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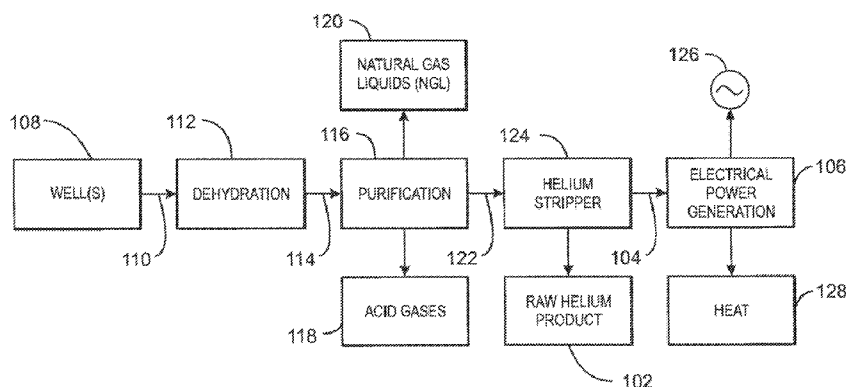
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(54) Title: HELIUM RECOVERY FROM NATURAL GAS STREAMS

100
FIG. 1

(57) Abstract: A system and methods for recovering helium from a natural gas stream are disclosed. The system may include a cold box configured to chill a feed stream and a cryogenic stripper column configured to separate the feed stream into a gaseous top stream and a liquid bottom stream. The gaseous top stream includes an enhanced concentration of helium. A Joule-Thompson (J-T) valve is configured to flash at least a portion of the liquid bottom stream into a first gaseous stream into a heat exchanger in a cold box to chill the feed stream.

HELIUM RECOVERY FROM NATURAL GAS STREAMS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent
5 Application 61/510,854 filed July 22, 2011 entitled HELIUM RECOVERY FROM
NATURAL GAS STREAMS, the entirety of which is incorporated by reference
herein.

FIELD

[0002] The present application is directed to isolating helium from natural gas
10 in a high pressure process.

BACKGROUND

[0003] Helium is the second most abundant chemical in the universe after
hydrogen, and is formed during nuclear fusion of hydrogen in stars. It is an
important industrial gas used in cooling, cryogenics, inert atmospheres, lighting,
15 research, and test labs. However, the total amount of helium on the earth is limited,
as helium escapes into the atmosphere and is lost.

[0004] Almost all terrestrial helium is formed in the subsurface of the earth by
the radioactive decay of other elements, such as uranium, as most decay by the
emission of alpha particles (charged helium nuclei). The helium may collect in
20 natural gas reservoirs in mixtures with other gases, such as methane, hydrogen
sulfide, carbon dioxide, and nitrogen. The helium content of the natural gas may
range in concentration from a few parts-per-million up to several percent. This
helium can be a potentially valuable byproduct of the production of natural gas if it
can be extracted economically.

25 [0005] In the past, many natural gas processors have not isolated the helium,
due to the costs of reaching the very low temperatures required. Helium has a lower
boiling point than any other element, at around -452 °F (-269 °C). By comparison,
methane has a boiling point of about -434 °F (-259 °C) and nitrogen has a boiling
point of about -321 °F (-196 °C). Carbon dioxide has a sublimation point of about
30 minus 108 °F (-78 °C) and does not form a liquid at atmospheric pressure conditions.
Another component that may be found in natural gas, hydrogen sulfide, has a boiling

point of about -76 °F (-60 °C).

[0006] Certain processes for using and shipping natural gas, such as the production of liquefied natural gas (LNG), may generate the temperatures needed to isolate helium. In current helium recovery schemes, the helium is extracted as a vapor from either the liquid methane in an LNG plant, from liquid nitrogen in a nitrogen rejection unit (NRU), or from demethanizer reflux in an NGL recovery plant. All of these processes lower the gas temperature until almost all other components are liquefied, except the helium, nominally about -250 °F (-157 °C) for LNG or NRU, or -150 °F (-101 °C) for an NGL recovery plant. Helium is produced as a vapor byproduct at these conditions. However, there is a need for a process to recover the helium from a gas stream without using a LNG, NRU, or NGL Plant process.

[0007] The government recognized the strategic significance of helium, and advocated conservation and production measures, including more recovery from natural gas streams, in the 1950's and 1960's. For example, as part of this initiative, Guccione, E., "New Approach to Recovery of Helium from Natural Gas," Chem. Engr., Sep. 30, 1963, pp. 76-78, described a plant used to isolate helium from natural gas in the Hugoton field. The Hugoton field ranges from western Kansas through the Oklahoma panhandle and into the panhandle of Texas. After purification of the natural gas to remove CO₂ and H₂S, the plant first condensed heavier hydrocarbons, then nitrogen and methane, resulting in a product stream that was about 65 % helium, and around 35 % nitrogen.

