Methods, apparatuses and systems for processing fluid streams having multiple constituents

ABSTRACT

Methods, apparatuses and systems for processing fluid streams having multiple constituents are provided including embodiments utilizing ascending temperature separation processes as well as combined ascending and descending temperature separation processes. For example, in one embodiment, a mixed gas stream may be processed by flowing the stream through multiple heat exchangers, expanding the stream, and then separating the stream into a liquid portion and a vapor portion. The vapor portion, having an increased or decreased concentration of an identified constituent may then pass through the heat exchangers again in reverse order and collected. The liquid portion may then be subjected to further, sequential separation acts which each take place at increasing temperatures. In another embodiment, numerous, sequential separation acts take place in, for example, at decreasing temperatures and, subsequently, at increasing temperatures. Such a mixed fluid stream, for example, may include constituents such as hydrogen, carbon monoxide and methane.
METHODS, APPARATUSES AND SYSTEMS FOR PROCESSING FLUID STREAMS HAVING MULTIPLE CONSTITUENTS

GOVERNMENT RIGHTS

[0001] The United States Government has certain rights in this invention pursuant to Contract No. DE-AC07-05ID14517 between the United States Department of Energy and Battelle Energy Alliance, LLC.

TECHNICAL FIELD

[0002] Embodiments of the present invention relate, generally, to the processing of fluid streams having multiple constituents and, more particularly, to processes and systems for the separation and recovery of desired components or constituents of a mixed fluid stream including the production of multiple streams from the mixed fluid stream, the produced streams having increased or reduced component concentrations as compared to the mixed gas stream.

BACKGROUND

[0003] A number of processes, such as those associated with, for example, the processing of hydrocarbons, result in a waste gas stream having a mixture of components. When these components are capable of being recovered, economics of the process improves. However, many of the costs associated with the process of recovering specific component gases from the gas stream or other mixed gas streams are tied to the equipment required to recover such gases along with the recurring expense of regeneration.

[0004] Regeneration is the general process of removing trapped components in, for example, separators and filters. The cost of such activities can easily exceed the value of the component gases recovered from the gas streams. Likewise, the cost of separating constituents from a mixed gas stream may be considered “waste gas” or not, often exceed the value of the separated constituent making it cost prohibitive to conduct such activities.

[0005] In a capital-intensive marketplace, the ability to improve the economics of a given process by even a few percentage points may provide the difference between a profitable plant and one that is not economically feasible.

[0006] A variety of processes is currently known, or at least asserted to be useful, for separating components of a mixed gas stream. For example, U.S. Pat. No. 6,105,390 to Bingham et al. (assigned to the assignee hereof, the disclosure of which is incorporated by reference herein in its entirety) describes systems and methods for liquefying gas and separating components from a pressurized mixed gas stream. The process generally includes a descending temperature method of separation including cooling the mixed gas stream to condense certain components, and then separating the condensed components from the mixed gas stream.

[0007] U.S. Pat. No. 5,026,952 to Bauer describes a process for separating C2+, C3+ or C4+ hydrocarbons from a gas mixture. The gas mixture is cooled to condense a portion of the hydrocarbons. A gaseous fraction is removed and cooled in a heat exchanger to further condense the hydrocarbons.

[0008] U.S. Pat. No. 5,505,048 to Ha et al. describes an apparatus for separating C4 hydrocarbons from a gaseous mixture containing the same and lower hydrocarbons and hydrogen. The gas mixture is cooled until a portion of the C4 hydrocarbons is condensed. The mixture of gas and liquid C4 is separated. Further cooling and separation acts take place to condense substantially all of the C4 hydrocarbons while leaving the hydrogen in the gas stream.

[0009] U.S. Pat. No. 5,450,728 to Vora et al. describes a process and system for recovering volatile organic compounds and water vapor from a low boiling gas. The process includes compressing the gas and then cooling the gas in stages to condense volatile components and water while avoiding freezing in the system.

[0010] PCT Publication WO 90/10837 describes a process for the recovery of natural gas liquids, methane and nitrogen from a gaseous feed stream. The process utilizes cooling and expansion principles and employs multiple “fractionation” zones and attempts to minimize the need for external refrigerant requirements.

[0011] The scale of a process operation can be a substantial factor in the ability to recover value added components. If the operation is large enough, conventional methods of separation may prove to be economically practical. However, in many instances, smaller scale processes are replacing conventional large scale operation in order to improve distribution and provide more localized control.

[0012] Small to medium scale processing plants are often designed to service a particular customer or set of customers. Such a distributed service option provides operators and customers more flexibility in situating and operating plants in closer proximity to the end users. However, in some cases, deriving value from the waste gas, or removal of certain components, may be required simply to make the plant profitable. Smaller scale processing plants conventionally produce smaller waste gas streams, making it difficult to economically and efficiently treat the waste gas streams using traditional methods.

[0013] As noted above, the purification or separation of different gases from a mixed gas stream is not just a process associated with waste gas streams. Rather, separation or purification techniques are utilized in a number of other environments and operations. For example, purification and/or separation of the different gases from a main mixed gas are often accomplished prior to a liquefaction process and can significantly add to the expense and complexity of the process. As a result, many productive gas wells having high concentrations of undesired gases or elements are often capped rather than processed.

[0014] Improvements to systems and processes for separating components or constituents of a mixed gas stream are continually sought after by various industries. Embodiments of the presently disclosed invention include processes of separating mixed gas streams and associated systems for carrying out such processes.

BRIEF SUMMARY OF THE INVENTION

[0015] Various embodiments of the present invention include methods, apparatuses and systems for processing fluid streams having multiple constituents. According to various embodiments, configurations may utilize ascending temperature separation processes, descending temperature processes or a combination thereof. Additionally, various embodiments may employ pressure and temperature management, including use of expansion devices, to assist in the processing of the mixed gas stream.

