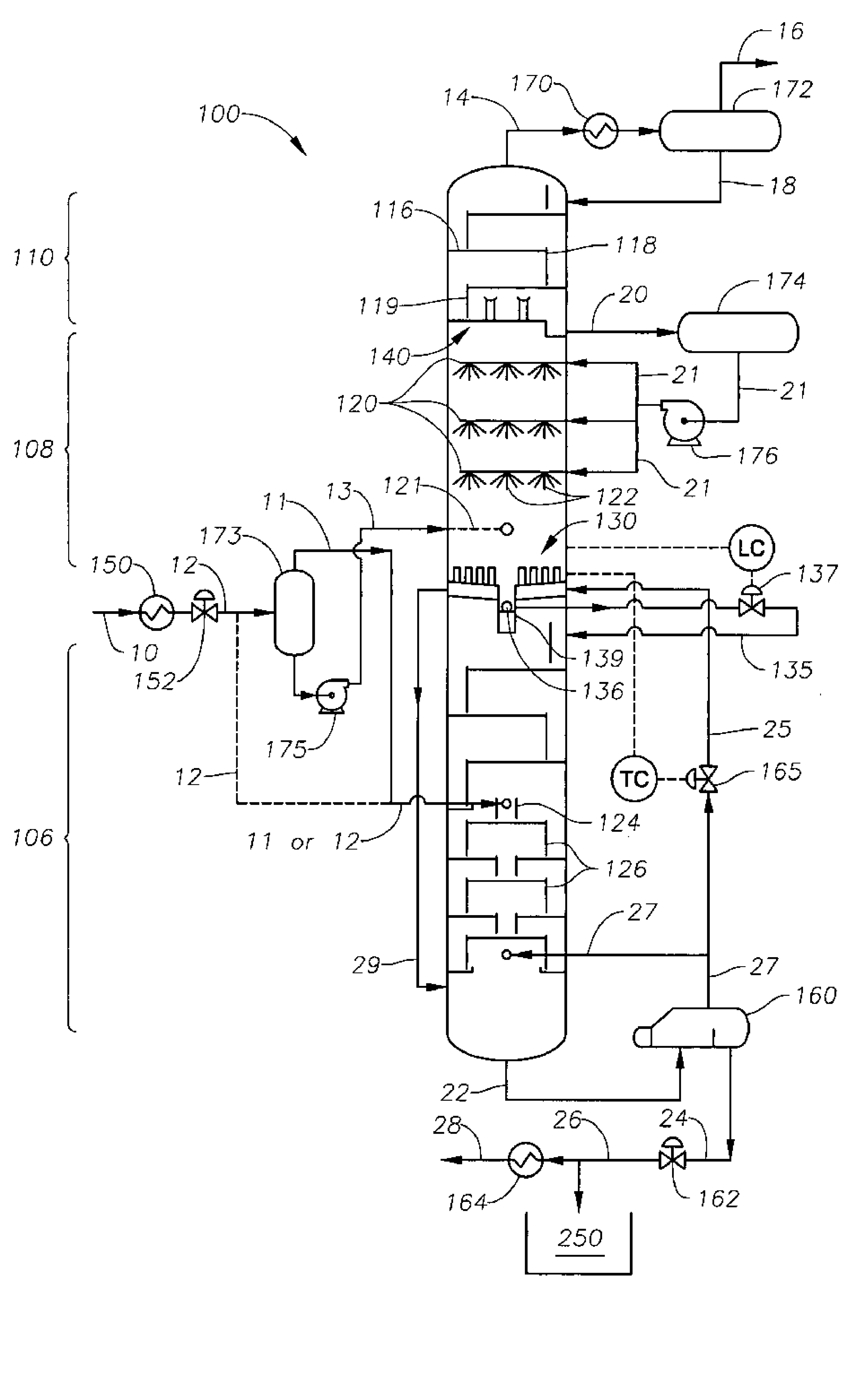
(57) ABSTRACT

A cryogenic distillation tower is provided for the separation of a fluid stream containing at least methane and carbon dioxide. The cryogenic distillation tower has a lower stripping section, an upper rectification section, and an intermediate spray section. The intermediate spray section includes a plurality of spray nozzles that inject a liquid freeze zone stream. The nozzles are configured such that substantial liquid coverage is provided across the inner diameter of the intermediate spray section. The liquid freeze zone stream generally includes methane at a temperature and pressure whereby both solid carbon dioxide particles and a methane-enriched vapor stream are formed. The tower may further include one or more baffles below the nozzles to create frictional resistance to the gravitational flow of the liquid freeze zone stream. This aids in the breakout and recovery of methane gas. Additional internal components are provided to improve heat transfer and to facilitate the breakout of methane gas.



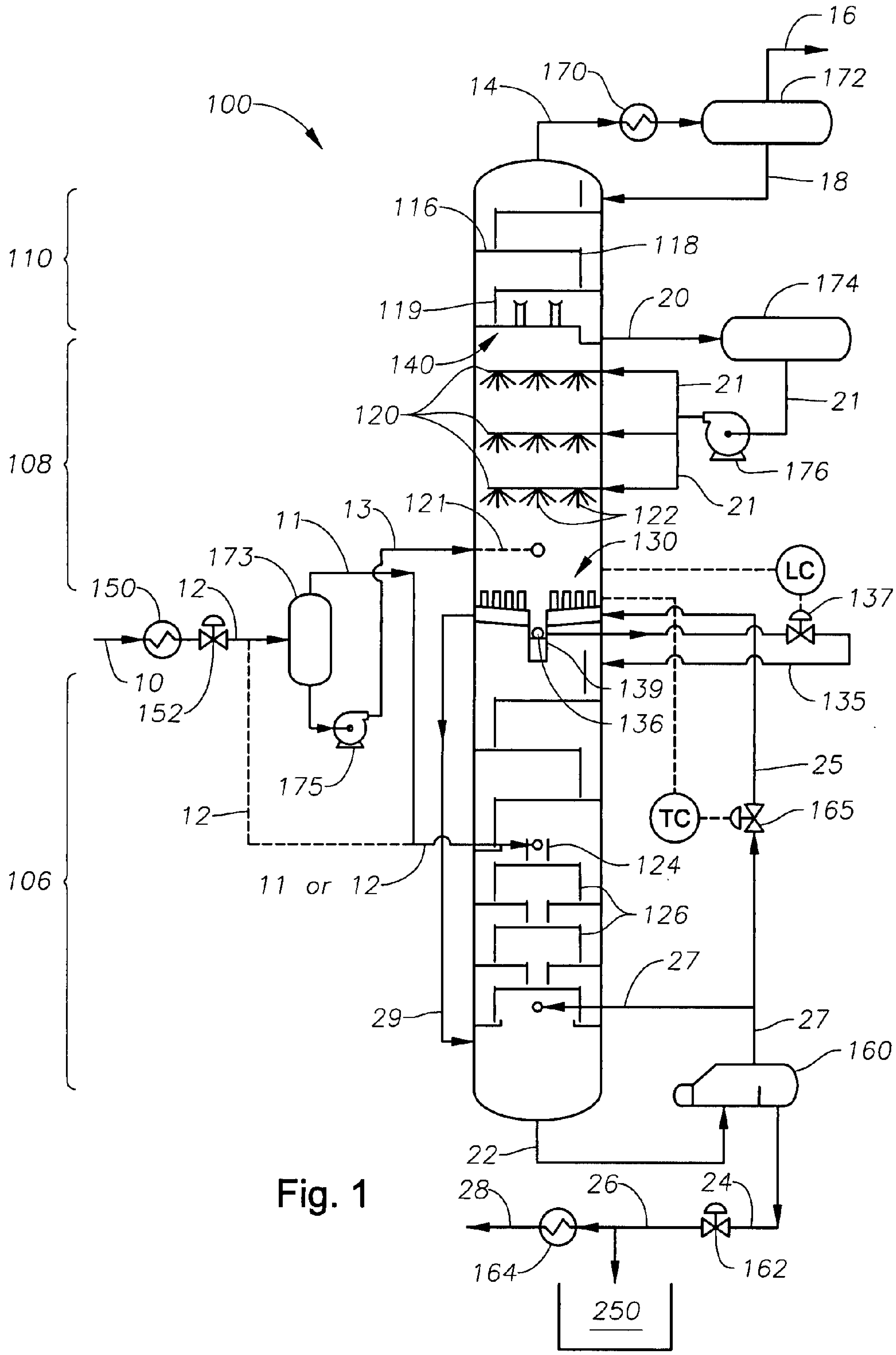

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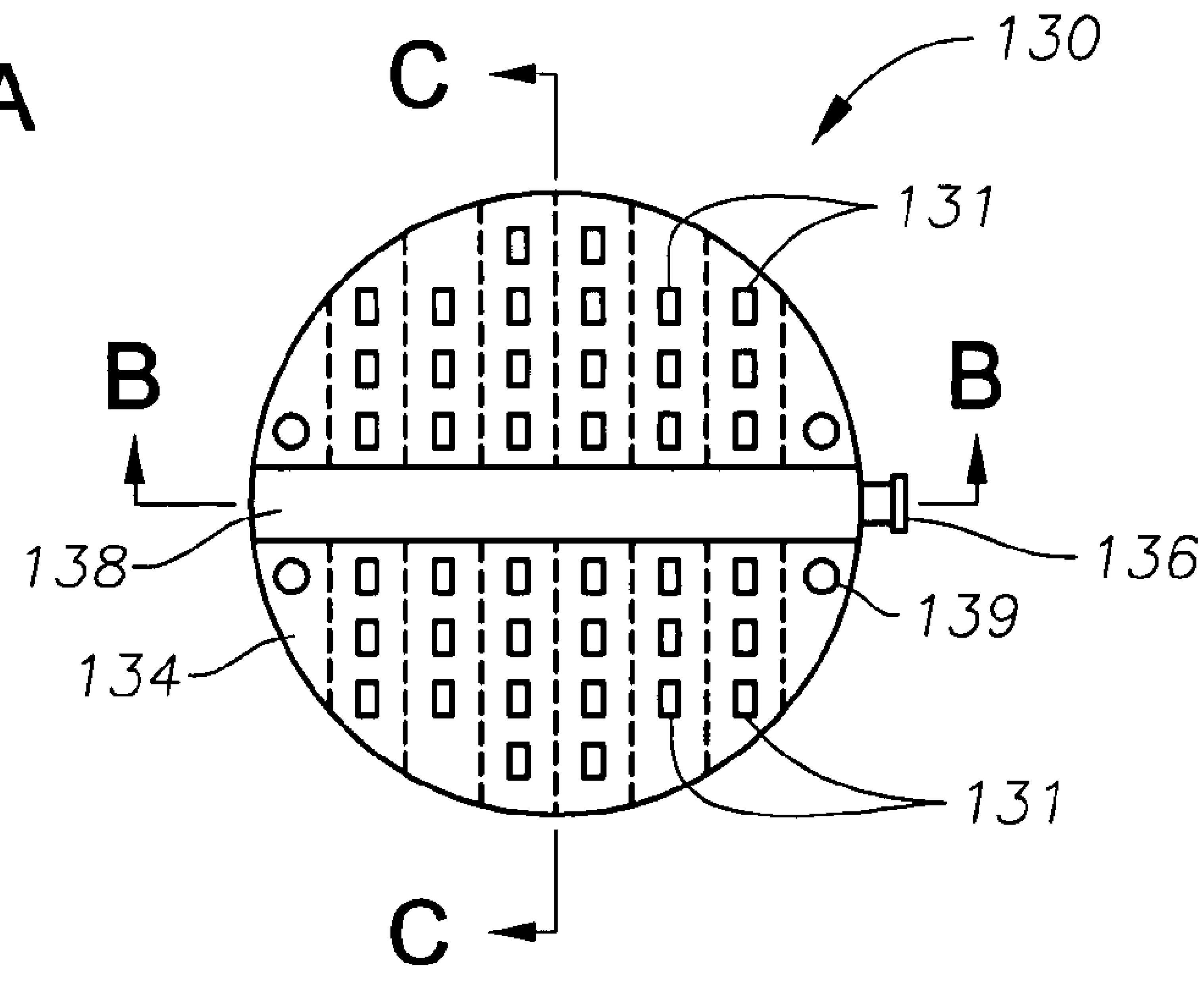
Fig. 1