[0008] In this plant, as in LNG plants, a series of phase-change refrigeration steps were used to accomplish the separation. In a first refrigeration step, a closed-loop propane refrigeration cycle chilled the feed to remove pentanes and heavier hydrocarbons. In a second step, a closed-loop methane refrigeration cycle was used in conjunction with a stripper column to generate a rich liquid tail stream having a helium content of about 0.001 mole %. The gaseous product from this stripper column was further chilled by the methane refrigeration cycle and fed into a final stripper column. The final stripper column had a closed-loop nitrogen-cycle chilled stripper in the top section and a methane chiller in the bottom section. The gas from this column provided the helium enhanced product stream.

[0009] The plant described by Guccione was quite complex, using three

distinct refrigeration cycles. Each of these cycles used its own refrigerant and compressors, i.e., a propane refrigeration cycle, a methane refrigeration cycle, and a nitrogen refrigeration cycle. Similar cycles are often used to achieve the temperatures needed for LNG production, which can form helium rich product streams as a by-product.

[0010] Similar systems were discussed by Wilson, R.W., and Newsom, H.R., "Helium: Its Extraction and Purification," J. Petrol. Tech., 20, pp. 341-344 (1968), who disclosed general considerations for the design of the cryogenic plants, intended to isolate raw helium from natural gas. Generally, these helium recovery plants generally use a number of closed loop refrigeration cycles based on refrigerants such as propane, methane, and nitrogen.

[0011] A few systems have been proposed for stripping helium from natural gas without extensive closed-loop refrigeration cycles. For example, U.S. Patent No. 5,011,521 to Gottier, et al., discloses a low pressure stripping process for the production of crude helium. The process may prefractionate a pressurized, helium-containing feed gas mixture, which may contain helium, natural gas, and nitrogen, to produce a helium-enriched stream having a helium content of > 30 vol. % helium. The process includes liquefying and subcooling the pressurized, helium-containing feed gas mixture by indirect heat exchange. The liquefied and subcooled feed gas mixture is expanded to produce a partially vaporized fractionation feed stream. The partially vaporized fractionation feed stream is stripped in a cryogenic distillation column, thereby producing a helium-enriched stream, and a bottoms liquid. The cryogenic distillation column is reboiled by vaporizing at least a portion of the helium-lean stream. However, the process depends on subcooling to achieve complete liquefaction, which may not be possible as the helium concentration increases.

[0012] To prepare a natural gas stream for helium removal, a number of techniques may be used to separate acid gases, such as CO₂, H₂S, and other components from the natural gas stream. For example, U.S. Patent No. 5,335,504 to Durr, et al., discloses a process for recovering carbon dioxide from a natural gas stream. The process may be used to recover CO₂ that has been injected for enhanced oil recovery. The process is based on a cryogenic distillation column, but does not reach the temperatures necessary to substantially enhance a concentration

of helium.

[0013] Further, U.S. Patent No. 4,318,723 to Holmes discloses a cryogenic distillative separation of acid gases from methane, hereinafter termed the “Ryan-Holmes Process.” The Ryan-Holmes Process is a method of eliminating solids
5 formation during a cryogenic distillative separation of acid gases from methane. The method includes adding an agent to control solids formation to a zone of a distillation column at which solids formation may occur. Typical agents are C₂-C₅ alkanes or other nonpolar liquids which are miscible with methane at the column conditions. Preventing the formation of solids permits a more complete separation to be
10 achieved.

[0014] Another technique for cryogenic purification of natural gas is provided in International Patent Application Publication No. WO/2008/091316, which discloses a controlled freeze zone (CFZ) tower. The controlled freeze zone tower is a cryogenic distillation tower which allows for the separation of a fluid stream
15 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
20 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
25 internal components are provided to improve heat transfer and to facilitate the breakout of methane gas.

[0015] In addition to the newer cryogenic techniques, numerous techniques have traditionally been used to prepare natural gas for marketing to customers. Collectively, these techniques are referred to herein as “warm gas processing.” In
30 warm gas processing, the raw gas is processed to remove acid gases, such as hydrogen sulfide and carbon dioxide. This was historically performed by amine treatment, in which an amine reacts with the acid gas. When exhausted, the amine

may be regenerated to remove the acid gas. More recently, newer technology has been developed, based on the use of polymeric membranes to separate carbon dioxide and hydrogen sulfide from a natural gas stream.

[0016] The acid gases can then be routed into a sulfur recovery unit which
5 converts the hydrogen sulfide in the acid gas into sulfur products, such as elemental sulfur or sulfuric acid. After removal of the acid gases, water vapor can be removed, using any number of methods.

[0017] Other components may be removed from the remaining product, such as mercury, and natural gas liquids. This produces a gas that may have methane
10 blended with a number of inert and hydrocarbon components, including nitrogen and helium, among others. Higher carbon number components, such as C_2S and higher, may be removed and marketed separately as natural gas liquids (NGL), liquid propane gas (LPG), and the like.

[0018] The techniques described above do not provide for generation of a
15 product stream having a substantially enhanced helium concentration. However, these techniques may provide a gas stream that can be used as a source feed to a helium separator.