[0016] In accordance with one embodiment of the present invention, a method is provided for processing a mixed gas stream having multiple constituents. The method includes flowing the mixed gas stream through a plurality of heat
exchangers to cool the mixed gas stream and then expanding the cooled mixed gas stream. The expanded mixed gas stream is separated into a vapor portion and a liquid portion and the vapor portion is flowed through at least some of the plurality of heat exchangers to assist in cooling the mixed gas stream. The liquid portion is flowed through the plurality of heat exchangers and also subjected to a plurality of liquid-vapor separation processes, wherein the first liquid-vapor separation process is conducted after flowing the liquid portion through at least one heat exchanger and wherein each subsequent liquid-vapor separation process takes place at a temperature warmer than a previous liquid-vapor separation process.

[0017] In accordance with another embodiment of the present invention, a gas processing plant is provided. The plant includes a plurality of heat exchangers and a first flow path configured to convey a fluid stream sequentially through each of the plurality of heat exchangers. An expansion device is disposed in the first flow path downstream of the plurality of heat exchangers. A first separation tank is coupled with the first flow path downstream of the expansion device. A second flow path is configured to convey a vapor stream through the plurality of heat exchangers in a reverse sequential order as compared to the first flow path. The plant also includes a plurality of additional separation tanks, wherein each of the plurality of separation tanks is disposed between, and in communication with, two different heat exchangers. The plurality of additional separation tanks and the plurality of heat exchangers are located and configured to flow fluid sequentially through the plurality of additional separation tanks while increasing the temperature of any fluid flowing there-through from one separation tank to another.

[0018] In accordance with a further embodiment of the present invention, another method of processing a mixed gas stream having multiple constituents is provided. The method includes subjecting at least a portion of the mixed gas stream to a first plurality of sequentially conducted gas-liquid separation acts, wherein each of the first plurality of sequentially conducted gas-liquid separation acts is conducted at a reduced temperature as compared to a previously conducted gas-liquid separation act of the first plurality of separation acts. The portion of the mixed gas stream is expanded and the expanded stream is further separated into a liquid portion and a vapor portion. At least a portion of the liquid portion is subjected to an additional plurality of sequentially conducted gas-liquid separation acts, wherein each of the additional plurality of sequentially conducted gas-liquid separation acts is conducted at an increased temperature as compared to a previously conducted gas-liquid separation act of the additional plurality of sequentially conducted gas-liquid separation acts of the additional plurality.

[0019] In accordance with yet another embodiment of the present invention, a gas processing plant is provided. The plant includes a plurality of heat exchangers and a first plurality of separation tanks. Each of the first plurality of separation tanks includes at least one inlet in communication with one of the plurality of heat exchangers and at least one outlet in communication with another of the plurality of heat exchangers. A second plurality of separation tanks, likewise, each have at least one inlet in communication with one of the plurality of heat exchangers and at least one outlet in communication with another of the plurality of heat exchangers. A first flow path is configured to convey a fluid stream through each of the plurality of heat exchangers and through the first plurality of separation tanks such that any fluid flowing there-through enters each separation tank of the first plurality of separation tanks at a reduced temperature as compared to any upstream separation tank of the first plurality of separation tanks. An expansion device is disposed in the first flow path downstream of the plurality of heat exchangers. An additional separation tank is coupled with the first flow path downstream of the expansion device. A second flow path is configured to convey a fluid stream through the plurality of heat exchangers and the second plurality of separation tanks such that any fluid flowing there-through enters each separation tank of the second plurality of separation tanks at an increased temperature as compared to any upstream separation tank of the second plurality of separation tanks.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0020] The foregoing and other advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

[0021] FIG. 1 is process flow diagram depicting the processing of a fluid stream in accordance with one embodiment of the present invention; and

[0022] FIG. 2 is process flow diagram depicting the processing of a fluid stream in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0023] Various embodiments of the present invention provide economical and efficient processes for separating constituents of a fluid stream, such as a gas stream, or for purifying a given fluid stream. The processes and systems described herein are particularly amenable to implementation with medium and small scale process operations, but are also applicable to larger scale operations. As will be described in further detail hereinbelow, embodiments of the present invention may include a combination of heat exchangers, separation tanks and pressure letdown controls to effectively separate constituents of gaseous streams.

[0024] For example, in one embodiment, a process using multiple pressure drops may be employed to remove different components from a mixed composition stream. Such a process may use a series of heat exchangers, valves, and separation tanks positioned along the flow stream to effectively remove different components at different pressures and temperatures. Most gases experience a reduction in temperature with an associated drop in pressure. This temperature-pressure drop is normally referred to as a Joule-Thompson or a "JT" effect. In addition to the JT effect, an expansion engine, such as a turbo expander may be used in embodiments of the present invention to improve the temperature drop, especially in the warmer regions where the Joule-Thompson effect is minimal. In accordance with different embodiments of the present invention, the separation process may be conducted as an ascending temperature process, a descending temperature process or a combination of both ascending temperature and descending temperature processes.

[0025] In certain embodiments, each pressure drop may be associated with a tank that separates the condensed liquid stream from the vapor stream. Each stream may be returned to the process to further enhance the heat exchange process.
taking place. The separation acts can be configured to work on a descending or ascending temperature basis or on a combination thereof.

In certain embodiments, heat exchangers may be designed with multi-passes to accommodate the separated streams and to prevent undesired mixing of already separated components. The use of multi-pass heat exchangers may also enable more effective and efficient extraction of heat energy using each of the streams.

In various embodiments, the pressure drop at each separation event may be based on the desired components that are to be removed and may vary based on overall composition. The number of required acts of separation may also vary based on the level of desired separation and the magnitude of the pressure drop associated therewith.

For example, some components may exhibit similar characteristics in terms of temperature and pressure properties and may separate as a binary component. In the cases where the components still need to be separated into elemental components, further separation methods and techniques may be employed.

In various embodiments, the process and system may be configured to produce component streams at desired temperatures. For example, if desired, some components may be left in a cryogenic state such as liquefied methane.