Fig. 2A



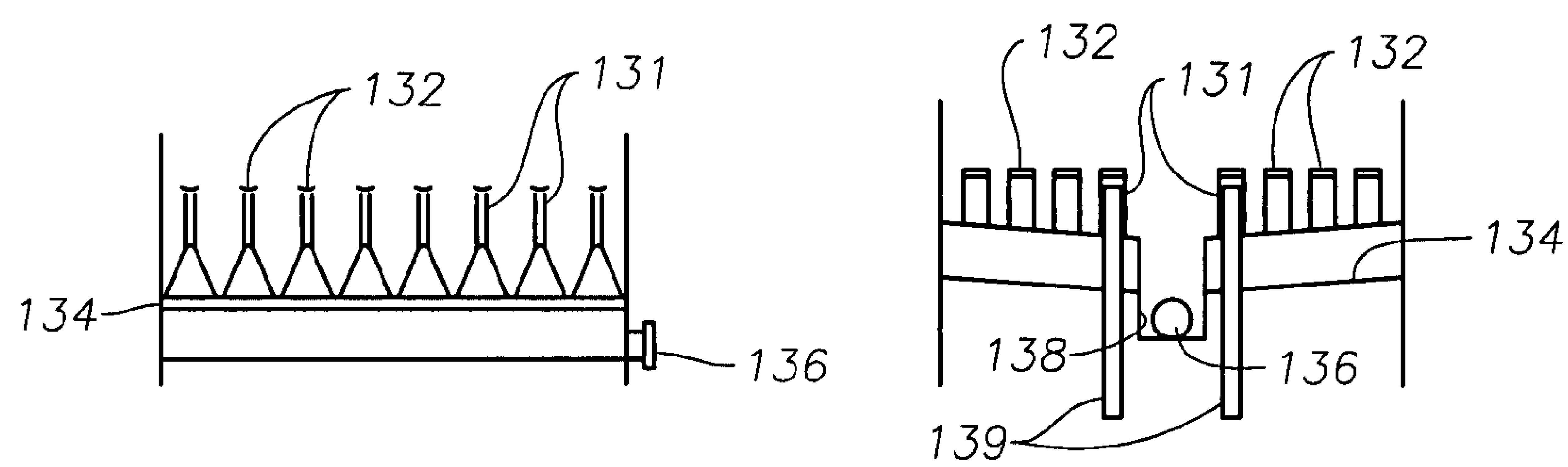


Fig. 2B

Fig. 2C

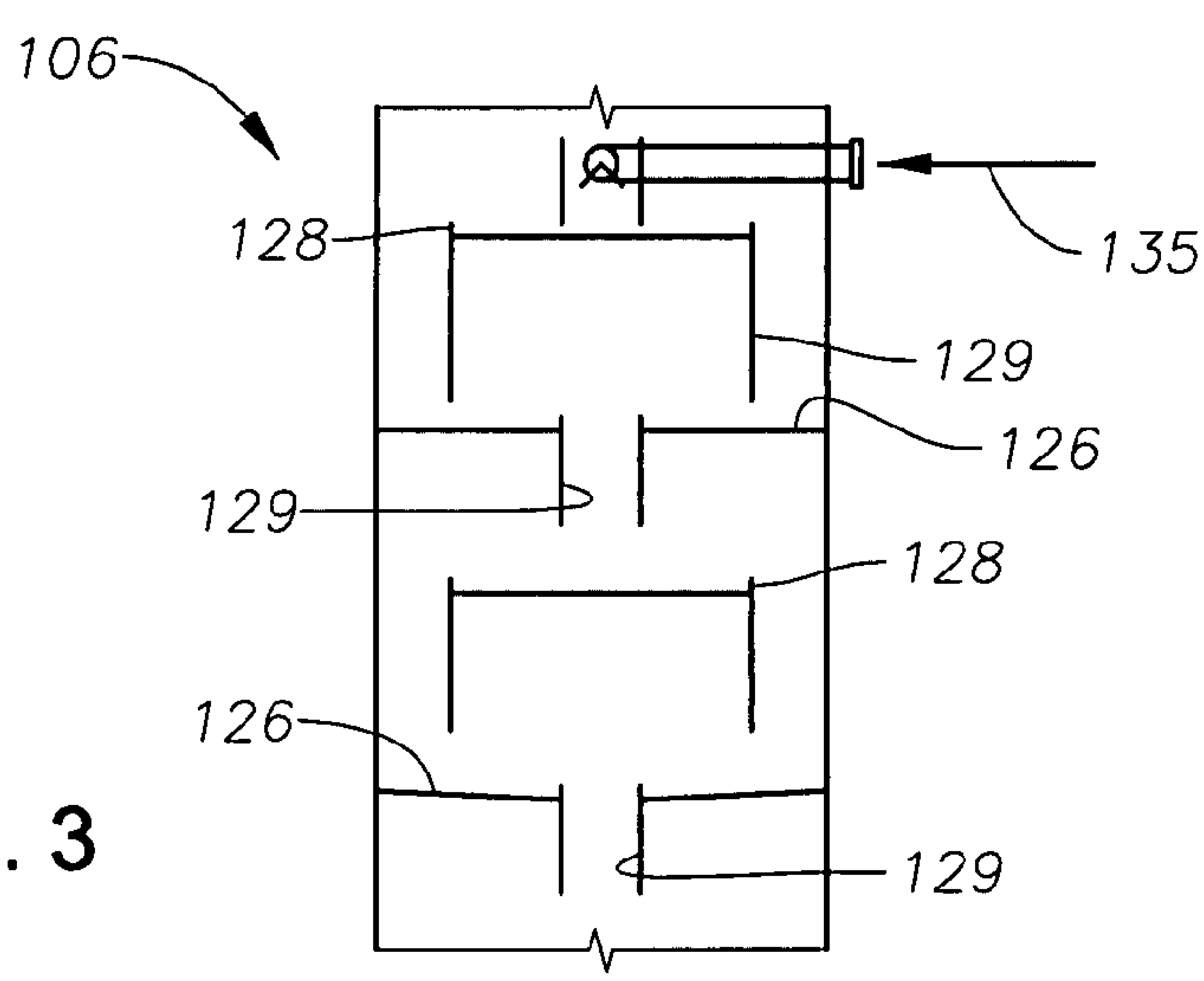


Fig. 3

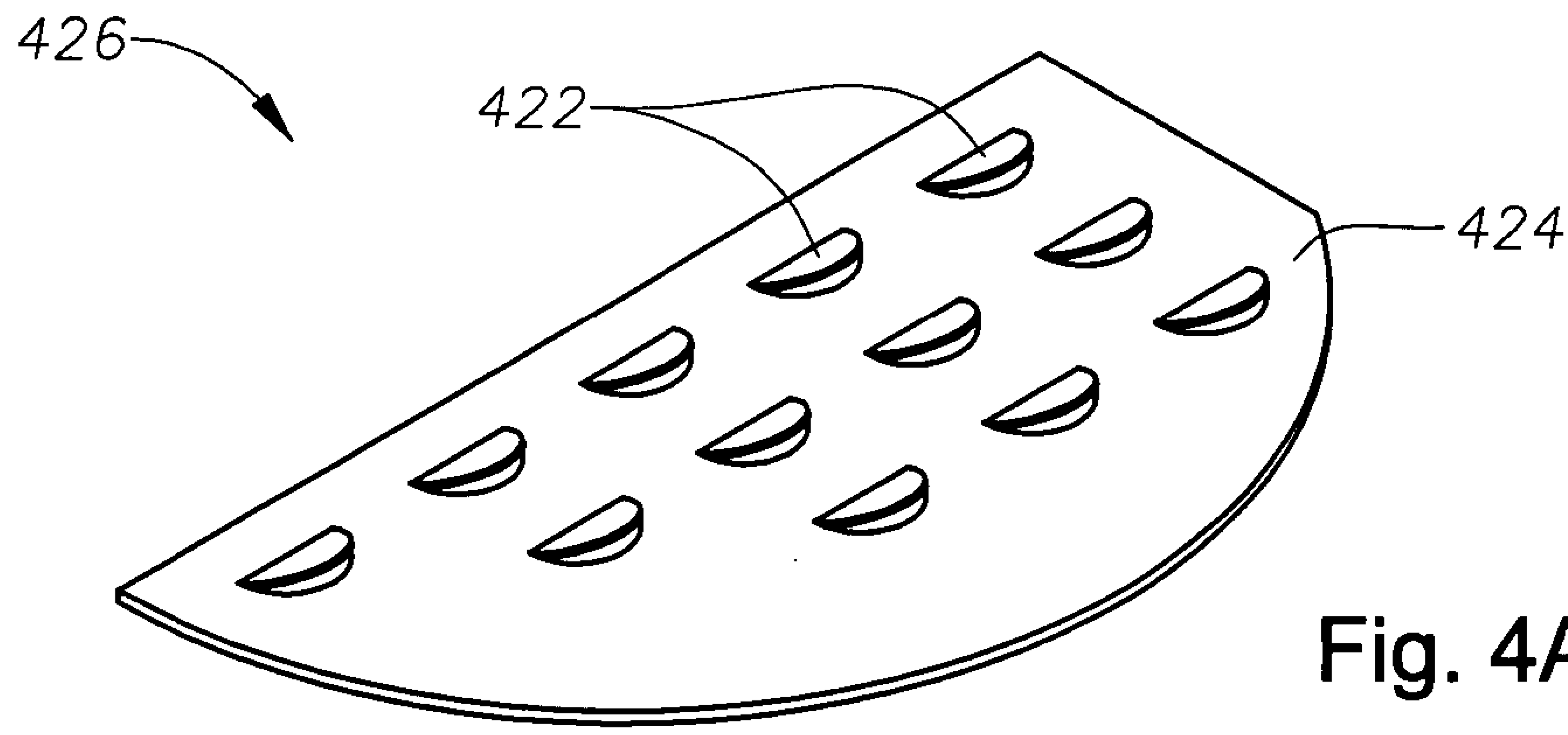


Fig. 4A

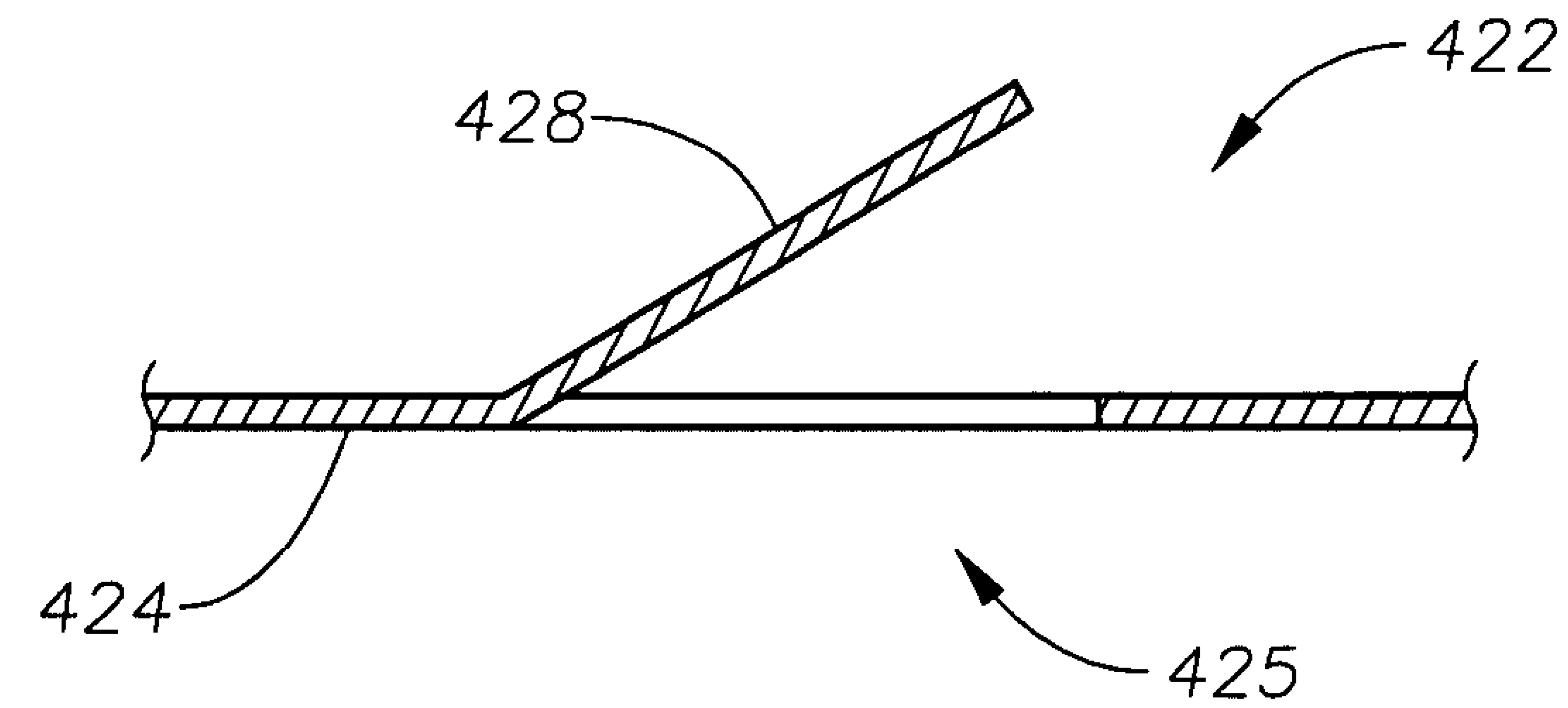


Fig. 4B