SUMMARY

[0019] An embodiment provides a method for removing helium from natural
20 gas (LNG). The method includes flowing a compressed natural gas stream through a cold box to condense liquids. The cooled stream is metered into a cryogenic stripper column and a raw helium product is removed from the top of the cryogenic stripper column. A liquid product stream is removed from the bottom of the cryogenic stripper column. The temperature in the cold box is controlled by flashing
25 a first portion of the liquid product stream into the cold box to form a first flash gas stream, flashing a second portion of the liquid product stream into the cold box to form a second flash gas stream, and controlling the ratio of the first portion to the second portion to adjust the temperature in the cold box.

[0020] The raw helium product may be fed through the cold box to provide
30 further cooling. Further, the raw helium product may be fed through a cryogenic concentrator to increase the helium concentration. After concentration, the raw helium product may be provided to a marketplace through a pipeline.

[0021] In an embodiment, the first flash gas stream may be compressed to substantially match a pressure of the second flash gas stream, and the two streams may be combined. The combined stream can be compressed to form a product stream. The product stream may include a low BTU natural gas, which may be used to generate electrical power.

[0022] Another embodiment provides a system for recovering helium from a natural gas stream. The system includes a cold box configured to chill a feed stream and a cryogenic stripper column configured to separate the feed stream into a gaseous top stream and a liquid bottom stream, wherein the gaseous top stream comprises an enhanced concentration of helium. A Joule-Thompson (J-T) valve may be configured to flash at least a portion of the liquid bottom stream into a first gaseous stream into a heat exchanger in a cold box to chill the feed stream.

[0023] The system may include a cryogenic distillation, such as a Ryan-Holmes cryogenic distillation, for example, to supply an initial feed stream. Further, the system may include a warm-gas processing plant to supply the feed stream.

[0024] A helium concentrator may be included in the system to increase the concentration of the helium product. The helium concentrator may include a second cold box configured to chill an overhead gas stream from a cryogenic stripper column to form a second chilled stream and a J-T valve configured to flash the second chilled stream to form a two phase stream. A separation vessel may be configured to separate gas and liquid components from the two phase stream.

[0025] The system may include a product heat exchanger configured to chill plant streams in a cryogenic purification plant using cold from the liquid bottom stream. A second J-T valve may be configured to flash a second portion of the liquid bottoms stream into a second gaseous stream, wherein the ratio of the flows through the J-T valve and the second J-T valve can be used to control the temperature of the cold box.

[0026] The system may include a compressor to boost the pressure of the first gaseous stream to a sales pressure. A compressor may also be used to boost the pressure of the second gaseous stream to match a pressure of the first gaseous stream. An electrical generation plant may be configured to burn the first gaseous stream as a low-BTU natural gas fuel.

[0027] Another embodiment provides a method for using low-BTU natural gas from a field. The method includes harvesting the low-BTU natural gas from a well, dehydrating the low-BTU natural gas to remove at least a portion of any water vapor present, and removing at least a portion of any natural gas liquids present from the low-BTU natural gas. Acid gases may be removed from the low-BTU natural gas and at least a portion of helium may be removed from the low-BTU natural gas in a cryogenic stripper column, wherein the energy to lower the temperature for the helium removal is provided by flashing at least a portion of a liquid bottoms stream from the cryogenic stripper column through a cold box. After removal of the helium, the low-BTU natural gas may be provided to customers, such as power plants.

[0028] The temperature of the cold box may be adjusted by controlling a ratio between two portions of the liquid bottoms stream that are each being flashed, wherein one portion is flashing at a first pressure, and another portion is flashing at a lower pressure. A further portion of the helium may be removed from the low-BTU natural gas using a helium concentrator.

DESCRIPTION OF THE DRAWINGS

[0029] The advantages of the present techniques are better understood by referring to the following detailed description and the attached drawings, in which:

[0030] Fig. 1 is a block diagram of a system that generates a raw helium stream and provides the remaining gas as a product stream;

[0031] Fig. 2 is a block diagram of a helium stripper;

[0032] Fig. 3 is a drawing of a system that can use a helium stripper to generate a raw helium stream from the overhead gas from a cryogenic separation process;

[0033] Fig. 4 is a drawing of a system that uses a helium concentrator in addition to the helium stripper;

[0034] Fig. 5 is a diagram of a system that uses a helium stripper to generate a helium product stream from a gas stream provided from a warm gas processing plant;

[0035] Fig. 6 is a plot of a CO₂ freezing curve; and

[0036] Fig. 7 is a block diagram of a method for extracting helium from a

natural gas stream, for example, using the systems described with respect to Figs. 1-5.

DETAILED DESCRIPTION

[0037] In the following detailed description section, specific embodiments of the present techniques are described. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the techniques are not limited to the specific embodiments described below, but rather, include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0038] At the outset, for ease of reference, certain terms used in this application and their meanings as used in this context are set forth. To the extent a term used herein is not defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Further, the present techniques are not limited by the usage of the terms shown below, as all equivalents, synonyms, new developments, and terms or techniques that serve the same or a similar purpose are considered to be within the scope of the present claims.