Referring to FIG. 1, a process diagram is shown for a separation plant 100 in accordance with one embodiment of the present invention. The plant 100 includes a variety of flow paths associated with different separation acts of the process as will be described in detail hereinafter. A first flow path may include a feed stream 102 of, for example, a mixed gas. As used herein, “mixed gas” refers to a gaseous or substantially gaseous fluid having multiple components or constituents. For example, a mixed gas may include so-called “natural gas” having a methane constituent, a propane constituent, an ethane constituent as well as other constituents or components as will be appreciated by those of ordinary skill in the art.

The feed stream 102 flows through a series of heat exchangers to reduce the temperature of any fluid flowing therethrough. In the embodiment depicted in FIG. 1, the feed stream 102 flows through a first heat exchanger 104, a second heat exchanger 106 and a third heat exchanger 108, and experiences a temperature drop as it passes from a first side to a second side of each of the three heat exchangers 104, 106, 108. It is noted, that depending on a variety of conditions, including the composition of the feed stream 102, a different number of heat exchangers may be utilized and that the use of three heat exchangers in the presently described embodiment is not to be limiting.

The heat exchangers 104, 106 and 108 may include similarly configured heat exchangers, or they may include heat exchangers of different sizes, different types or both. Depending on the conditions that will be experienced by such heat exchangers (e.g., temperature and pressure), a number of different types of heat exchangers may be appropriate for use with the present invention. As depicted in FIG. 1, countercflow type heat exchangers may be utilized wherein the feed stream 102 enters a “warm side” of the heat exchanger and one or more relatively colder fluid streams enter a “cold side” of the heat exchanger to reduce the temperature of the feed stream 102. Some nonlimiting examples of different heat exchangers that may be used in accordance with one or more embodiments of the present invention include those described in U.S. Pat. No. 6,581,409 entitled APPARATUS FOR THE LIQUEFACTION OF NATURAL GAS AND METHODS RELATING TO SAME, the disclosure of which is incorporated by reference herein in its entirety.

After passing through the series of heat exchangers 104, 106 and 108, the feed stream 102 passes through an expansion device to reduce the pressure of the gas in the feed stream 102. For example, the feed stream 102 may pass through a Joule-Thomson (JT) valve 110 to expand the gas flowing therethrough and decrease the pressure of such gas. The JT valve 110 utilizes the JT principle, as discussed above, that the expansion of a gas will result in an associated cooling of the gas as well. Thus, the feed stream 102 experiences both a pressure drop and a temperature drop by passing through the JT valve 110.

The feed stream 102, having passed through the JT valve 110 or other expansion device, flows into a separation tank 112 wherein liquid and vapor (or gas) components are separated from one another. The vapor or gas may include a particular constituent (or a group of constituents) while the liquid may include a different constituent (or group of constituents). In one example, if the feed stream 102 includes a mixed gas that has constituents that include methane, carbon monoxide and hydrogen, the gas or vapor in the separation tank 112 may primarily include carbon monoxide (or at least an increased concentration thereof as compared to the mixed gas) while the liquid in the separation tank 112 may primarily include methane and hydrogen (or at least an increased concentration thereof as compared to the composition of the mixed gas). It is noted, however, that the liquid may still include a minor constituent of carbon monoxide and the gas or vapor may still include a minor constituent of hydrogen, methane or both.

The separated gas or vapor portion leaves the separation tank (referred to herein for sake of convenience and clarity as a first separation tank 112) as a separated component (which shall be referred to herein for purposes of convenience and clarity as a first component stream 114) and passes back through the heat exchangers 104, 106 and 108 in a countercflowing manner relative to the feed stream 102 so as to provide cooling to the feed stream 102.

The liquid leaves the separation tank 112 (and may be referred to as a diminished stream 116 for purposes of clarity and convenience—including being diminished in composition as compared to the feed stream 102) and passes through the last heat exchanger 108 in the series of heat exchangers to help cool the feed stream 102. After exiting the heat exchanger 108, the diminished stream 116 which has experienced an increase in temperature by virtue of the heat exchange process, enters into a second separation tank 118 where the diminished stream 116 is separated again into a liquid portion and a gas or vapor portion.

The gas or vapor portion leaves the separation tank 118 and passes through one or more of the sequentially intermediate heat exchangers (e.g., heat exchanger 106) and may join another gas or vapor stream to be mixed therewith as shall be discussed further hereinafter. The gas or vapor portion may also pass through one or more additional heat exchangers (e.g., heat exchanger 104) as a second component stream 120 providing further cooling to the feed stream 102. As described previously with respect to the first component stream 114, the second component stream 120 may comprise an increased concentration of a given constituent as compared to the composition of the mixed gas of the feed stream 102, while the
liquid in the separation tank 118 may comprise increased concentrations of other components or constituents while having a reduced concentration of the given constituent as compared to the composition of the mixed gas stream.

[0038] The liquid leaving the second separation tank 118 leaves as what may be referred to as a further diminished stream 122 (having had another component or constituent substantially removed therefrom—or at least reduced in concentration), and may likewise pass through one or more of the sequentially intermediate heat exchangers (e.g., heat exchanger 106) to provide cooling to the feed stream 102, and then pass to a third separation tank 124. The gas or vapor leaving the third separation tank 124 may be combined with the gas or vapor from the second separation tank 118, such as by way of an appropriate mixing valve 126 or through other piping arrangements, and pass through one or more heat exchangers (e.g., heat exchanger 104) as the second component stream 120.

[0039] The liquid leaves the third separation tank 124 as a third component stream 128 and passes through one or more heat exchangers (e.g., heat exchanger 104) to further assist with the heat exchange process in cooling the feed stream 102.

[0040] Thus, depending, for example, on the composition of the feed stream 102, a single, mixed gas feed stream may be processed into multiple component streams (e.g., component streams 114, 120, and 128) each differing in their composition from the mixed gas stream.