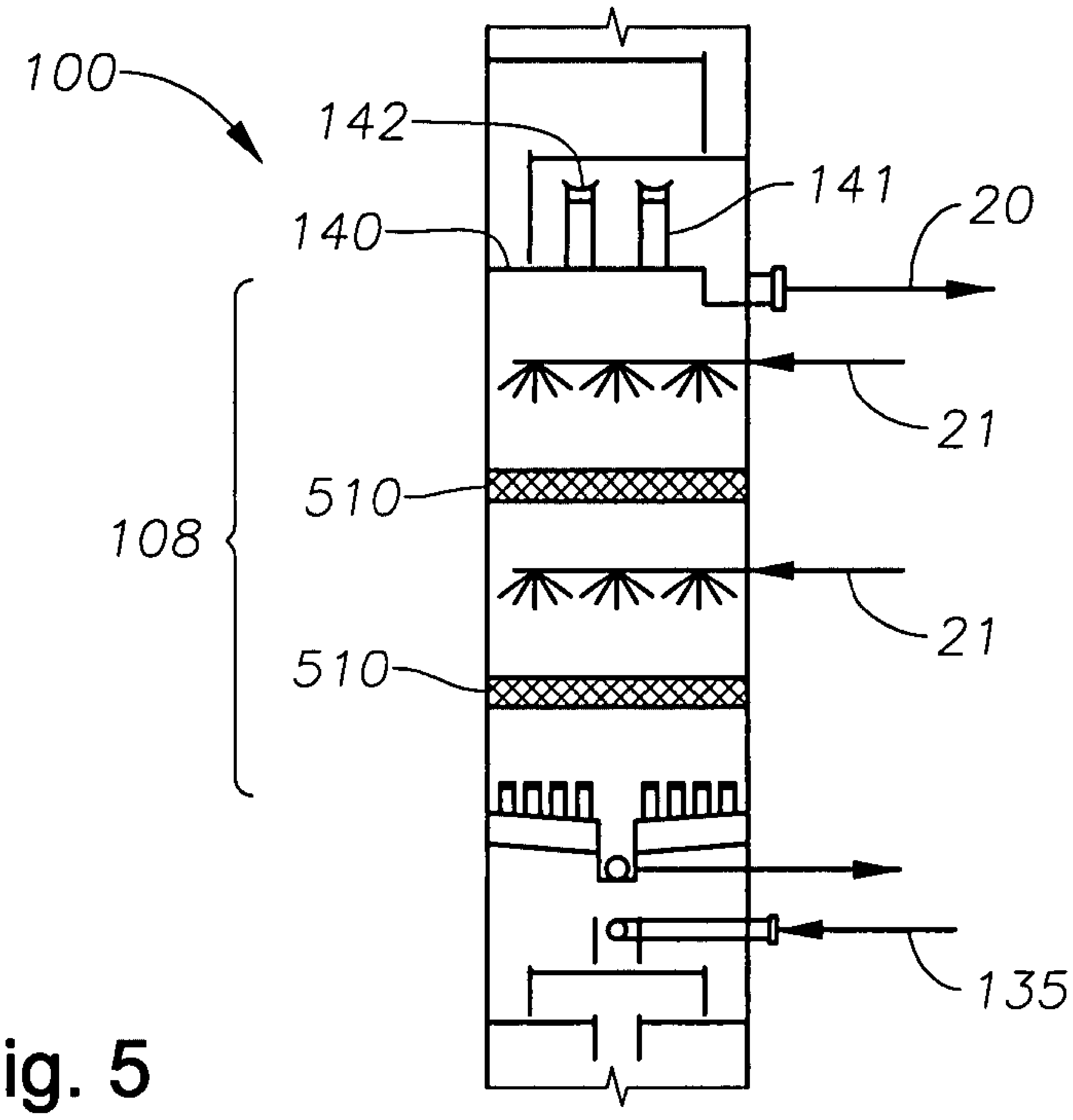


Fig. 5

Fig. 6A

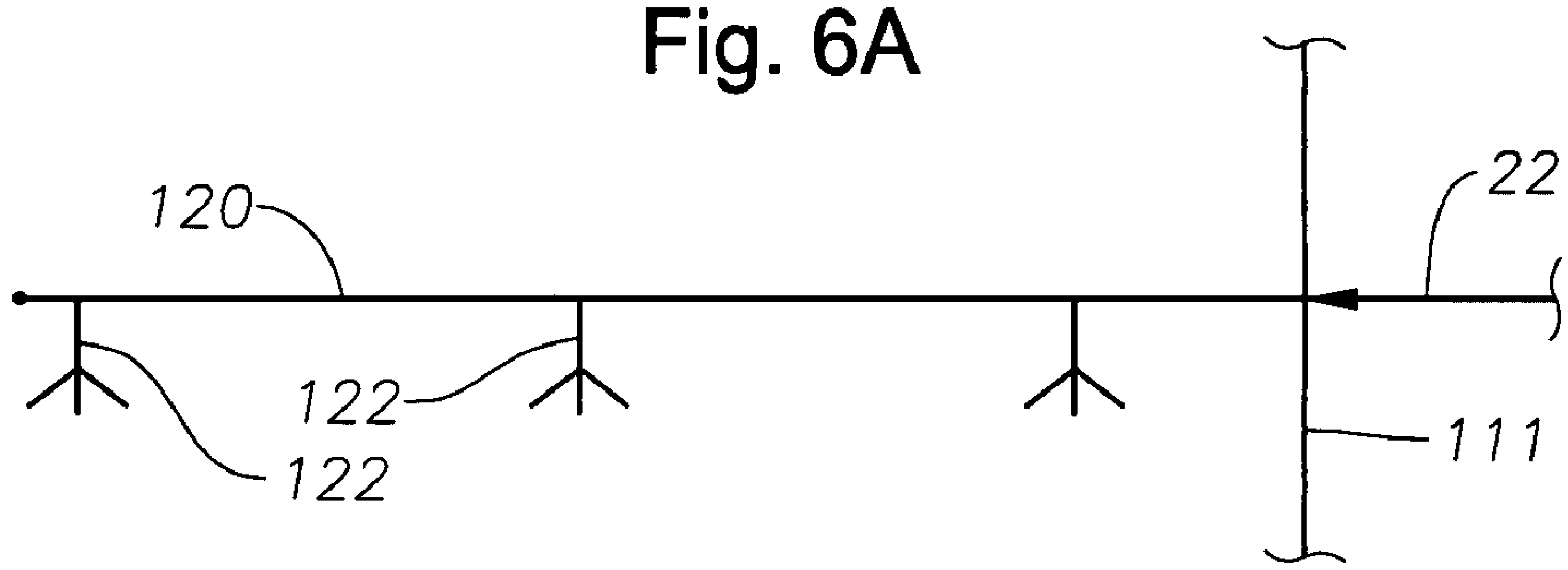
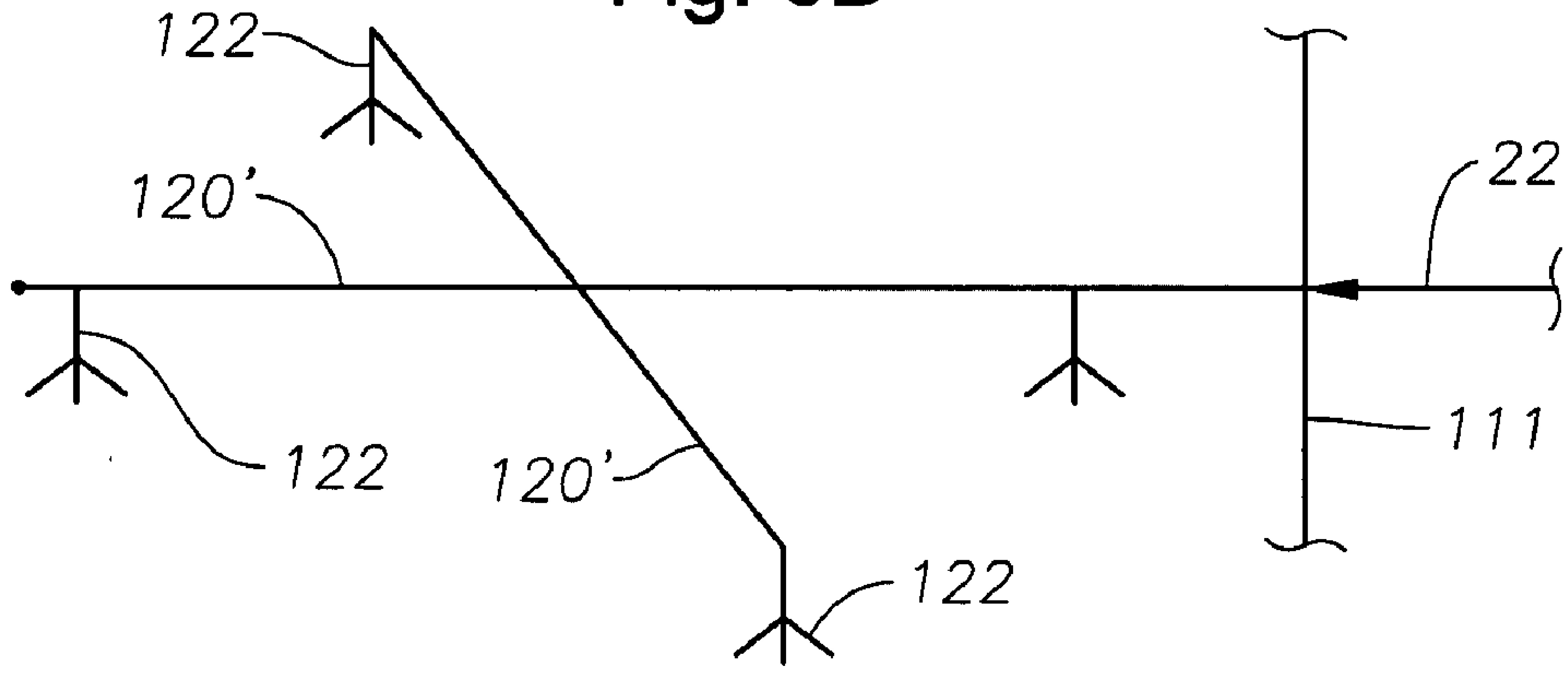


Fig. 6B



CONTROLLED FREEZE ZONE TOWER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/881,395, filed 19 Jan. 2007.