[0039] “Acid gases” are contaminants that are often encountered in natural gas streams. Typically, these gases include carbon dioxide and hydrogen sulfide, although any number of other contaminants may also form acids. Acid gases are commonly removed by contacting the gas stream with an absorbent, such as an amine, which may react with the acid gas. When the absorbent becomes acid-gas “rich,” a desorption step can be used to separate the acid gases from the absorbent. The “lean” absorbent is then typically recycled for further absorption.

[0040] “Cold box” refers to an insulated enclosure which encompasses sets of process equipment such as heat exchangers, columns, and phase separators. Such sets of process equipment may form the whole or part of a given process.

[0041] “Compressor” refers to a device for compressing a working gas, including gas-vapor mixtures or exhaust gases, and includes pumps, compressor turbines, reciprocating compressors, piston compressors, rotary vane or screw

compressors, and devices and combinations capable of compressing a working gas.

[0042] “Cryogenic distillation” has been used to separate carbon dioxide from methane since the relative volatility between methane and carbon dioxide is reasonably high. The overhead vapor is enriched with methane and the bottoms product is enriched with carbon dioxide and other heavier hydrocarbons. Cryogenic distillation processing requires the proper combination of pressure and temperature to achieve the desired product recovery.

[0043] The term “gas” is used interchangeably with “vapor,” and means a substance or mixture of substances in the gaseous state as distinguished from the liquid or solid state. Likewise, the term “liquid” means a substance or mixture of substances in the liquid state as distinguished from the gas or solid state.

[0044] “Heat exchanger” refers to any column, tower, unit or other arrangement adapted to allow the passage of one or more streams and to affect direct or indirect heat exchange between one or more lines of refrigerant, and one or more feed streams. Examples include a tube-in-shell heat exchanger, a cryogenic spool-wound heat exchanger, or a brazed aluminum-plate fin type, among others.

[0045] A “hydrocarbon” is an organic compound that primarily includes the elements hydrogen and carbon, although nitrogen, sulfur, oxygen, metals, or any number of other elements may be present in small amounts. As used herein, hydrocarbons generally refer to organic materials that are harvested from hydrocarbon containing sub-surface rock layers, termed reservoirs. For example, natural gas is primarily composed of the hydrocarbon methane.

[0046] “Liquefied natural gas” or “LNG” is a cryogenic liquid form of natural gas generally known to include a high percentage of methane, but may also include trace amounts of other elements and/or compounds including, but not limited to, ethane, propane, butane, carbon dioxide, nitrogen, helium, hydrogen sulfide, or combinations thereof. The natural gas may have been processed to remove one or more components (for instance, helium) or impurities (for instance, water and/or heavy hydrocarbons) and then condensed into the liquid at almost atmospheric pressure by cooling.

[0047] The term “natural gas” refers to a multi-component gas obtained from a crude oil well (associated gas) or from a subterranean gas-bearing formation (non-

associated gas). The composition and pressure of natural gas can vary significantly. A typical natural gas stream contains methane (C₁) as a significant component. Raw natural gas will also typically contain ethane (C₂), higher molecular weight hydrocarbons, one or more acid gases (such as carbon dioxide, hydrogen sulfide, carbonyl sulfide, carbon disulfide, and mercaptans), and minor amounts of contaminants such as water, helium, nitrogen, iron sulfide, wax, and crude oil.

[0048] Low-BTU natural gas indicates a natural gas with a BTU content that is generally lower than commercial standards for pipeline service, e.g., less than about 1000 BTU per standard cubic foot. While low-BTU natural gas can be upgraded to match pipeline gas standards, it may not be economically practical. For this reason, low-BTU natural gas reservoirs were often not harvested in the past. However, low-BTU natural gas can be used to fire power plants, upgrading the energy to electricity.

[0049] A "Joule-Thomson (J-T) valve" refers to a device for expanding a stream, thereby reducing its temperature. A J-T valve utilizes the Joule-Thomson principle that expansion of gas will result in an associated cooling of the gas. In various embodiments described herein, a J-T valve may be substituted by other expansion devices, such as turbo-expanders, and the like.

[0050] "Pressure" is the force exerted per unit area by the gas on the walls of the volume. Pressure can be shown as pounds per square inch (psi). "Atmospheric pressure" refers to the local pressure of the air. "Absolute pressure" (psia) refers to the sum of the atmospheric pressure (14.7 psia at standard conditions) plus the gage pressure (psig). "Gauge pressure" (psig) refers to the pressure measured by a gauge, which indicates only the pressure exceeding the local atmospheric pressure (i.e., a gauge pressure of 0 psig corresponds to an absolute pressure of 14.7 psia). The term "vapor pressure" has the usual thermodynamic meaning. For a pure component in an enclosed system at a given pressure, the component vapor pressure is essentially equal to the total pressure in the system.

[0051] A "separation vessel" is a vessel wherein an incoming two phase feed is separated into individual vapor and liquid fractions. Typically, the vessel has sufficient cross-sectional area so that the vapor and liquid are separated by gravity.