[0041] It is noted that the embodiment described with respect to FIG. 1 shows a configuration wherein separation acts take place on an ascending temperature basis. In other words, each subsequent separation act within the process takes place at a temperature that is higher than any previous separation acts. Thus, for example, the separation activities that take place in the second separation tank 118 occur at a higher temperature than the separation activities taking place in the first separation tank 112. Likewise, the separation activities that take place in the third separation tank 124 take place at a higher temperature than the activities taking place in the second separation tank 118.

[0042] Referring now to FIG. 2, a process diagram is shown for a separation plant 200 in accordance with another embodiment of the present invention. The plant 200 includes a variety of flow paths associated with different separation acts of the process as will be described in detail hereinbelow.

[0043] A first flow path may include a feed stream 202 of, for example, a mixed gas. The feed stream 202 flows through a first heat exchanger 204 to reduce the temperature of any fluid flowing therethrough. The feed stream 202 exits the first heat exchanger 204 and enters a first separation tank 206. The feed stream 202, when introduced into the separation tank 206 at the reduced temperature, produces a liquid portion and a gas or a vapor portion. The gas or vapor portion exits as a stream (referred to as a vapor stream 208 for convenience) while the liquid portion exits as a liquid stream.

[0044] This first vapor stream 208 exits the first separation tank 206 and enters into a second heat exchanger 210 for additional temperature reduction. A first liquid stream 212 leaves the first separation tank 206 for further processing as will be discussed subsequently. It is noted that the use of “first,” “second” or other numerical identifiers, when used in association with various streams or plant components herein, is not intended to be limiting or to necessarily indicate a sequential order or a level of criticality or importance but, rather, is used as a matter of convenience and for clarity in identifying the numerous and varied components and streams of the described plant and process.

[0045] As previously noted, the first vapor stream 208 passes through a second heat exchanger 210 to reduce its temperature. The first vapor stream 210 then passes to a second separation tank 214 where the stream separates into a liquid portion and a gas or vapor portion. The gas or vapor portion exits the second separation tank 214 as a second vapor stream 216 and passes through a third heat exchanger 218 to reduce its temperature. The liquid portion exits the second separation tank 214 as a second liquid stream 220 for further processing as will be discussed hereinbelow.

[0046] The second vapor stream 216, after passing through the third heat exchanger 218, enters a third separation tank 222 where it separates into a liquid portion and a gas or vapor portion. The vapor portion exits the third separation tank 222 as a third vapor stream 224 and passes through a fourth heat exchanger 226 to reduce its temperature. The liquid portion exits the third separation tank 222 as a third liquid stream 228 for further processing as will be detailed hereinbelow.

[0047] The third vapor stream 224, after being cooled by the fourth heat exchanger 226, passes through an expansion device such as, for example, a JT valve 230 and into a mixing valve 232 or other device to recombine it with the third liquid stream 228, the third liquid stream 228 having also passed through an expansion device such as a JT valve 234. This recombined stream then enters a fourth separation tank 236 where it separates again into a liquid portion and a gas or a vapor portion. The gas or vapor portion exits the fourth separation tank 236 as a vapor stream and is what will be referred to herein as a first component stream 238. The first component stream 238 passes through the various heat exchangers 226, 218, 210 and 204 to assist in cooling of the feed stream 202 and various vapor streams previously described. The first component stream 238 thus includes a substantially separated component or constituent previously contained in the mixed gas feed stream 202. In other words, the first component stream 238 includes a composition having a selected constituent present at a higher concentration as compared to the mixed gas stream.

[0048] The liquid portion contained in the fourth separation tank 236 exits as a fourth liquid stream 240 and passes through the fourth heat exchanger 226 to assist with the cooling of the third vapor stream 224. The fourth liquid stream 240 is combined with the second liquid stream 220 using a mixing valve 242 or other mixing device and the combined stream enters a fifth separation tank 244. Prior to entering the mixing valve 242, the second liquid stream 220 passes through an expansion device, such as a JT valve 246, to lower the temperature and pressure of the stream. The fluid entering the fifth separation tank 244 separates into a liquid portion and a gas or a vapor portion. The liquid portion leaves as a fifth liquid stream 248 and the vapor or gas portion leaves as a fifth vapor stream 250 and both the fifth liquid stream 248 and the fifth vapor stream 250 pass through the third heat exchanger 218 to assist with cooling of the second vapor stream 216.

[0049] The fifth liquid stream 248, after passing through the third heat exchanger 218, is combined with the first liquid stream 212 using a mixing valve 252 or other mixing device. Prior to entering the mixing valve 252, the first liquid stream 212 passes through an expansion device, such as a JT valve 254, to lower the temperature and pressure of the stream. The
combined stream leaves the mixing valve 252 and enters into a sixth separation tank 256 where it is separated into a liquid portion and a gas or vapor portion. The gas or vapor portion leaves the sixth separation tank 256 as a sixth vapor stream 258 and is combined with the fifth vapor stream 250 (after the fifth vapor stream 250 has passed through the fourth heat exchanger 218) in a mixing valve 260 or other mixing device. The combined vapor stream forms a second component stream 262 which passes through the second heat exchanger 210 to assist with cooling of the first vapor stream 208 and then through the first heat exchanger 204 to assist with cooling of the feed stream 202.

[0050] The liquid portion in the sixth separation tank 256 exits as a sixth liquid stream 266 and flows through the second heat exchanger 210 where it is warmed as it assists with cooling of the first vapor stream 208. The sixth liquid stream 266 then enters a seventh separation tank 268 where it is separated into a liquid portion and a gas or vapor portion. The liquid portion leaves the seventh separation tank 268 and passes through the first heat exchanger 204, assisting with the cooling of the feed stream 202, as a third component stream 270. The gas or vapor portion leaves the seventh separation tank 268 and passes through the first heat exchanger 204, assisting with the cooling of the feed stream 202, as a fourth component stream 272.