[0002] This application is related to U.S. Provisional No. 60/881,391, entitled Integrated Controlled Freeze Zone (CFZ) Tower and Dividing Wall (DWC) for Enhanced Hydrocarbon Recovery, filed 19 Jan. 2007, by Vikram Singh, Edward J. Grave, Paul Scott Northrop, and Narasimhan Sundaram.

BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention

[0004] The present invention relates to the field of fluid separation. More specifically, the present invention relates to the cryogenic separation of carbon dioxide from a hydrocarbon fluid stream.

[0005] 2. Background of the Invention

[0006] The production of hydrocarbons from a reservoir oftentimes carries with it the incidental production of non-hydrocarbon gases. Such gases include contaminants, such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2). When H_2S and CO_2 are produced along with a hydrocarbon gas stream (such as methane or ethane), the gas stream is sometimes referred to as "sour gas."

[0007] Sour gas is usually treated to remove CO_2, H_2S, and other contaminants before it is sent downstream for further processing or sale. The separation process creates an issue as to the disposal of the separated contaminants. In some cases, the concentrated acid gas (consisting primarily of H_2S and CO_2) is sent to a sulfur recovery unit ("SRU"). The SRU converts the H_2S into benign elemental sulfur. However, in some areas (such as the Caspian Sea region), additional elemental sulfur production is undesirable because there is a limited market. Consequently, millions of tons of sulfur have been stored in large, above-ground blocks in some areas of the world, most notably Canada and Kazakhstan.

[0008] As for the carbon dioxide gas, it is oftentimes vented to the atmosphere. However, the practice of venting CO_2 is coming under greater scrutiny, particularly in countries that have ratified the Kyoto protocol which requires the reduction of CO_2 emissions. Further, CO_2 gas can and is being sold as a miscible flood agent for enhanced oil recovery. That is, it may not be a disposal prospect, but is potentially a business opportunity to get additional revenue from CO_2 sales and/or additional production from its use.

[0009] For these reasons, acid gas injection ("AGI") may be a preferred alternative to sulfur recovery and CO_2 venting. AGI means that unwanted sour gases are reinjected into a subterranean formation and sequestered for potential later use.

[0010] For "highly sour" streams, that is, production streams containing greater than about 15% to about 20% CO_2 and H_2S, it can be particularly challenging to design, construct, and operate a process that can economically separate these contaminants from the desired hydrocarbons. Cryogenic gas processing (i.e., distillation) is a known procedure for sour gas separation. Cryogenic gas separation avoids the use of solvents, minimizes acid gas removal equipment, and generates a cooled and liquefied acid gas stream at moderate pressures (e.g., 350-500 pounds per square inch gauge (psig)). The cold, liquefied stream is particularly suitable for injection into a subterranean reservoir through AGI. Because the liquefied acid gas has a relatively high density, a hydrostatic head can be used in an AGI well. That is, the energy required to pump the liquefied acid gas is lower than the energy required to compress low-pressure acid gases to reservoir pressure. In addition, there are fewer stages involving compressors and pumps, so there is less equipment utilized for the acid gas stream.

[0011] One problem which has been encountered in the practice of cryogenic gas processing relates to the relatively low temperature at which CO_2 phase changes into a solid. If CO_2 is present at concentrations greater than about 5% in the gas to be processed, it freezes out as a solid in a standard cryogenic distillation unit. The formation of CO_2 as a solid interrupts the cryogenic distillation process. To circumvent this problem, a "Controlled Freeze Zone" (CFZ) process was developed to anticipate the formation of solid CO_2 and captures the frozen CO_2 particles at the bottom of a specially-designed distillation tower. As a result, a clean methane stream (along with any nitrogen or helium present in the raw gas) is generated overhead, while a liquid CO_2/H_2S stream at 30° to 40° F. (Fahrenheit) is generated at the bottom of the tower. The liquid sour gas stream is thus synergetic with AGI. Certain aspects of the CFZ process, associated equipment and technology are described in U.S. Pat. No. 4,533,372; U.S. Pat. No. 4,923,493; U.S. Pat. No. 5,062,270; U.S. Pat. No. 5,120,338; and U.S. Pat. No. 6,053,007. Each of these patents is incorporated herein by reference in its respective entirety.

[0012] The cryogenic distillation column employing the CFZ technology provides a spray zone in the middle of the column. The spray zone (or CFZ section) serves as a freezing section that causes gaseous CO_2 to freeze out of methane (or other light hydrocarbons) within the column, and gravitationally fall. A cold liquid (primarily methane) is injected into the intermediate spray section to provide a liquid spray. The cold liquid within the spray zone contacts gas as it rises in the column, causing the CO_2 to solidify and fall down.

[0013] Below the spray zone is a stripping section of the distillation column. The stripping section receives the raw feed stream (gas and liquid) for initial stripping of CO_2 from the gas stream. The bottom of the stripping section is warmer than the feed temperature. Upon entering the column, the liquid portion of the feed stream falls through the stripping section. As it moves downward, dissolved methane vaporizes and rises through the spray section. In the spray zone, entrained CO_2 vapor contacts the cold liquid spray, which causes the CO_2 to freeze out of the gas phase. In some embodiments, the feed stream can be introduced directly into the intermediate spray section.

[0014] Above the spray zone is a rectification section of the column. In the rectification section, an overhead gas is captured and made available for fuel or piped away for sales. The overhead gas may be partially liquefied by cooling, and the liquid returned to the column as "reflux." The reflux liquid is injected as the cold spray into the spray section.

[0015] There is a need for improved internal features and components of the CFZ distillation column. More specifically, there is a need for improvements to the CFZ cryogenic distillation tower to facilitate heat and mass transfer within the column. Further, there is a need for a cryogenic distillation tower offering improved internal features above and below the controlled freeze zone section to facilitate the extraction of CO_2 from a gas stream. Still further, there is a need for an improved sour gas removal chamber producing a liquefied acid gas stream, thereby facilitating the injection and sequestration of H_2S and CO_2 at low wellhead pressure.

SUMMARY OF THE INVENTION

[0016] A cryogenic distillation tower is provided for the separation of sour gasses in a fluid stream. The fluid stream contains at least methane and carbon dioxide. The distillation tower has an inner diameter that houses internal components that facilitate the separation process. The tower generally includes a lower stripping section, an intermediate spray section, and an upper rectification section.

[0017] The lower stripping section comprises a melt tray, and at least one stripping tray or packed bed below the melt tray. The stripping section is configured to operate at a temperature and pressure at which substantially no carbon dioxide solids are formed, but methane vapor is released.

[0018] The intermediate spray section comprises one or more spray nozzles configured to inject a liquid freeze zone stream. The nozzles are uniquely configured such that substantial liquid coverage of the intermediate spray section across the inner diameter is provided. The liquid sprayed into the freeze zone substantially comprises methane at a temperature and pressure whereby both solid carbon dioxide particles and a methane-enriched vapor stream are formed upon injection.

[0019] The upper rectification section comprises a rectification tray and, preferably, one or more additional trays, or packing. The upper rectification section is configured to receive vaporized methane from the lower stripping section and the methane-enriched vapor stream from the intermediate spray section. The rectification section may also receive a return liquefied stream of condensed vapor for further capture of residual CO_2 and H_2S. Unvaporized fluids are collected in the bottom rectification tray, released from the rectification section, optionally further chilled, and then reinjected into the spray section as the liquid freeze zone stream.

[0020] As noted, the nozzles in the intermediate spray section are uniquely configured such that substantial liquid coverage of the spray section across the inner diameter is provided. Preferably, the spray nozzles are disposed within one or more spray heads. In one aspect, the one or more spray heads define one or more spray nozzles, each having one or more nozzles and each being positioned at different levels in the spray section. In another aspect, a first spray header forms a substantially linear arrangement of spray nozzles, and a second spray header forms a substantially linear arrangement of spray nozzles transverse to and below the first spray header. In yet another aspect, the spray nozzles are positioned in (i) a first substantially linear spray head having a plurality of nozzles, (ii) a second substantially linear spray header below the first spray header also having a plurality of nozzles, and (iii) a third substantially linear spray head below the second spray header also having a plurality of nozzles, with the first, second and third spray headers being offset from one another

[0021] Preferably, the melt tray in the lower stripping section includes a base, and a plurality of chimneys extending upward from the base. The melt tray preferably also includes a cap over each chimney. In one aspect, the base defines a generally radial base extending across the inner diameter of the distillation tower, with the base having first and second opposite sides sloped inwardly towards an intermediate portion of the base. A downcomer is then disposed within the intermediate portion of the base to receive liquids collected by the melt tray. In another aspect, the base has a generally sinusoidal or other corrugated profile to increase its surface area.

[0022] In similar fashion, the rectification tray preferably includes a base and a plurality of chimneys extending upward from the base. Preferably again, a cap is disposed over each chimney.

[0023] Any commercially-available mass transfer device may be employed in either the stripping section or the rectification section. Such mass transfer devices may be fabricated from an anti-sticking material, such as Teflon, or from a fouling-resistant material.

[0024] In another embodiment, the spray section further includes one or more baffles or grid-type packing. In one aspect, a baffle is disposed below at least one of the spray headers for creating a fluid path for liquids moving down the spray section.

[0025] A method for producing hydrocarbon gases is also provided. In one embodiment, the method includes the steps of receiving a fluid stream containing at least methane and carbon dioxide, and then chilling the fluid stream to substantially liquefied phase. The fluid stream is introduced into a cryogenic distillation tower, such as any of the towers described above. Low molecular weight gases are recovered from the upper rectification section.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] So that the manner in which the features of the present invention can be better understood, certain drawings, charts and flow charts are appended hereto. It is to be noted, however, that the drawings illustrate only selected embodiments of the inventions and are therefore not to be considered limiting of scope, for the inventions may admit to other equally effective embodiments and applications.

[0027] FIG. **1** is a side view of a controlled freeze zone distillation tower of the present invention, in one embodiment. The initial feed stream is seen being injected into the intermediate spray section of the tower.

[0028] FIG. **2**A is a plan view of the melt tray, in one embodiment.

[0029] FIG. **2**B is a cross-sectional view of the melt tray of FIG. **2**A taken across line **2**B-**2**B.

[0030] FIG. **2**C is a cross-sectional view of the melt tray of FIG. **2**A taken across line **2**C-**2**C.

[0031] FIG. **3** is an enlarged side view of the stripping trays in the stripping section of the distillation tower, in one embodiment.

[0032] FIG. **4**A is perspective view of a jet tray as may be used in either the stripping section or rectification section of the distillation tower, in one embodiment.

[0033] FIG. **4**B is a side view of one of the openings in the jet tray of FIG. **4**A.

[0034] FIG. **5** is a side view of the intermediate spray section of the distillation tower of FIG. **1**. In this view, two baffles have been added to the spray section.

[0035] FIGS. **6**A and **6**B are nozzle arrangements, in other embodiments.