[0052] "Substantial" when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to an amount that is sufficient to

provide an effect that the material or characteristic was intended to provide. The exact degree of deviation allowable may in some cases depend on the specific context.

Overview

5 [0053] As discussed above, current techniques for the isolation of helium from natural gas streams generally use multiple closed-loop refrigeration systems, e.g., cascaded refrigeration systems, to chill feed streams down to cryogenic temperatures and condense out materials. This can add significant cost and complexity to a natural gas purifications system. In gas streams requiring nitrogen
10 separation, such as feed streams for LNG production, it may be practical to include a helium removal step. However, in fields having low BTU natural gas that can be directly used for power generation without Nitrogen removal, it may not be economical to isolate the helium.

[0054] Embodiments described herein provide a system and methods for
15 generating an enriched helium stream from a natural gas stream without the use of separate closed loop cooling systems. The systems and methods take advantage of the energy provided by compression to chill a gas stream in one or more cool boxes.

[0055] Fig. 1 is a block diagram of a system **100** that generates a raw helium product **102** and provides the remaining gas as a product stream **104**. The gas may,
20 for example, be used to power an electrical generation plant **106**. The system **100** is not limited to the blocks shown, but may include any number of configurations, including, for example, providing the product stream **104** to other customers through a commercial pipeline.

[0056] In the system **100**, one or more production wells **108** can be used to
25 produce a raw natural gas stream **110**. In some embodiments, the raw natural gas stream may include a substantial amount of nitrogen, and have a low-BTU content, e.g., between about 500 and 950 BTUs per standard cubic foot.

[0057] The raw natural gas stream **110** can be fed to a dehydration unit **112** in which water vapor may be removed using glycol dehydration, desiccants, or a
30 Pressure Swing Adsorption (PSA) unit, among other processes. The dehydration unit **112** is not limited to following production as shown.

[0058] The dehydrated stream **114** may be fed to a purification system **116**,

which may use any number of processes to remove acid gases **118** and other contaminants. In some embodiments, the purification system **116** may precede the dehydration unit **112**. The purification unit may be a cryogenic distillation unit, such as a Ryan-Holmes process. Other cryogenic distillation techniques may be used, such as the controlled freeze zone (CFZ) technology available from ExxonMobil, discussed in International Patent Application Publication No. WO/2008/091316, herein included by reference in its entirety. Non-cryogenic techniques may also be used for purification, such as a warm gas processing system.

[0059] The acid gases **118** from the purification may be marketed. For example, a CO₂ stream may be sold for enhanced oil recovery or a H₂S stream may be used to produce sulfur using the Claus process. In addition to removing acid gases **118**, the purification system **116** may also remove higher carbon number hydrocarbons, e.g., C₂S and higher. The higher carbon number hydrocarbons may be condensed to form an NGL stream **120**, among others, which may also be marketed as a product.

[0060] The resulting feed gas stream **122** may be a mixture of methane and various inert gases, such as nitrogen and helium. Previously, this feed gas stream **122** was directly used as a low BTU natural gas stream, for example, in electric power generation. This saved the cost of removing nitrogen and other components. As described herein, however, the helium may be a valuable side product that can be recovered and marketed. Accordingly, the feed gas stream **122** may be fed as an input to a helium stripper **124**. Depending on the purification system **116** used, the feed gas stream **122** may be a cold stream or a warm stream. In either case, the feed gas stream **122** can be at high pressure. In some embodiments, additional compression and cooling steps may be used to boost the inlet pressure to the helium stripper **124**.

[0061] The helium stripper **124** generates the raw helium product **102**. In various embodiments, the raw helium product **102** may be about 20 mole % helium, or higher. The raw helium product **102** may be sold as is, or may be used as a feed to another purification process to generate a final helium product, for example, having a helium concentration of 99 % or higher. Removal of the raw helium product **102** produces a product stream **104** that may include nitrogen and methane.

[0062] Depending on the nitrogen content, the product stream **104** may be considered a low BTU natural gas that can be used, for example, as fuel for an electrical generation plant **106**. The electrical generation plant **106** may provide other, higher value, products for sale, including electrical power **126** to a power grid, heat **128** for other processes, or both. In some embodiments, the electrical generation plant **106** may purchase the product stream **104** from a pipeline associated with the producer.

[0063] Fig. 2 is a block diagram of the helium stripper **124**. As used herein, the term "helium stripper" includes all equipment used to generate a helium enhanced product stream, including any cold boxes, stripper columns, or additional helium concentrators. In the helium stripper **124**, the feed gas stream **122** is first chilled in a cold box **202** under pressure to liquefy almost all of the gas stream, forming a cooled stream **204**. In some embodiments, the feed gas **122** may be a compressed cold stream from a cryogenic distillation, such as a CFZ or a Ryan-Holmes process. In other embodiments, the feed gas **122** may be provided from a warm gas processing plant. If the feed gas **122** is not at a sufficiently high pressure, such as the pressure discussed with respect to the examples, one or more compressors may be placed in the feed gas **122** prior to the helium stripper **124**. The compressed feed may be passed through a heat exchanger prior to the helium stripper **124** to remove the heat from the compression.