[0051] Thus, depending, for example, on the composition of the feed stream 202, a single, mixed gas feed stream 202 may be processed into multiple component streams (e.g., component streams 238, 262, 270 and 272) each comprising, a desired constituent from the mixed gas stream in an increased or reduced concentration as compared to the input stream.

[0052] The separation plant 200, thus, provides an example of a separation process that uses descending and ascending separation techniques while also employing multiple pressure drops. In certain embodiments, such as the separation plant 200 described with respect to FIG. 2, a separation point may be placed between each heat exchanger on both the cooling and warming sides of the various heat exchangers (i.e., heat exchangers 204, 210, 218 and 226). Additionally, a separation point may further be placed at the end of the cooling sequence. In other words, the fourth separation tank 236 is a separation point wherein a stream exits the fourth heat exchanger 226 with both the liquid and vapor portions reentering the fourth heat exchanger 226 (after a pressure let down event) with the vapor portion being a component stream and the liquid portion being further separated in the process.

EXAMPLE 1

[0053] Modeling has been conducted for a separation plant such as described with respect to FIG. 1. As previously noted, the separation plant 100 described with respect to FIG. 1 is an embodiment that employs a process of separation using an ascending temperature method of separation. In other words, each successive act of separation is conducted at a temperature that is warmer than the previous separation act. It is noted that in this example (as well as in Example 2 described below), minor pressure drops have been ignored in order to simplify the modeling. Those of ordinary skill in the art will recognize that minor pressure drops will occur at the heat exchangers and at various places in the process piping.

[0054] Referring to FIG. 1, conditions or “state points” of fluid flowing throughout the plant 100 are now described.

[0055] Considering such modeling, the feed stream 102 may include a mixed gas including, among other potential constituents, 0.0107 mass fraction of hydrogen, 0.2489 mass fraction of carbon monoxide (CO), and 0.2967 mass fraction of methane. The mixed gas stream may include other constituents which, at the present time, are not of particular interest to the presently described embodiment. The feed stream 102 may enter the plant 100 at a pressure of approximately 285 pounds per square inch absolute (psia), at a temperature of approximately 60°F and at a mass flow rate of approximately 1.913×10^5 pounds per hour (lb/hr).

[0056] At a location between the first heat exchanger 104 and the second heat exchanger 106, the feed stream 102 will exhibit a temperature of approximately −140°F at a pressure of approximately 283 psia. At a location between the second heat exchanger 106 and the third heat exchanger 108, the feed stream will exhibit a temperature of approximately −173°F at a pressure of approximately 283 psia.

[0057] After exiting the third heat exchanger 108 and prior to passing through the expansion device 110, the feed stream will exhibit a temperature of approximately −244°F at a pressure of approximately 283 psia.

[0058] As previously discussed, the expansion device 110 will cause a reduction in pressure as well as a reduction in temperature of the feed stream 102. As such, the feed stream 102 will exhibit a temperature of approximately −289.4°F and a pressure of approximately 15 psia at the location between the expansion device and the first separation tank 112.

[0059] The first component stream 114 leaving the first separation tank 112 will leave as vapor at a temperature of approximately −289.4°F, at a pressure of approximately 15 psia and at a mass flow rate of approximately 8.089×10^4 lb/hr. At a location between the third heat exchanger 108 and the second heat exchanger 106, the first component stream will exhibit a temperature of approximately −194°F and a pressure of approximately 15 psia.

[0060] At a location between the second heat exchanger 106 and the first heat exchanger 104, the first component stream 114 will exhibit a temperature of approximately −150°F and a temperature of approximately 15 psia.

[0061] As the first component stream 114 exits the first heat exchanger 104, it will exhibit a temperature of approximately 50°F at a pressure of approximately 15 psia. The composition of the first component stream 114 will include a mass fraction of approximately 0.0254 hydrogen, a mass fraction of approximately 0.5007 CO, and a mass fraction of approximately 0.1092 methane. Stated another way, the first component stream 114 contains approximately 2.5% hydrogen, 50% carbon monoxide, and 11% methane by mass. The component stream will include other components, not of particular interest in the present example, which will account for the remainder of the mass in the first component stream 114.

[0062] Returning back to the first separation tank, the diminished stream 116, leaving the first separation tank 112 as liquid, will exhibit a temperature of approximately −289.4°F, a pressure of approximately 15 psia and at a mass flow rate of approximately 1.104×10^5 lb/hour. After passing through the third heat exchanger 108, and prior to entering the second separation tank 118, the diminished stream 116 will exhibit a temperature of approximately −226.2°F at a pressure of approximately 15 psia.

[0063] The vapor leaving the second separation tank 118 will exit at a temperature of approximately −226.2°F at a
pressure of approximately 15 psia and then passes through the second heat exchanger 106. Between the second heat exchanger 106 and the mixing valve 126, this vapor stream will exhibit a temperature of approximately $\sim150^\circ F$ and at a pressure of approximately 15 psia.

The liquid leaving the second separation tank 118 (as the further diminished stream 122) will exhibit a temperature of approximately $\sim226.2^\circ$ F. at a pressure of approximately 15 psia prior to entering the second heat exchanger 106 and will exhibit a temperature of approximately $\sim182.9^\circ$ F. and a pressure of approximately 15 psia at a location between the second heat exchanger 106 and the third separation tank 124.

The vapor portion in the third separation tank 124 will exit the third separation tank at a temperature of approximately $\sim182.9^\circ$ F. and a pressure of approximately 15 psia and enter the mixing valve 126. The second component stream 120 will exit the mixing valve 126 at a temperature of approximately $\sim152.3^\circ$ F., a pressure of approximately 15 psia and a mass flow rate of approximately $5.795\times10^3$ lb/hr. After passing through the first heat exchanger 104, the second component stream 120 will exhibit a temperature of approximately $34.5^\circ$ F. and at a pressure of approximately 15 psia. The composition of the second component stream 120 will include substantial no hydrogen, a mass fraction of approximately 0.1228 of CO and a mass fraction of approximately 0.8051 methane. In other words, the second component stream 120 includes approximately 81% methane, 12% CO and some other constituents not of particular interest in the presently described embodiment.