[0036] FIG. **6**A presents a substantially linear spray head supporting three spray nozzles. The spray head may be used in the intermediate spray section of the distillation tower, either to inject the initial feed stream or to inject the liquid freeze zone stream, or both. More than one such spray head arrangement may be placed at different levels in the spray section.

[0037] FIG. 6B presents a pair of transverse, substantially linear spray heads supporting multiple spray nozzles. The spray heads may be used in the intermediate spray section of the distillation tower to inject the initial feed stream. More than one such spray head arrangement may be placed at different levels in the spray section.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

Definitions

[0038] As used herein, the term "mass transfer device" refers to any object that receives fluid and passes it to another object, such as through gravitational flow. One non-limiting example is a tray for stripping out certain fluids. A grid packing is another example.

[0039] The term "baffle" means any object that interferes with the direct gravitational flow of liquid.

Description of Specific Embodiments

[0040] FIG. **1** presents a schematic view of a cryogenic distillation tower of the present invention, in one embodiment. The cryogenic distillation tower is referred to generally as **100**. The tower **100** may be interchangeably referred to herein as a "cryogenic distillation tower," a "column," a "CFZ column," or a "splitter tower."

[0041] The cryogenic distillation tower **100** of FIG. **1** receives an initial fluid stream **10**. The fluid stream **10** is comprised of production gasses. Typically, the fluid stream represents a dried gas stream from a wellhead (not shown), and contains about 65% to about 95% methane. Some ethane may be present as a light hydrocarbon, along with certain contaminants, such as CO_2 and H_2S. Not uncommonly, helium and nitrogen gasses may also be present. The initial fluid stream **10** is at a post-production pressure of approximately 600 pounds per square inch (psi). In some instances, the pressure of initial fluid stream **10** may be up to 1,000 psi.

[0042] The fluid stream **10** is typically chilled before entering the distillation tower **100**. A refrigeration unit **150**, such as a propane refrigerator, is provided for the initial fluid stream **10**, which may be a gas feed stream. The refrigeration unit **150** is used to bring the temperature of the initial fluid stream **10** down to about −30° to about −40° F. The chilled fluid stream may then be moved through an expansion device **152**, such as a Joule-Thompson ("J-T") valve. The expansion device **152** serves as an expander to obtain subcooling and preferably, partial liquification of the feed gas. A J-T valve is preferred for gas feed streams that are prone to forming solids. The expansion device **152** is preferably mounted close to the cryogenic distillation tower **100** to minimize heat loss in the piping.

[0043] As an alternative to a J-T valve, the expander device **152** may be a turbo expander. A turbo expander provides greater cooling and creates a source of shaft work for processes like the refrigeration unit **150**. In this manner, the operator may minimize the overall energy requirements for the distillation process. However, because the cryogenic distillation tower **100** is normally used in fields where the operator anticipates a high CO_2 stream, such that solids formation is likely, solids formation may become a matter of concern within not only the cryogenic distillation tower **100**, but also within a turbo expander. Thus, the J-T valve is likely the preferred expander device **152**.

[0044] In either instance, the refrigeration unit **150** and expander device **152** convert the raw gas in the initial fluid stream **10** into a chilled fluid stream **12** comprised primarily of liquids. Preferably, the temperature of the chilled fluid stream **12** is around −30° to −70° F. In one aspect, the cryogenic distillation tower **100** is operated at a pressure of 550 psi, and the chilled fluid stream **12** is at approximately −62° F. At these conditions, the chilled fluid stream **12** is in a substantially liquid phase, although some vapor phase may inevitably be entrained into the chilled fluid stream **12**. Most likely, no solids formation has arisen from the presence of CO_2.

[0045] The cryogenic distillation tower **100** is divided into three primary sections. These are a stripping section **106**, an intermediate spray section or "freeze zone" **108**, and a rectification section **110**. In the tower arrangement of FIG. **1**, the chilled fluid stream **12** is introduced into the distillation tower **100** near the top of the stripping section **106**. However, the chilled fluid stream **12** may alternatively be introduced into the spray section **108**.

[0046] It is noted in the arrangement of FIG. **1** that the stripping section **106**, the intermediate spray section **108**, the rectification section **110**, and all the components are housed within a single vessel **100**. This is believed to be the most economical design. However, for offshore applications in which height of the tower **100** and motion considerations may need to be considered, or for remote locations in which transportation limitations are an issue, the tower **110** may optionally be split into two separate pressure vessels (not shown). For example, the rectification section **110** and the freeze zone **108** may be located in one vessel, while the stripping section **106** is in another section. External piping would then be used to interconnect the two vessels portions.

[0047] In either embodiment, the temperature of the stripping section **106** is higher than the feed temperature of the chilled fluid stream **12**. The temperature of the stripping section **106** is designed to be above the vapor point of the methane in the chilled fluid stream **12**. In this manner, methane is preferentially stripped from the heavier hydrocarbon and acid liquid components. Of course, those of ordinary skill in the art will understand that the liquid within the distillation tower **100** is a mixture, meaning that the liquid boils at some intermediate temperature between methane and CO_2. Further, in the event that there are heavier hydrocarbons present in the mixture, this increases the boiling temperature of the mixture. These factors become design considerations for the operating temperatures within the distillation tower **100**.

[0048] In the stripping section **106**, the CO_2 and any other liquid-phase fluids gravitationally fall towards the bottom of the cryogenic distillation tower **100**. At the same time, methane and other vapor-phase fluids break out and rise upwards towards the top of the tower **100**. This separation is accomplished primarily through the density differential between the gas and liquid phases. However, the separation process is aided by internal components within the distillation tower **100**. As described below, these include a melt tray **130**, a plurality of advantageously-configured mass transfer devices **126**, and an optional heater line **25**.

[0049] Referring again to FIG. **1**, the chilled fluid stream **12** may be introduced into the column **100** near the top section of the stripping section **106**. Alternatively, it may be desirable to introduce the feed stream **12** into the intermediate spray section **108** above the melt tray **130**. Again, the point of injection of the chilled fluid stream **12** is a design issue dictated by the composition of the initial fluid stream **10**.

[0050] As with most distillation columns, the feed stream **12** is put onto a tray or region of the column **100** that has similar composition to the feed composition. Thus, where the CO_2 content of the feed stream **12** is high enough (such as greater than 60%) such that solids are not expected, it may be preferable to inject the feed stream **12** directly into the stripping section **106** through a two phase flashbox type device (or vapor distributor) **124** in the column **100**. In this case, the expander device **152** could be a turbo expander or a J-T valve or other device. A turbo expander would be preferred as it would extract greater thermal energy from the feed stream **12**, as well as recover some work for use elsewhere in the process. If the likelihood of solids formation is significant, the expander device **152** of choice would be a J-T valve. In this case, stream **12** is separated in a two phase vessel **173** to minimize the possibility of solids plugging the inlet line and internals. The vapor leaving the inlet separator **11** is introduced into the column **100** through the vapor distributor **124**. The liquid/solid slurry **13** is discharged through an inlet distributor **121** such that it would not be prone to plugging by solids. Inlet feed **13** can be fed to the tower by gravity or by pump **175**. Thus, where the initial fluid stream **10** has a sufficiently high CO_2 content such that early solids formation is contemplated, it may be desirable to separate the chilled fluid stream **10** in a separator instead of discharging directly into the lower portion of spray section **108** to avoid vapor maldistribution into the freeze zone **108**.

[0051] In the arrangement of FIG. **1**, the chilled fluid stream **12** may be distributed directly into the cryogenic distillation tower **100** through one or more two-phase flashboxes **124**, as long as significant solids or hydrates are not expected. The feed distributor is slotted such that the two-phase fluid impinges against baffles in the flashbox **124**. The use of a flashbox **124** serves to separate the two-phase vapor-liquid mixture in the chilled fluid stream **12**. If solids are anticipated, the feed may need to be separated in a vessel **173** prior to feeding the column **100** as described above.

[0052] The chilled fluid stream **12** (or **11**) exits the flashbox **124**. The location of the feed inlet in section **106** is dependent on feed composition. The liquid leaving the flashbox travels down the stripping trays. Because of the temperature and composition of the chilled fluid stream **12**, carbon dioxide primarily exists in liquid form. The vapor leaving the flashbox **124** travels through one or more trays, depending on the composition to maximize mass transfer. The vapor proceeds to travel through the risers of the melt tray **130** and into the freeze zone **108**. The melt tray risers act as a vapor distributor for uniform distribution through this zone **108**. The vapor contacts the cold liquid from spray headers **120** to "freeze out" the CO_2. Stated another way, the solid CO_2 "snow" onto the melt tray **130** and then gravitationally flow in liquid form down the melt tray **130** and through the stripping section **106** there below. As will be discussed more fully below, the intermediate spray section **108** is an intermediate freeze zone of the cryogenic distillation tower **100**. With the alternate configuration in which feed stream **12** is separated in vessel **173** prior to entering the tower **100**, the separated cooled fluid stream **13** is introduced into the tower **100** above the melt tray **130**. Thus, a liquid-solid mixture of sour gas and heavier hydrocarbon components flows from the distributor **121** with liquids falling down onto the melt tray **130**.

[0053] The melt tray **130** is configured to gravitationally receive liquid and solid materials, primarily CO_2 and H_2S, from the intermediate spray section **108**. The melt tray **130** is referred to as a "melt tray" as it serves to warm the liquid and solid materials and direct them downward through the stripping section **106** in liquid form for further purification. The melt tray **130** collects and warms the solid-liquid mixture from the intermediate spray section **108** in a pool of liquid. The melt tray **130** is designed to release vapor flow back to the intermediate spray section **108**, to provide adequate heat transfer to melt the solid CO_2, and to facilitate liquid/slurry drainage to the lower distillation or stripping section **106** of the column **100** below the melt tray **130**.

[0054] FIG. **2**A provides a plan view of the melt tray **130**, in one embodiment. FIG. **2**B provides a cross-sectional view of the melt tray **130**, taken across line **2**B-**2**B of FIG. **2**A. FIG. **2**C shows a cross-sectional view of the melt tray **130**, taken across line **2**C-**2**C. The melt tray **130** will be described with reference to these three drawings collectively.

[0055] First, the melt tray **130** includes a base **134**. The base may be a substantially planar body. However, in the preferred embodiment shown in FIGS. **2**A, **2**B and **2**C, the base **134** employs a substantially non-planar profile. The non-planar base configuration provides an increased surface area for contacting liquids and solids landing on the melt tray **130** from the intermediate spray section **108**. This serves to increase heat transfer from the vapors passing up from the stripping section **106** of the column **100** to the liquids and thawing solids. In one embodiment, the base **134** is corrugated. In another embodiment, the base **134** is substantially sinusoidal. The corrugated embodiment of the tray design is shown in FIG. **2**B. It is understood that other non-planar geometries may be used to increase the heat transfer area of the melt tray **130**.

[0056] The melt tray base **134** is preferably inclined. The incline is demonstrated in the side view of FIG. **2**C. Although most solids should be melted, the incline serves to ensure that any unmelted solids in the liquid mixture drain off of the melt tray **130** and into the stripping section **106** there below.

[0057] In the view of FIG. **2**C, a sump or "downcomer" **138** is seen central to the melt tray **130**. The melt tray base **134** slopes inwardly towards the downcomer **138** to deliver the solid-liquid mixture. The base **134** may be sloped in any manner to facilitate liquid draw-off.

[0058] As described in U.S. Pat. No. 4,533,372, the melt tray was referred to as a "chimney tray." This was due to the presence of a single venting chimney. The chimney provided an opening through which vapors may move upward through the chimney tray. However, the presence of a single chimney meant that all gasses moving upward through the chimney tray had to egress through the single opening. On the other hand, in the melt tray **130** of FIGS. **2**A, **2**B and **2**C, a plurality of chimneys **131** (or "risers") is provided. The use of multiple chimneys **131** provides improved vapor distribution. This contributes to better heat/mass transfer in the intermediate spray section **108**.