[0064] The cooled stream **204** can then be fed into a cryogenic stripper column **206**. The cooled stream **204** may be metered into the column by a flow control valve **208**, such as a diaphragm motor valve (DMV) or a globe valve. In various embodiments described herein, the flow control valve **208** is merely used for controlling flow into the cryogenic stripper column **206** and not for temperature control. The overhead vapor stream **210** from the cryogenic stripper column **206** can be controlled by the stripper reboiler duty **212** to maximize helium recovery and the helium concentration in the vapor stream **210**. The stripper reboiler duty **212** may assist in chilling the feed gas stream **122** in the cold box **202**. The remaining feed gas cooling duty in the cold box **202** may be provided by heating the overhead vapor stream **210** to form the raw helium product **102** stream and by vaporizing the liquid product stream **214** from the bottom of the cryogenic stripper column **206**.

[0065] The temperature control of the cold box **202** may be provided by one or more Joule-Thompson (J-T) valves **216** and **218** on the liquid product stream **214**. As the liquid product stream **214** flashes across the J-T valves **216** and **218** and into the cold box **202**, heat energy may be removed from the cold box **202**. In an embodiment, a first J-T valve **216** may allow a larger pressure drop than a second J-T valve **218**, wherein the balance in flow between the two J-T valves **216** and **218** can be used to control the temperature in the cold box **202**. The difference in pressure drops results in the formation of two flash gas streams **220** and **222**.

[0066] The first flash gas stream **220** may be at a lower pressure than the second flash gas stream **222** and can be compressed in a first compressor stage **224** to be brought to the same pressure as the second flash gas stream **222**. The two flash gas streams **220** and **222** may then be combined and flowed through a second compressor stage **226** to achieve a final sales pressure for the product stream **104**. Since the gas liquefier, e.g., the cold box **202**, operates at higher pressure, the temperature required to liquefy the gas stream can be warmer than in either a LNG process or in an NRU. This makes the helium stripper **124** more tolerant to higher CO₂ or H₂O levels than either an LNG process or an NRU process.

[0067] In an embodiment a helium concentrator may be placed on the overhead vapor stream **210** after the cryogenic stripper column **206**, as discussed with respect to Fig. 4. The helium concentrator may provide a higher concentration on helium in the overhead vapor stream **210**. However, the addition of the helium concentrator may make the helium stripper **124** more susceptible to fouling from carbon dioxide. Thus, the use of a helium concentrator would require lower CO₂ levels, comparable to an NRU.

[0068] Further embodiments are described in the following Embodiments:

Embodiment 1: A method for removing helium from natural gas (LNG), comprising: flowing a compressed natural gas stream through a cold box to condense liquids; metering the cooled stream into a cryogenic stripper column;

removing a raw helium product from the top of the cryogenic stripper column; and

removing a liquid product stream from the bottom of the cryogenic stripper column, wherein the temperature in the cold box is controlled by:

flashing a first portion of the liquid product stream into the cold box to form a first flash gas stream;

flashing a second portion of the liquid product stream into the cold box to form a second flash gas stream; and

- 5 controlling the ratio of the first portion to the second portion to adjust the temperature in the cold box.

Embodiment 2: The method of Embodiment 1, comprising feeding the raw helium product through the cold box to provide further cooling.

- Embodiment 3: The method of Embodiment 1 or 2, comprising feeding the raw
10 helium product through a cryogenic concentrator to increase the helium concentration.

Embodiment 4: The method of any of Embodiments 1-3, comprising:

compressing the first flash gas stream to substantially match a pressure of the second flash gas stream;

- 15 combining the first flash gas stream and the second flash gas stream to form a combined stream; and

compressing the combined stream to form a product stream.

Embodiment 5: The method of any of Embodiments 1-4, comprising producing a product stream comprising a low BTU natural gas.

- 20 Embodiment 6: The method of any of Embodiments 1-5, comprising generating electrical power from the product stream.

Embodiment 7: The method of any of Embodiments 1-6, comprising providing the raw helium product to a marketplace through a pipeline.

- Embodiment 8: A system for recovering helium from a natural gas stream,
25 comprising:

a cold box configured to chill a feed stream;

a cryogenic stripper column configured to separate the feed stream into a gaseous top stream and a liquid bottom stream, wherein the gaseous top stream comprises an enhanced concentration of helium; and

- 30 a Joule-Thompson (J-T) valve configured to flash at least a portion of the liquid bottom stream into a first gaseous stream into a heat exchanger in a cold box to chill the feed stream.

Embodiment 9: The system of Embodiment 8, comprising a cryogenic distillation.

Embodiment 10: The system of Embodiment 8 or 9, comprising a Ryan-Holmes cryogenic distillation.

Embodiment 11: The system of any of Embodiments 8-10, comprising a warm-gas processing plant.