Returning to the third separation tank 124, the liquid portion exit as the third component stream 128 at a temperature of approximately $\sim182.9^\circ$ F., at a pressure of approximately 15 psia and at a mass flow rate of approximately $5.246\times10^3$ lb/hr. The third component stream 128 will pass through the first heat exchanger 104 and exit at a temperature of approximately $50^\circ$ F. and at a pressure of approximately 15 psia. The composition of the third component stream 128 will include substantially no mass fraction of hydrogen or CO, and approximately 0.0243 mass fraction methane. Stated another way, there will be essentially no hydrogen or carbon monoxide content, while the methane content will be approximately 2.5% by mass of the second component stream 114.

Thus, multiple component streams may be produced from a mixed gas stream wherein the component streams each contain an increased or enhanced percentage of a selected or desired constituent.

**EXAMPLE 2**

Modeling has been also been conducted for a separation plant such as described with respect to FIG. 2. As previously noted, the separation plant 200 described with respect to FIG. 2 includes an embodiment that employs a process of separation using both descending and ascending temperature methods of separation. In other words, one series of separation acts may be conducted such that each act occurs at a temperature that is colder than a previous separation act in the series while another series of separation acts is conducted such that each act of separation occurs at a temperature that is warmer than a previous act of separation in the series.

Referring to FIG. 2, conditions or “state points” of fluid flowing throughout the plant 200 are now described.

The feed stream 202 will include a mixed gas stream having numerous constituents including 0.0007 mass fraction of hydrogen, 0.2489 mass fraction of carbon monoxide, 0.2967 mass fraction of methane, 0.0896 mass fraction ethane and 0.0616 mass fraction propane. The mixed gas stream may include other constituents which, at the present time, are not of particular interest to the presently described embodiment.

The feed stream 202 may enter the plant 200 at a pressure of approximately 283 psia, at a temperature of approximately 60.6$^\circ$ F. and at a mass flow rate of approximately $1.913\times10^5$ pounds per hour (lb/hr).

After passing through the first heat exchanger 204, and prior to entering the first separation tank 206, the feed stream 202 will exhibit a temperature of approximately $\sim100^\circ$ F. at a pressure of approximately 283 psia. After separating into liquid and vapor components, the first liquid stream 212 and the first vapor stream 208 will each exit the first separation tank at $\sim100^\circ$ F. at a pressure of approximately 283 psia, with the first vapor stream 208 exhibiting a flow rate of approximately $1.473\times10^5$ lb/hr and the liquid stream 212 exhibiting a flow rate of approximately $4.404\times10^4$ lb/hr.

The first vapor stream 208, after passing through the second heat exchanger 210 and prior to entering the second separation tank 214, will exhibit a temperature of approximately $\sim140^\circ$ F. and a pressure of approximately 283 psia. The second vapor stream 216 and the second liquid stream 220 will likewise exhibit temperatures of approximately $\sim140^\circ$ F. and pressures of approximately 283 psia. The second vapor stream 216 will exhibit a mass flow rate of approximately $1.419\times10^5$ lb/hr and the second liquid stream 220 will exhibit a mass flow rate of approximately $5.399\times10^4$ lb/hr.

The second vapor stream 216, after passing through the third heat exchanger 218 and prior to entering the third separation tank 222, will exhibit a temperature of approximately $\sim173^\circ$ F. and a pressure of approximately 283 psia. The third vapor stream 224 and the third liquid stream 228 will both exhibit similar temperatures of approximately $\sim173^\circ$ F. and pressures of approximately 283 psia. The third vapor stream 224 will exhibit a mass flow rate of approximately $1.340\times10^5$ lb/hr while the third liquid stream 228 will exhibit a mass flow rate of approximately $7.857\times10^4$ lb/hr.

The third vapor stream 224, subsequent passing through the fourth heat exchanger 226 and prior to passing through the JT valve 230, will exhibit a temperature of approximately $\sim244^\circ$ F. and a pressure of approximately 283 psia. Subsequent passing through the JT valve 230 and prior to entering the mixing valve 232, the third vapor stream 224 will exhibit a temperature of approximately $\sim296.1^\circ$ F. and a pressure of approximately 15 psia.

The third liquid stream 228, subsequent passing through the JT valve 234 and prior to entering the mixing valve 232, will exhibit a temperature of approximately $\sim241.4^\circ$ F. and a pressure of approximately 15 psia. The combined stream leaving the mixing valve 232 will exhibit a temperature of approximately $\sim292.5^\circ$ F. and a pressure of approximately 15 psia.

The vapor portion leaving the fourth separation tank 236, or the first component stream 238, will exhibit a mass flow rate of approximately $7.778\times10^4$ lb/hr, will exhibit a temperature of approximately $\sim194^\circ$ F., and a pressure of approximately 15 psia at a location between the fourth heat exchanger 226 and the third heat exchanger 218. The first component stream 238 will continue through the remaining heat exchangers exhibiting substantially the same pressure and mass flow rate and an increasing temperature as it passes through each heat exchanger. For example, at a location
between the third heat exchanger 218 and the second heat exchanger 210 the first component stream 238 will exhibit a temperature of approximately -150° F; at a location between the second heat exchanger 210 and the first heat exchanger 204, the first component stream 238 will exhibit a temperature of approximately -100° F; and after passing through the first heat exchanger 204 the temperature of the first component stream 238 will be approximately 50° F.