[0059] Referring again to FIG. **1**, the chimneys **131** may be of any profile. For instance, the chimneys **131** may be round, rectangular, or any other shape that allows vapor to pass through the melt tray **130**. The chimneys **131** may also be narrow and extend upwards into the intermediate spray section **108**. This enables a beneficial pressure drop to distribute the vapor evenly as it rises into the CFZ intermediate spray section **108**. The chimneys **131** are preferably located on peaks of the corrugated base **134** to provide additional heat transfer area.

[0060] Optionally, a heater may be placed below or just above the melt tray base **134** to facilitate thawing of the solid. A heater line **25** is shown and will be discussed further below. The heater line **25** utilizes thermal energy already available from a bottom reboiler **160**.

[0061] The top openings of the chimneys **131** are preferably covered with hats or caps **132**. This minimizes interaction between the vapor flowing upwards out of the chimneys **131** and the liquid/solid mixture falling onto the melt tray **130**. In FIGS. **2**A, **2**B and **2**C, caps **132** are seen above each of the chimneys **131**.

[0062] The melt tray **130** may also be designed with bubble caps. The bubble caps define convex indentations in the base **134** rising from underneath the melt tray **130**. The bubble caps further increase surface area in the melt tray **130** to provide additional heat transfer to the CO_2-rich liquid. With this design, a suitable liquid draw off, such as an increase incline angle, should be provided to ensure clear liquid is directed to the stripping trays **126** below.

[0063] The melt tray **130** may also be designed with an internal reflux system. The reflux system serves to ensure that all liquid is substantially free of solids and that sufficient heat transfer has been provided. The reflux system first includes a draw-off nozzle **136**. In one embodiment, the draw-off nozzle **136** resides within the draw-off sump **138**. Fluids collected in draw-off sump **136** are delivered to a reflux line **135**. Flow through reflux line **135** is controlled by a control valve **137** and a level controller "LC." Fluids are returned to the stripping section **106** via the reflux line **135**. If the liquid level is too high, the control valve **137** opens; if the level is too low, the control valve **137** closes. If the operator chooses not to employ the reflux system in the stripping section **106**, then the control valve **137** is closed and fluids are directed immediately to the mass transfer devices, or "stripping trays" **126** below the melt tray **130** for stripping via an overflow downcomer **139**.

[0064] Whether or not an internal reflux system is used, solid CO_2 is warmed on the melt tray **130** and converted to a CO_2-rich liquid. The melt tray **130** is heated from below by vapors from the stripping section **106**. Supplemental heat may optionally be added to the melt tray **130** by various means such as heater line **25**. The CO_2-rich liquid is drawn off from the melt tray **130** under liquid level control and gravitationally introduced to the stripping section **106**.

[0065] As noted, a plurality of stripping trays **126** are provided in the stripping section **106** below the melt tray **130**. The stripping trays **126** are preferably in a substantially parallel relation, one above the other. Each of the stripping trays **126** may optionally be positioned at a very slight incline, with a weir such that a liquid level is maintained on the tray. Fluids gravitationally flow along each tray, over the weir, and then flow down onto the next tray via a downcomer.

[0066] The stripping trays **126** may be in a variety of arrangements. The stripping trays **126** may be arranged in generally horizontal relation to form a sinusoidal, cascading liquid flow. However, it is preferred that the stripping trays **126** be arranged to create a cascading liquid flow that is divided by separate stripping trays substantially along the same horizontal plane. This is shown in the arrangement of FIG. **3**, where the liquid flow is split at least once so that liquid falls over two opposing downcomers **129**.

[0067] FIG. **3** provides a side view of a stripping tray **126** arrangement, in one embodiment. Each of the stripping trays **126** receives and collects fluids from above. Each stripping tray **126** preferably has a weir **128** that serves as a dam to enable the collection of a small pool of fluid on each of the stripping trays **126**. The fluid is contacted with upcoming vapor rich in lighter hydrocarbons that strip out the methane from the cross flowing liquid in this "contact area" of the trays **126**. The weirs **128** serve to dynamically seal the downcomers **129** to prevent vapor bypassing through the downcomers **129** and to further facilitate the breakout of hydrocarbon gasses.

[0068] The percent of methane becomes increasingly small as the fluids move downward in the stripping section **106**. In the upper part of the stripping section **106**, the methane content of the liquid may be as high as 25 mol %, while at the bottom stripping tray the methane content may be as low as 0.04 mol %. The methane content flashes out quickly along the stripping trays or packing **126**. The number of mass transfer devices **126** used in the stripping section **106** is a matter of composition. However, only a few levels of stripping trays **126** may be utilized to remove methane to a desired level of 1% or less in the liquefied acid gas, for example. The level of purity depends on the number of equilibrium stages in the stripping section.

[0069] Various individual stripping tray **126** configurations that facilitate methane breakout may be employed. The stripping tray **126** may simply be a panel with sieve holes, valves or bubble caps. Sieve holes, valves and bubble caps can be a variety of sizes and open area, depending on hydraulics. However, to provide further heat transfer to the fluid and to prevent unwanted blockage due solids, so called "jet trays" may be employed below the melt tray. In lieu of trays, random or structured packing may also be employed.

[0070] FIG. **4**A provides a plan view of an illustrative jet tray **426**, in one embodiment. FIG. **4**B provides a cross-sectional view of a jet tab **422** from the jet tray **426**. As shown, each jet tray **426** has a body **424**, with a plurality of jet tabs **422** formed within the body **424**. Each jet tab **422** includes an inclined tab member **428** covering an opening **425**. Thus, a jet tray **426** has a plurality of small openings **425**.

[0071] In operation, one or more jet trays **426** may be located in the stripping **106** or rectification **110** sections of the tower **100** where solids accumulation is possible. The trays **426** may be arranged with multiple passes such as the pattern of stripping trays **126** in FIG. **3**. However, any tray or packing arrangement may be utilized that facilitates the breakout of methane gas. Fluid cascades down upon each jet tray **426**. The fluids then flow along the body **424**. The fluid is then contacted with the vapor exiting the openings **425**. The tabs **422** are optimally oriented to move the fluid quickly and efficiently across the tray **426**. An adjoined downcomer (not shown) is provided to move the liquid to the subsequent tray **426**. The openings **425** also permit gas vapors released during the fluid movement process in the stripping section **106** to travel upwards more efficiently to the melt tray **130** and through the chimneys **131**.

[0072] In one aspect, the trays **126** or **426** may be fabricated from fouling-resistant materials, that is, materials that prevent solids-buildup. Fouling-resistant materials are utilized in some processing equipment to prevent the buildup of corrosive metal particles, polymers, salts, hydrates, catalyst fines, or other chemical solids compounds. In the case of the cryogenic distillation tower **100**, fouling resistant materials may be used in the trays **126** or **426** to limit sticking of CO_2 solids. For example, a Teflon coating may be applied to the surface of the trays **126** or **426**.

[0073] Alternatively, a physical design may be provided to ensure that the CO_2 does not start to build up in solid form along the inner diameter of the column **100**. In this respect, the jet tabs **422** may be oriented to push liquid along the wall of the column **100**, thereby preventing solids accumulation along the wall of the column **100** and ensuring good vapor liquid contact.

[0074] In any of the tray arrangements, as the fluids hit the stripping trays **126**, separation of materials occurs. Methane gasses break out of solution and move upward in vapor form. The CO_2, however, is cold enough and in high enough concentration that it remains in its liquid form and travels down to the bottom of the stripping section **106**. The liquid is then moved out of the cryogenic distillation tower **100** in an exit line as an exit fluid stream **22**.

[0075] Upon exiting the distillation tower **100**, the exit fluid stream **22** enters a reboiler **160**. In FIG. **1**, the reboiler **160** is a kettle type that provides reboiled vapor to the bottom of the stripping trays. A heater line **25** from the reboiler vapor stream may be used to provide supplemental heat to the melt tray **130**. The supplemental heat is controlled through a valve **165** and temperature controller TC. Alternately, a thermosyphon heat exchanger may be used for the initial fluid stream **10** to economize energy. In this respect, the liquids entering the reboiler **160** remain at a relatively low temperature, for example, about 30° to 40° F. By heat integrating with the initial fluid stream **10**, the operator may warm the cold exit fluid stream **22** from the distillation tower **100** while cooling the production fluid stream **10**. For this case, the fluid providing supplemental heat through line **25** is a mixed phase return from the reboiler **160**.

[0076] It is contemplated that under some conditions, the melt tray **130** may operate without a heater. In these instances, the melt tray **130** may be designed with a heating feature. The heater may be electric. The heating medium may reside external to the cryogenic distillation tower **100**. However, it is preferred that a heater be offered that employs the heat energy available in exit fluid stream **22**. The vapor stream **25** captured from exit fluid stream **22** after exiting reboiler **160** exists in one aspect at 30° to 40° F., so they contain relative heat energy. Thus, in FIG. **1**, vapor stream **25** is shown being directed to the melt tray **130** through a heating coil on the melt tray **130** (not shown). As the supplemental heat stream passes through and warms the melt tray **130**, it is return to the tower **100** bottom liquid pool through line **29**.

[0077] In operation, reboiled vapor stream **27** is introduced at the bottom of the column, above the bottom liquid level and below the last stripping tray **126**. As the reboiled vapor passes through each tray, residual methane is stripped out of the liquid. This vapor cools off as it travels up the tower. By the time the stripping vapors of stream **27** reach the corrugated melt tray **130**, the temperature may have dropped to about 0° F. to −20° F. However, this remains quite warm compared to the melting solid on the melt tray **130**, which may be around −50° F. to −80° F. The vapor still has enough enthalpy to melt the solids CO_2 as it comes in contact with the melt tray **130** to warm the melt tray **130**.

[0078] Referring back to reboiler **160**, fluids in a bottom stream **24** that remain in liquid form may optionally enter a valve **162**. The valve **162** reduces the pressure of the bottom liquid product, effectively providing a refrigeration effect. Thus, a chilled bottom stream **26** is provided. The bottom stream **24** may be maintained at pressure for direct feed to a pump, then to an acid gas injection (AGI) well.

[0079] The chilled bottom stream **26** may be reinjected in its liquid phase into a geologic reservoir through an AGI well (seen schematically at **250** in FIG. **1**). The liquid exiting the reboiler **160** is pumped downhole. In some situations, the liquid CO_2 may be pumped into a partially recovered oil reservoir as part of an enhanced oil recovery process. Thus, the CO_2 could be a miscible injectant. As an alternative, the CO_2 may be used as a miscible flood agent for enhanced oil recovery.

[0080] Some or all of the chilled bottom stream **26** may optionally be moved through a heat exchanger **164**. The heat exchanger **164** recovers additional cold from the liquid stream before the CO_2 is warmed into its gas phase for energy recovery. This final stage is shown at stream **28**. However, this step is optional, and it is preferred that the CO_2 be reinjected through AGI well **250** in its liquid phase to avoid CO_2 venting.

[0081] Referring again to the stripping section **106** of the column **100**, gas moves up through the stripping section **106**, through the chimneys **131** in the melt tray **130**, and into the intermediate spray section **108**. The spray section **108** is an open chamber having a plurality of spray nozzles **122**. As the vapor moves through the spray section **108**, the temperature in the intermediate spray section **108** becomes colder. As the vapor moves upward, the light gas products are contacted by liquid methane coming from the spray nozzles **122**. This liquid methane is colder than the vaporized methane moving upward, having been chilled through a refrigerator **170**. In one arrangement, the liquid methane exits from spray nozzles **122** at a temperature of about −120° F. to −130° F.