5 Embodiment 12: The system of any of Embodiments 8-11, comprising a helium concentrator, wherein the helium concentrator comprises:

a second cold box configured to chill an overhead gas stream from a cryogenic stripper column to form a second chilled stream;

10 a J-T valve configured to flash the second chilled stream to form a two phase stream; and

a separation vessel configured to separate gas and liquid components from the two phase stream.

Embodiment 13: The system of any of Embodiments 8-12, comprising a product heat exchanger configured to chill plant streams in a cryogenic purification plant
15 using cold from the liquid bottom stream.

Embodiment 14: The system of any of Embodiments 8-13, comprising a second J-T valve configured to flash a second portion of the liquid bottoms stream into a second gaseous stream, wherein the ratio of the flows through the J-T valve and the second J-T valve is used to control the temperature of the cold box.

20 Embodiment 15: The system of any of Embodiments 8-14, comprising a compressor configured to boost the pressure of the first gaseous stream to a sales pressure.

Embodiment 16: The system of Embodiment 14 or 15, comprising a compressor configured to boost the pressure of the second gaseous stream to match a pressure of the first gaseous stream.

25 Embodiment 17: The system of any of Embodiments 8-16, comprising an electrical generation plant configured to burn a low-BTU natural gas comprising at least the first gaseous stream.

Embodiment 18: A method for using low-BTU natural gas from a field, comprising:

30 harvesting a low-BTU natural gas from a well;
dehydrating the low-BTU natural gas to remove at least a portion of a water vapor;

removing at least a portion of natural gas liquids from the low-BTU natural gas;

removing at least a portion of acid gases from the low-BTU natural gas;

removing at least a portion of helium from the low-BTU natural gas in a cryogenic stripper column, wherein the energy to lower a temperature for the helium removal is provided by flashing at least a portion of a liquid bottoms stream from the cryogenic stripper column through a cold box; and

providing the low-BTU natural gas to customers.

Embodiment 19: The method of Embodiment 18, comprising adjusting the temperature of the cold box by controlling a ratio between two portions of the liquid bottoms stream that are each being flashed, wherein one portion is flashing at a first pressure, and another portion is flashing at a lower pressure.

Embodiment 20: The method of Embodiment 18 or 19, comprising removing a further portion of the helium from the low-BTU natural gas using a helium concentrator.

Examples

Three embodiments are discussed with respect to Figs. 3, 4, and 6. The two examples, discussed with respect to Figs. 3 and 4, can be used to recover helium from feed provided by a cryogenic distillation, such as a Ryan-Holmes or CFZ process. The second example, discussed with respect to Fig. 4, includes a helium concentrator to provide a higher concentration helium stream, but requires a lower feed gas CO₂ level. The third example, discussed with respect to Fig. 6, can be used to recover helium from a warm gas processing feed, such as from a solvent process or an NGL Recovery Plant, having an elevated CO₂ level. In an embodiment, a helium concentrator, as discussed with respect to Fig. 4, can also be added to the system shown in Fig. 6.

Fig. 3 is a drawing of a system **300** that can use a helium stripper **124** to generate a raw helium stream from the overhead gas from a cryogenic separation process. Like numbered items are as discussed with respect to Figs. 1 and 2. Simulated process data for the system **300** at each of the points labeled with a diamond is shown in Table 1.

Table 1: Process Data for Example Shown in Fig. 3

	3-1	3-2	3-3	3-4	3-5	3-6	3-7
Temperature -°F	-151.4	-197.1	-197.5	-196.5	-166.8	-160.5	-172.5
Temperature -°C	-101.9	-127.3	-127.5	-126.9	-110.4	-106.9	-113.6
Pressure - psia	590.0	580.0	560.0	560.0	570.0	555.0	343.2
Flowrate (MMSCFD)	276.9	276.9	276.9	27.3	249.6	27.3	197.2
Methane Mole Fraction	0.69804	0.69804	0.69804	0.28907	0.74272	0.28907	0.74272
Nitrogen Mole Fraction	0.28029	0.28029	0.28029	0.49130	0.25724	0.49130	0.25724
CO ₂ Mole Fraction	0.00002	0.00002	0.00002	0.00000	0.00002	0.00000	0.00002
Helium Mole Fraction	0.02165	0.02165	0.02165	0.21963	0.00002	0.21963	0.00002
	3-8	3-9	3-10	3-11			
Temperature -°F	-160.5	86.5	86.5	182.3			
Temperature -°C	-106.9	30.3	30.3	83.5			
Pressure - psia	200.0	542.5	187.5	491.7			
Flowrate (MMSCFD)	52.4	27.3	52.4	249.6			
Methane Mole Fraction	0.74272	0.28907	0.74272	0.74272			
Nitrogen Mole Fraction	0.25724	0.49130	0.25724	0.25724			
CO ₂ Mole Fraction	0.00002	0.00000	0.00002	0.00002			
Helium Mole Fraction	0.00002	0.21963	0.00002	0.00002			

[0071] In this example, a portion of the cold is recovered in a product heat exchanger **302** that may remove heat from various other streams in the cryogenic distillation process, upstream of the helium stripper **124**. The liquid product stream **214** from the cryogenic stripper column **206** can be flashed through two J-T valves **216** and **218**, as described with respect to Fig. 2. The flashed vapor streams **304** and **306** are used to cool the cold box **202** before flowing through the product heat exchanger **302**. The resulting flash gas streams **220** and **222** may then be compressed and combined as discussed with respect to Fig. 2. Similarly, the overhead vapor stream **210** assists in cooling the cold box **202**, forming a warmed product stream **308**, which is flowed through the product heat exchanger **302** to assist in cooling other streams. The product heat exchanger **302** may be integrated into the cold box **202** to form a single cold box.