Returning to the fourth separation tank 236, the fourth liquid stream 240 will leave the fourth separation tank 236 at a temperature of approximately -292.5° F, a pressure of approximately 15 psia, and at a mass flow rate of approximately 6.409 x 10^6 lb/hr. After passing back through the fourth heat exchanger 226, and prior to entering the mixing valve 242, the fourth liquid stream 240 will exhibit a temperature of approximately -221.4° F and a pressure of approximately 15 psia. The second liquid stream 220 will pass through the JT valve 246 and, prior to entering the mixing valve 242, will exhibit a temperature of approximately -190.9° F and a pressure of approximately 15 psia. At a location between the mixing valve 242 and the fifth separation tank 244, the combined stream will exhibit a temperature of approximately -218.4° F and a pressure of approximately 15 psia.

The fifth liquid stream 248 and the fifth vapor stream 250 will leave the fifth separation tank 244 at temperatures of approximately -218.4° F and a pressures of approximately 15 psia with the fifth vapor stream 250 exhibiting a mass flow rate of approximately 5.9 x 10^6 lb/hr and the fifth liquid stream 248 exhibiting a mass flow rate of approximately 1.049 x 10^6 lb/hr.

After passing through the third heat exchanger 218, and prior to entering the mixing valve 252, the fifth liquid stream 248 will exhibit a temperature of approximately -165° F and a pressure of approximately 15 psia. The first liquid stream 212, after passing through the JT valve 254, will exhibit a pressure of approximately -134.6° F and a pressure of approximately 15 psia and then enter the mixing valve 252. After passing through the mixing valve 252, and prior to entering the sixth separation tank 256, the combined stream will exhibit a temperature of approximately -143.7° F and a pressure of approximately 15 psia.

The sixth vapor stream 258 and the sixth liquid stream 266 will each exit the sixth separation tank 256 at a temperature of approximately -143.7° F and a pressure of approximately 15 psia with the sixth vapor stream 258 exhibiting a mass flow rate of approximately 5.853 x 10^6 lb/hr and sixth liquid stream 266 exhibiting a mass flow rate of approximately 4.868 x 10^6 lb/hr.

The sixth vapor stream 258 will enter the mixing valve 260 at a temperature of -143.7° F and a pressure of approximately 15 psia to mix with the fifth vapor stream 250. The combined stream (which will be the second component stream 262) exiting the mixing valve 260, and prior to entering the second heat exchanger 210, will exhibit a temperature of approximately -149.5° F and a pressure of approximately 15 psia.

After passing through the second heat exchanger 210, the second component stream 262 will exhibit a temperature of approximately -100.6° F and a pressure of approximately 15 psia. After passing through the first heat exchanger 204, the second component stream 262 will exhibit a temperature of approximately 41.79° F and a pressure of approximately 15 psia. The second component stream will exhibit a mass flow rate of approximately 6.485 x 10^6 lb/hr and will have approximately 0.0001 mass fraction of hydrogen, approximately 0.0866 mass fraction of carbon monoxide, approximately 0.7453 mass fraction methane, approximately 0.0337 mass fraction ethane, and approximately 0.0007 mass fraction propane.

Returning back to the sixth separation tank 258, the sixth liquid stream 266, after passing through the second heat exchanger 210, will exhibit a temperature of approximately -110° F and a pressure of approximately 15 psia. The liquid exiting the seventh separation tank 268 (i.e., the third component stream 270), and after passing through the first heat exchanger will exhibit a temperature of approximately 40.44° F and a pressure of approximately 15 psia.

The third component stream 270 will exhibit a mass flow rate of 4.719 x 10^6 lb/hr and will have approximately 0.0065 mass fraction methane, approximately 0.2637 mass fraction ethane, approximately 0.2436 mass fraction propane and substantially no hydrogen or carbon monoxide.

The vapor exiting the seventh separation tank 268 (i.e., the fourth component stream 272), after passing through the first heat exchanger 204 will exhibit a temperature of approximately 50° F and a pressure of approximately 15 psia.

The fourth component stream 272 will exhibit a mass flow rate of approximately 1.481 lb/hr and will have approximately 0.0051 mass fraction carbon monoxide, 0.3088 mass fraction methane, approximately 0.6304 mass fraction ethane, approximately 0.0361 mass fraction propane and substantially no hydrogen.

The two examples set forth above are nonlimiting examples showing the ability of embodiments of the present invention to separate gas components of a mixed gas stream into streams that comprise an increase or a reduction of selected constituents. The extent of the separation in a given embodiment may be governed to some extent by the available pressure and composition of a given gas stream provided as a feed stream.

In some embodiments, the pressure of the feed stream may be based on that of a resulting gas stream from a preceding process. In other embodiments, the pressure of the feed stream may be boosted to a desired level.

Multi-pass heat exchangers, separation tanks, and valves, such as described hereinabove, may provide the balance of the most basic system providing a very low maintenance system. Arrangements that require higher degrees of separation may be supplemented by additional means implemented on specific, selected gas or liquid streams. By using additional separation equipment or processes in conjunction with selected streams, costs may be reduced by requiring lower flow and maintenance equipment.