[0082] As the methane vapors move further up the cryogenic distillation tower **100**, they leave the intermediate spray section **108** and enter the rectification section **110**. The vapors continue to move upward along with other light gasses broken out from the original chilled fluid stream **12**. The combined hydrocarbon vapors move out of the top of the cryogenic distillation tower **100**, becoming a condenser exit stream **14**, or "condenser feed."

[0083] The hydrocarbon gas in condenser exit stream **14** is moved into the external refrigeration unit **170**. In one aspect, the refrigeration unit **170** uses an ethylene refrigerant or other refrigerant capable of chilling the condenser exit stream **14** down to about −138° to −142° F. This serves to at least partially liquefy the condenser exit stream **14**. The liquefied condenser exit stream **14** is then moved to a separation chamber **172**.

[0084] In another embodiment, the condenser exit stream **14** is taken through an open-loop refrigeration system (not shown). In this alternative arrangement, the condenser exit stream **14** is actually used as a refrigerant. The condenser exit stream **14** is pressurized to about 1,000 psi to 1,400 psi, then cooled using ambient air, and possibly an external propane refrigerant. The chilled and pressurized gas stream is then directed through an expander for further cooling. At this point, a turbo expander could be used to recover even more liquid as well as some shaft work. It is understood here that the present inventions are not limited by the cooling method for the condenser exit stream **14**.

[0085] It is also noted that the degree of cooling between refrigerator **170** and the refrigeration unit **150** may be varied. In some instances, it may be desirable to operate the refrigeration unit **150** at a higher temperature, but then be more aggressive with cooling the overhead stream **14** in refrigerator **170**. Again, the present inventions are not limited to these types of design choices.

[0086] As noted above, the chilled gas stream exiting refrigerator **170** is directed to a reflux vessel or separation chamber **172**. Separation chamber **172** is used to separate gas from liquid. A pump may be used to move liquid back into the column **100** if the separation chamber **172** is not mounted above the column **100** to provide gravity feed of liquid. A portion of the condenser exit stream **14** entering the refrigerator **170** is not condensed; instead, this portion remains in the vapor phase. This portion represents the lighter hydrocarbon gasses, primarily methane. The methane is, of course, the "product" ultimately sought to be captured and sold commercially, along with any ethane. The methane and, perhaps, some ethane, is captured as represented in FIG. **1** by product stream **16**. Nitrogen and helium may also be present in product stream **16**.

[0087] The remaining liquefied gasses primarily represent residual sour gasses dissolved in methane. The sour gases are liquefied by refrigerator **170**, and are directed back to the cryogenic distillation tower **100** for further processing. Optionally, additional heat exchanging may take place to capture cold energy from the condenser exit stream **14**.

[0088] It should be noted here that the refrigerator **170** may be referred to as a "reflux condenser." A reflux condenser is a heat exchanger that causes condensation. This means that a portion of the condenser exit stream **14** coming from the top of the rectification section **110** is condensed, and then returned to the rectification section **110**. The condensed gas, or "reflux," is represented as reflux fluid stream **18**. Most of the reflux fluid stream **18** is methane, typically 95% or more, with traces of nitrogen, carbon dioxide and hydrogen sulfide. Sufficient reflux fluid is generated such that the desired CO_2 or H_2S specification is met at the top of the column **100**.

[0089] The reflux fluid stream **18** is returned into the rectification section **110**. The reflux fluid stream **18** is then gravitationally carried through one or more mass transfer devices **116** in the rectification section **110**. In one embodiment, the mass transfer devices **116** are rectification trays that provide a cascading series of weirs **118** and downcomers **119**.

[0090] As fluids from reflux fluid stream **18** move downward through the rectification trays **116**, additional methane vaporizes out of the rectification section **110**. The methane gasses rejoin the condenser exit stream **14** to become product stream **16**. However, the remaining liquid phase of reflux fluid stream **18** falls onto a collector tray **140**. As it does so, the reflux fluid stream **18** unavoidably picks up a small percentage of hydrocarbon and residual acid gasses moving upward from the stripping section **106**. The liquid mixture of methane and carbon dioxide is collected at collector tray **140**.

[0091] The collector tray **140** preferably defines a substantially planar body for collecting liquids. However, as with melt tray **130**, collector tray **140** also has one, and preferably a plurality of chimneys for venting gasses coming up from the spray section **108**. A chimney and cap arrangement such as that presented by components **131** and **132** in FIG. **2**B may be used. Chimneys **141** and caps **142** for collector tray **140** are shown in the enlarged view of FIG. **5**, discussed further below.

[0092] It is noted here that in the rectification section **110**, any H_2S present has a slight preference towards being a liquid versus the gas at the processing temperature. In this respect, the H_2S has a comparatively low relative volatility. By contacting the remaining vapor with more liquid, the cryogenic distillation tower **100** drives the H_2S concentration down to within the desired parts-per-million (ppm) limit, such as a 4 ppm specification. As fluid moves through the mass transfer devices **116**, the H_2S contacts the liquid methane and is pulled out of the vapor phase and becomes a part of a chamber liquid stream **20**. From there, the H_2S moves in liquid form downward through the stripping section **106** and ultimately exits the cryogenic distillation tower **100** as the liquefied acid gas stream **22**.

[0093] In cryogenic distillation tower **100**, the liquid captured at collector tray **140** is drawn off of the rectification section **110** as a liquid stream **20**. The liquid stream **20** is comprised primarily of methane. In one aspect, the liquid stream **20** is comprised of about 93% methane, 3% CO_2, 0.5% H_2S, and 3.5% N_2, At this point, liquid stream **20** is at about −125° F. to −130° F. This is only slightly warmer than the reflux fluid stream **18**. The liquid stream **20** is directed into a reflux drum **174**. The purpose of the reflux drum **174** is to provide surge capacity for a pump **176**. Upon exiting the reflux drum **174**, a spray stream **21** is created. Spray stream **21** is pressurized in a pump **176** for a second reintroduction into the cryogenic distillation tower **100**. In this instance, the spray stream **21** is pumped into the intermediate spray section **108** and emitted through nozzles **122**.

[0094] Some portion of the spray stream **21**, particularly the methane, vaporizes upon exiting the nozzles **122**. From there, the methane rises through the intermediate spray section **108**, through the chimneys in the collector tray **140**, through the rectification mass transfer devices **116** in the rectification section **110**, and ultimately become commercial product in product stream **16**. However, another portion of the liquid from nozzles **122** vaporizes as it cools upflowing feed gas, causing carbon dioxide to desublime from the gas phase. The CO_2 "snow" falls upon the melt tray **130**, and melts into the liquid phase. From there, the CO_2-rich liquid cascades down mass transfer devices **126** in the stripping section **106** along with liquid CO_2 from the chilled fluid stream **12** described above. At that point, any remaining hydrocarbons from the spray stream **21** of the nozzles **122** should quickly break out into vapor. These vapors move upwards in the cryogenic distillation tower **100** and re-enter the rectification section **110**.

[0095] In accordance with one of the many aspects of the present invention, it has been determined that it is desirable to provide some additional form of resistance to fluid flow in the spray section **108** below the nozzles **122**. The fluid flow resistance interferes with the flow of the liquid as it moves down the intermediate spray section **108** and onto the melt tray **130**. Thus, the cryogenic distillation tower **100** may optionally include baffles or grid packing.

[0096] FIG. **5** provides an enlarged view of the cryogenic distillation tower **100**. In this view, the intermediate spray section **108** is primarily seen. Two sets of nozzles **122** are also seen. Further, a pair of illustrative baffles or grid packing **510** is shown disposed within the spray section **108**. The baffles or grid packing **510** preferably traverse the diameter of the column **100**. In the arrangement of FIG. **5**, one of the baffles or grid packing **510** is placed below each of the respective two sets of nozzles **122**. As methane-rich liquid is injected from the nozzles **122** into the spray section **108**, the fluid contacts the baffles or grid packing **510**. This, in turn, facilitates the breakout of methane from solution.

[0097] The baffles or grid packing **510** may take one of any number of shapes and forms. The baffles or grid packing **510** are configured to create a frictional flow path for liquids and snow as the material gravitationally travels down through the intermediate spray section **108**. As such, the baffles or grid packing **510** may offer angles, grids, perforations or other types of diversion surfaces. In general, the baffles or grid packing **510** should be made to be resistant to fouling as well.

[0098] The use of baffles or grid packing **510** in the intermediate spray section **108** improves the efficiency of fluid separation and heat transfer from the spray droplets to the upflowing gas. Baffles or grid packing **510** further reduce back-mixing of CO_2. In this respect, the frictional flow path created by the baffles or grid packing **510** prevent the fine, low mass CO_2 particles from moving back up the column **100** and re-entering the rectification section **110**. These particles would undesirably remix with methane and re-enter the condenser exit stream **14**, only to be recycled again.

[0099] Another feature of the column **100** that can improve the efficiency of fluid separation in the intermediate spray section **108** pertains to the configuration of the nozzles **122**. Rather than employing a single spray source at one or more levels in a reflux fluid stream, the present disclosure offers spray headers optionally designed with multiple spray nozzles **122** incorporated therein.

[0100] The configuration of the spray nozzles **122** has an impact on the mass transfer taking place within the intermediate spray section **108**. During the separation process, a chilled liquid stream is injected through the nozzles **122** and into the intermediate spray section **108**. As the liquid enters the intermediate spray section **108** and begins to fall within the cryogenic distillation tower **100**, liquefied methane is evaporated. Some CO_2 momentarily enters the gas phase and moves upward with the methane. However, because of the cold temperature within the intermediate spray section **108**, the vaporized carbon dioxide quickly turns into a solid phase and begins to "snow." This phenomenon is referred to as desublimation. In this way, some CO_2 never re-enters the liquid phase until it hits the melt tray **130**. The CO_2 particles move down the column **100** in snow form.

[0101] FIGS. **6**A and **6**B demonstrate various nozzle **122** arrangements in perspective views. In each of FIGS. **6**A and **6**B, a spray head incorporating multiple spray nozzles **122** is provided. In each Figure, injection line, which is the exit fluid stream **22**, is shown introducing the injectant fluid through a wall **111** of the column **100**.

[0102] FIG. **6**A is an enlarged view of the nozzle arrangement from FIG. **1**. Here, a spray header **120** supports three nozzles **122** in series. In FIG. **1**, two reflux spray headers are provided, each supporting three nozzles **122**. Thus, a 3×2 array is formed. Preferably, each nozzle is capable of providing 70° to 140° spray distribution. These multiple spray headers can be optimized by using a variety of nozzle sizes for turndown operation.

[0103] FIG. **6**B presents an alternate spray header **120'** in which two transverse lines support nozzles **122**. Alternatively, three spray headers **120** at different levels in the intermediate spray section **108** may be disposed at 120° (or other) relative angles. Alternatively still, the spray nozzles **122** may be supported by a first substantially linear spray header having a plurality of nozzles **122**, and a second substantially linear spray header transverse to and below the first spray header, also having a plurality of nozzles. These arrangements are not specifically shown but are readily understood from the views of FIG. **1** and FIG. **6**B, together. Other spray patterns are possible.

[0104] It is desirable to have chilled liquid contacting as much of the gas that is moving up the column as possible. If vapor bypasses the sprays, higher levels of CO_2 could reach the rectification section **110** of the tower **100**. The unique spray header arrangements **120**, **120'** (and others described above) avoid dry areas where vapor could bypass the spray. It is preferred that the individual nozzles **122** provide a more limited spray distribution, e.g., 100° to 120°, but that multiple nozzles **122** be used to achieve full distribution. The use of multiple spray nozzles **122** at a level of the intermediate spray section **108** provides fuller, overlapping liquid coverage of the intermediate spray section **108**. This serves to ensure 360° coverage within the spray section **108** and provide good vapor-liquid contact and heat/mass transfer. This, in turn, more effectively chills any gaseous carbon dioxide moving upward through the cryogenic distillation tower **100**.

[0105] The use of an overlapping nozzle **122** arrangement for complete coverage minimizes back-mixing as well. In this respect, complete coverage prevents the fine, low mass CO_2 particles from moving back up the column and re-entering the rectification section **110**. These particles would then remix with methane and re-enter the condenser exit stream **14**, only to be recycled again.

[0106] In one aspect, individual nozzles **122** may be configured to offer a particularly fine or atomized spray distribution. Finer distribution aids hydrocarbons in breaking out of solution as the liquid travels towards the stripping section **106**.

[0107] In yet an additional embodiment, separate spray heads **120** may be used to spray reflux liquid at different temperatures. In this instance, the reflux stream fed into the uppermost spray head is chilled to a temperature below that of the reflux stream fed into the lowermost spray head.

[0108] It can be seen that the process of cycling vapors through the cryogenic distillation tower **100** ultimately produces a hydrocarbon product comprised of methane and ethane gas in product stream **16**. The product is sent down a pipeline or processed to LNG. At the same time, sour gasses are removed through exit fluid stream **22**.

[0109] The above-described internal features are expected to improve mass transfer, heat transfer, and solids handling in the cryogenic distillation tower **100**. They are also expected to improve column operation during upset conditions, when CO_2 levels are not yet stabilized in the cryogenic distillation tower **100**. While it will be apparent that the invention herein described is well calculated to achieve the benefits and advantages set forth above, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the spirit thereof. For example, adjustments may be made to the operational temperatures within the tower **100** to maximize distillation and fluid separation. The temperature ranges disclosed herein are merely exemplary, and it is understood that temperatures could fall outside of these ranges such as during transients or upsets.

What is claimed is:

1. A cryogenic distillation tower for the separation of a fluid stream containing at least methane and carbon dioxide, the cryogenic distillation tower defining an inner diameter that houses internal components, comprising:

a lower stripping section comprising a melt tray and at least one mass transfer device below the melt tray, the lower stripping section being configured to operate at a temperature and pressure at which substantially no carbon dioxide solids are formed, and vaporized methane is released;

an intermediate spray section comprising a plurality of spray nozzles configured to inject a liquid freeze zone stream such that substantial liquid coverage of the intermediate spray section across the inner diameter is provided, the liquid freeze zone stream substantially comprising methane at a temperature and pressure whereby both solid carbon dioxide particles and a methane-enriched vapor stream are formed upon injection; and

an upper rectification section comprising a collector tray, and at least one mass transfer device above the collector tray, the upper rectification section being configured to receive the vaporized methane from the lower stripping section and the methane-enriched vapor stream from the intermediate spray section.

2. The cryogenic distillation tower of claim **1**, wherein the plurality of spray nozzles is disposed within at least one spray header.

3. The cryogenic distillation tower of claim **2**, wherein the plurality of spray nozzles is positioned in a first spray header having a first plurality of nozzles, and a second spray header below the first spray head also having a second plurality of nozzles.

4. The cryogenic distillation tower of claim **1**, wherein the plurality of nozzles are positioned at different levels within the upper rectification section.

5. The cryogenic distillation tower of claim **5**, wherein the plurality of spray nozzles in the first spray header forms a substantially linear arrangement, and the plurality of spray nozzles in the second spray header forms a substantially linear arrangement essentially transverse to and below the first spray header.

6. The cryogenic distillation tower of claim **5**, wherein the plurality of spray nozzles is positioned in:

a first substantially linear spray header having a first plurality of nozzles,

a second substantially linear spray header below the first spray header also having a second plurality of nozzles, and

a third substantially linear spray header below the second spray header also having a third plurality of nozzles,

with the first spray header, second spray head and third spray header being offset relative to one another.

7. The cryogenic distillation tower of claim **1**, wherein the melt tray comprises:

a base; and

a plurality of chimneys extending upward from the base.

8. The cryogenic distillation tower of claim **7**, wherein the melt tray further comprises a cap over each of the plurality of chimneys.

9. The cryogenic distillation tower of claim **7**, wherein:

the base of the melt tray defines a generally radial base extending across the inner diameter of the cryogenic distillation tower, the base having a first side, and a second side opposite the first side, wherein the first side and second side are sloped inwardly towards an intermediate portion of the base; and

the base further comprises a sump disposed within the intermediate portion of the base to receive and direct liquids.

10. The cryogenic distillation tower of claim **9**, wherein the base further comprises a draw-off nozzle for receiving internal reflux fluids collected in the sump.

11. The cryogenic distillation tower of claim **7**, wherein the base of the melt tray has a generally sinusoidal profile.

12. The cryogenic distillation tower of claim **7**, wherein the base of the melt tray has a generally corrugated profile.

13. The cryogenic distillation tower of claim **7**, wherein the at least one mass transfer device below the melt tray comprises:

a base;

a plurality of openings in the base; and

a plurality of tabs, wherein each of the plurality of tabs extend over one of the plurality of openings in the base to substantially interfere with the gravitational flow of liquids downward through the one of the plurality of openings.

14. The cryogenic distillation tower of claim **7**, wherein the at least one mass transfer device below the melt tray comprises:

a packing that creates a plurality of channels through which fluids gravitationally flow.

15. The cryogenic distillation tower of claim **1**, wherein the collector tray comprises:

a base; and

a plurality of chimneys extending upward from the base.

16. The cryogenic distillation tower of claim **15**, wherein the collector tray further comprises a cap over each of the plurality of chimneys.

17. The cryogenic distillation tower of claim **1**, wherein the at least one mass transfer devices in the lower stripping section is fabricated from or coated with a fouling-resistant material.

18. The cryogenic distillation tower of claim **1**, wherein the at least one mass transfer device above the collector tray comprises:

a base;

a plurality of openings in the base; and

a plurality of tabs, wherein each of the plurality of tabs extend over one of the plurality of openings in the base to substantially interfere with the gravitational flow of liquids downward through the one of the plurality of openings.

19. The cryogenic distillation tower of claim **1**, wherein the at least one mass transfer device above the collector tray comprises:

a packing that creates a plurality of channels through which fluids gravitationally flow.

20. The cryogenic distillation tower of claim **1**, wherein the at least one mass transfer device in the lower stripping section or in the upper rectification section above the rectification tray is fabricated from or coated with a fouling-resistant material.

21. The cryogenic distillation tower of claim **4**, further comprising a baffle or grid packing below at least one of the plurality of spray headers for creating a frictional fluid path for liquids moving down the intermediate spray section.

22. The cryogenic distillation tower of claim **1**, wherein the at least one stripping tray comprises a plurality of stripping trays arranged to create a cascading liquid flow.

23. The cryogenic distillation tower of claim **1**, further comprising:

an exit line which receives an exit fluid stream from the lower stripping section comprised primarily of carbon dioxide;

a reboiler wherein the exit fluids are warmed; and

a heater line for capturing gas vaporized by the reboiler, the vapor line carrying warmed vapor to the melt tray to heat the melt tray.

24. The cryogenic distillation tower of claim **1**, wherein the melt tray comprises a plurality of bubble caps to increase the surface area.

25. The cryogenic distillation tower of claim **2**, wherein the plurality of spray nozzles is arranged in:

a first spray header to distribute a portion of the liquid freeze zone stream at a first temperature; and

a second spray header positioned at a different level in the intermediate spray section to distribute a portion of the liquid freeze zone stream at a second temperature that is higher than the first temperature.

26. The cryogenic distillation tower of claim **25**, wherein the first spray header is positioned above the second spray header.

27. The cryogenic distillation tower of claim **1**, further comprising an internal downcomer on the melt tray to provide reflux to the stripping section.

28. The cryogenic distillation tower of claim **1**, wherein the fluid stream is injected into the cryogenic distillation tower through at least one spray header having a plurality of nozzles.

29. The cryogenic distillation tower of claim **28**, wherein the at least one spray header comprises a first spray header, and a second spray header below the first spray header.

30. A method for producing hydrocarbon gases, comprising:

receiving an initial fluid stream containing at least methane and carbon dioxide;

chilling the initial fluid stream to a substantially liquefied phase;

introducing the liquefied fluid stream into a cryogenic distillation tower to separate the carbon dioxide from the methane, the distillation tower defining an inner diameter which houses internal components comprising:

a lower stripping section comprising a melt tray and at least one mass transfer device below the melt tray, the lower stripping section being configured to operate at a temperature and pressure at which substantially no carbon dioxide solids are formed and vaporized methane is released;

an intermediate spray section comprising a plurality of spray nozzles configured to inject a spray stream such that substantial liquid coverage of the intermediate spray section across the inner diameter is provided, the spray stream substantially comprising methane at a temperature and pressure whereby both solid carbon dioxide particles and a methane-enriched vapor stream are formed upon injection; and

an upper rectification section comprising a collector tray, the upper rectification section being configured to receive vaporized methane from the lower stripping section and the methane-enriched vapor stream from the intermediate spray section; and

recovering vaporized methane from the upper rectification section.

31. The method of claim **30**, wherein the plurality of spray nozzles is disposed within at least one spray header.

32. The method of claim **31**, wherein the cryogenic distillation tower further comprises a baffle below at least one of the spray headers for creating a fluid path for liquids moving down the intermediate spray section.

33. The method of claim **30**, wherein the plurality of spray nozzles is positioned in a first spray head having a first plurality of nozzles, and a second spray header below the first spray header also having a second plurality of nozzles.

34. The method of claim **33**, wherein the plurality of spray nozzles in the first spray header forms a substantially linear arrangement, and the plurality of spray nozzles in the second spray header forms a substantially linear arrangement essentially transverse to and below the first spray header.

35. The method of claim **33**, wherein the plurality of spray nozzles is positioned in:

a first substantially linear spray header having a first plurality of nozzles,

a second substantially linear spray header below the first spray header also having a second plurality of nozzles, and

a third substantially linear spray header below the second spray header also having a third plurality of nozzles,

with the first spray header, second spray header and third spray header being offset relative to one another.

36. The method of claim **30**, wherein the spray nozzles are each capable of providing about a 70° to 140° spray distribution.

37. The method of claim **30**, wherein the spray header defines at least two intersecting fluid lines supporting nozzles.

38. The method of claim **30**, wherein the melt tray comprises:

a base; and

a plurality of chimneys extending upward from the base.

39. The method of claim **38** wherein the melt tray further comprises a cap over each chimney.

40. The method of claim **30**, wherein the at least one mass transfer device below the melt tray comprises:

a base;

a plurality of openings in the base; and

tabs extending over the respective openings in the base to substantially interfere with the gravitational flow of liquids downward through the openings.

41. The method of claim **40**, wherein the melt tray is fabricated from or coated with a fouling-resistant material.

42. The method of claim **30**, wherein the at least one mass transfer device below the melt tray comprises a plurality of stripping trays arranged to create a cascading liquid flow.

43. The method of claim **30**, wherein the cryogenic distillation tower further comprises:

an exit line which receives exit fluids from the stripping section comprised primarily of carbon dioxide; and

a reboiler wherein exit fluids are warmed.

44. The method of claim **43**, wherein the cryogenic distillation tower further comprises

a heater line for capturing gas vaporized by the reboiler, the vapor line carrying warmed vapor to the melt tray to heat the melt tray.

45. The method of claim **43**, further comprising:

collecting the carbon dioxide for use as a miscible agent in an enhanced oil recovery operation.

46. The method claim **30**, wherein the melt tray comprises a plurality of bubble caps to increase the surface area.

47. The method of claim **30**, wherein the spray nozzles are arranged in:

a first spray header to distribute a portion of the liquid stream at a first temperature; and

a second spray header positioned at a different level in the intermediate spray section to distribute a portion of the liquid stream at a second temperature that is higher than the first temperature.

48. The method of claim **47**, wherein the first spray header is positioned above the second spray header.

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