While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention includes all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.
What is claimed is:
1. A method of processing a mixed gas stream having multiple constituents, the method comprising:
   - flowing the mixed gas stream through a plurality of heat exchangers to cool the mixed gas stream;
   - expanding the cooled mixed gas stream;
   - separating the expanded mixed gas stream into a vapor portion and a liquid portion;
   - flowing the vapor portion through at least some of the plurality of heat exchangers to assist in cooling the mixed gas stream; and
   - flowing the liquid portion through the plurality of heat exchangers and subjecting the liquid portion to a plurality of liquid-vapor separation processes, wherein the first liquid-vapor separation process is conducted after flowing the liquid portion through at least one heat exchanger and wherein each subsequent liquid-vapor separation process takes place at a temperature warmer than a previous liquid-vapor separation process.
2. The method according to claim 1, further comprising collecting the vapor portion as a first component stream having an increased level of at least one selected constituent of the multiple constituents of the mixed gas stream as compared to the mixed gas stream.
3. The method according to claim 2, further comprising producing at least a second component stream from the liquid portion, the at least a second component stream having an increased level of at least one selected constituent of the multiple constituents of the mixed gas stream as compared to the mixed gas stream.
4. The method according to claim 3, further comprising providing the mixed gas stream with a composition comprising methane, hydrogen and carbon monoxide and wherein separating the expanded mixed gas stream into a vapor portion and a liquid portion includes separating the vapor portion with an increased concentration of carbon monoxide as compared to the mixed gas stream.
5. The method according to claim 4, wherein producing at least a second component stream further includes producing a stream with an increased concentration of methane.
6. The method according to claim 5, further comprising providing the mixed gas stream at a pressure of approximately 20 pounds pressure per square inch absolute (psia) or greater.
7. The method according to claim 6, wherein expanding the at least a portion of the mixed gas stream includes expanding the at least a portion of the mixed gas stream to a pressure of approximately 15 psia.
8. A gas processing plant comprising:
   - a plurality of heat exchangers;
   - a first flow path configured to convey a fluid stream sequentially through each of the plurality of heat exchangers;
   - an expansion device disposed in the first flow path downstream of the plurality of heat exchangers;
   - a first separation tank coupled with the first flow path downstream of the expansion device;
   - a second flow path configured to convey a vapor stream through the plurality of heat exchangers in a reverse sequential order as compared to the first flow path; and
   - a plurality of additional separation tanks, each of the plurality of separation tanks being disposed between, and in communication with, two different heat exchangers of the plurality of heat exchangers, the plurality of additional separation tanks and the plurality of heat exchangers being located and configured to flow fluid through the plurality of additional separation tanks while increasing the temperature of any fluid flowing therethrough as such fluid progresses from one separation tank of the plurality to another.
9. The gas processing plant of claim 8, further comprising a third flow path configured to convey a liquid stream through the plurality of heat exchangers and the plurality of additional separation tanks in an alternating manner.
10. The gas processing plant of claim 9, further comprising at least one additional flow path configured to convey at least one vapor steam from at least one of the plurality of additional separation tanks through one or more of the plurality of heat exchangers.
11. The gas processing plant of claim 9, further comprising at least a fourth flow path and a fifth flow path, each of the fourth and the fifth flow paths being configured to convey a vapor stream from different ones of the plurality of additional separation tanks to a mixing valve.
12. The gas processing plant of claim 10, further comprising a sixth flow path configured to convey a combined vapor stream from the mixing valve through at least one of the plurality of heat exchangers.
13. The gas processing plant of claim 11, wherein the plurality of heat exchangers includes at least four heat exchangers and wherein the plurality of additional separation tanks includes at least two additional separation tanks.
14. A method of processing a mixed gas stream having multiple constituents, the method comprising:
   - subjecting at least a portion of the mixed gas stream to a first plurality of sequentially conducted gas-liquid separation acts, wherein each of the first plurality of sequentially conducted gas-liquid separation acts is conducted at a reduced temperature as compared to a previously conducted gas-liquid separation act of the first plurality;
   - expanding the at least a portion of the mixed gas stream and further separating the expanded gas stream into a liquid portion and a vapor portion; and
   - subjecting at least a portion of the liquid portion to an additional plurality of sequentially conducted gas-liquid separation acts, wherein each of the additional plurality of sequentially conducted gas-liquid separation acts is conducted at an increased temperature as compared to a previously conducted gas-liquid separation act of the additional plurality of sequentially conducted gas-liquid separation acts of the additional plurality.
15. The method according to claim 14, further comprising:
   - expanding an additional liquid portion produced from at least one of the first plurality of gas-liquid separation acts; and
   - combining the expanded additional liquid portion with the at least a portion of the mixed gas stream subsequent further expanding the at least a portion of the mixed gas stream and prior to further separating the expanded stream into a liquid portion and a vapor portion.
16. The method according to claim 15, further comprising:
   - expanding another liquid portion produced from at least one of the first plurality of gas-liquid separation acts; and
   - combining the liquid portion with the expanded another liquid portion prior to subjecting at least a portion of the liquid portion to an additional plurality of sequentially conducted gas-liquid separation acts.
17. The method according to claim 14, wherein subjecting at least a portion of the mixed gas stream to a first plurality of...
sequentially conducted gas-liquid separation acts further includes flowing the at least a portion of the mixed gas stream through an alternating configuration of a plurality of heat exchangers and a first plurality of separation tanks.

18. The method according to claim 17, wherein subjecting at least a portion of the liquid portion to an additional plurality of sequentially conducted gas-liquid separation acts further includes flowing the at least a portion of the liquid portion through an alternating configuration of the plurality of heat exchangers and another plurality of separation tanks.

19. The method according to claim 14, further comprising providing the mixed gas stream with a composition comprising methane, ethane, propane, hydrogen and carbon monoxide.

20. The method according to claim 19, further comprising providing the mixed gas stream at a pressure of approximately 280 pounds per square inch absolute (psia) or greater.

21. The method according to claim 20, wherein expanding the at least a portion of the mixed gas stream includes expanding the at least a portion of the mixed gas stream to a pressure of approximately 15 psia.

22. A gas processing plant comprising:

- a plurality of heat exchangers;
- a first plurality of separation tanks, each of the first plurality of separation tanks having at least one inlet in communication with one of the plurality of heat exchangers and at least one outlet in communication with another of the plurality of heat exchangers;
- a second plurality of separation tanks, each of the second plurality of separation tanks having at least one inlet in communication with one of the plurality of heat exchangers and at least one outlet in communication with another of the plurality of heat exchangers; and
- an additional separation tank coupled with the first flow path downstream of the plurality of heat exchangers.

23. The gas processing plant of claim 22, further comprising a third flow path configured to convey a fluid stream through the plurality of heat exchangers and a second plurality of separation tanks.

24. The gas processing plant of claim 23, further comprising a fourth flow path configured to flow fluid from one of the first plurality of separation tanks to one of the second plurality of separation tanks.

25. The gas processing plant of claim 24, further comprising another expansion device disposed in the fourth flow path.

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