[0072] Fig. 4 is a drawing of a system **400** that uses a helium concentrator **402** in addition to the helium stripper **124**. Like numbered items are as discussed

with respect to Figs. 1, 2, and 3. Simulated process data for the system **400** at each of the points labeled with a diamond is shown in Table 2.

[0073] In the system **400**, the helium concentrator **402** may increase the concentration of the helium in the raw helium product **102** to around 50 %. The
5 helium concentrator **402** includes a second cold box **404**. The overhead stream **406** from the cryogenic stripper column **206** is passed through the second cold box **404** to further chill the overhead stream **406** and condense more liquids.

[0074] The condensed stream **408** is flashed across a J-T valve **410**, and the two phase flow **412** is fed into a separation vessel **414**. In the separation vessel **414**,
10 the helium concentrator liquid **416** from the bottom of the separation vessel **414** is fed through a pump **418** to return the helium concentrator liquid **416** through the second cold box **404** to assist in chilling the second cold box **404**. The resulting warmed stream **420** is joined with the liquid product stream **214**, for example, after the first J-T valve **216**.

15 [0075] The gas stream **422** from the top of the separation vessel **414** is flowed back through the second cold box **404** to assist in chilling the overhead stream **406**, forming a warmed stream **424**. The warmed stream **424** is passed through the cold box **202** to assist in chilling the feed gas **122**, prior to being fed to the product heat exchanger **302** as warmed product stream **308**, which exits as the raw helium
20 product **102**.

Table 2: Process Data for Example Shown in Fig. 4

	4-1	4-2	4-3	4-4	4-5	4-6	4-7
Temperature -°F	-151.4	-197.1	-197.5	-196.5	-263.8	-288.6	-288.6
Temperature -°C	-101.9	-127.3	-127.5	-126.9	-164.3	-178.1	-178.1
Pressure – psia	590.0	580.0	560.0	560.0	550.0	100.0	100.0
Flowrate (MMSCFD)	276.9	276.9	276.9	27.3	27.3	27.3	12.3
Methane Mole Fraction	0.69804	0.69804	0.69804	0.28907	0.28907	0.28907	0.02223
Nitrogen Mole Fraction	0.28029	0.28029	0.28029	0.49130	0.49130	0.49130	0.49415
CO ₂ Mole Fraction	0.00002	0.00002	0.00002	0.00000	0.00000	0.00000	0.00000
Helium Mole Fraction	0.02165	0.02165	0.02165	0.21963	0.21963	0.21963	0.48362
	4-8	4-9	4-10	4-11	4-12	4-13	4-14
Temperature -°F	-287.7	-210.8	-210.8	-172.5	-168.6	191.9	86.5
Temperature -°C	-177.6	-134.9	-134.9	-113.6	-111.4	88.8	30.3
Pressure – psia	195.0	190.0	95.0	343.2	185.0	491.7	77.5
Flowrate (MMSCFD)	14.9	14.9	12.3	198.7	65.9	264.6	12.3
Methane Mole Fraction	0.50938	0.50938	0.02223	0.74272	0.68980	0.72954	0.02223
Nitrogen Mole Fraction	0.48894	0.48894	0.49415	0.25724	0.30979	0.27032	0.49415
CO ₂ Mole Fraction	0.00000	0.00000	0.00000	0.00002	0.00002	0.00002	0.00000
Helium Mole Fraction	0.00168	0.00168	0.48362	0.00002	0.00040	0.00012	0.48362

[0076] Fig. 5 is a diagram of a system **500** that uses a helium stripper **124** to generate a helium product stream **102** from a gas stream provided from a warm gas processing plant. Like numbered items are as discussed with respect to Figs. 1 and 2. Simulated process data for this system **500** is shown in Table 3. As can be seen from column 5-1, the temperature of the feed gas stream **122** is much higher at about 100 °F (37.8 °C) than for the embodiments shown in Figs. 3 and 4, which both have a feed gas stream **122** at a temperature of -151.4 °F (-101.9 °C).

Table 3: Process Data for Example Shown in Fig. 5.

	5-1	5-2	5-3	5-4	5-5	5-6	5-7
Temperature -°F	100.0	-197.1	-197.5	-196.5	-166.8	88.3	88.3
Temperature -°C	37.8	-127.3	-127.5	-126.9	-110.4	31.3	31.3
Pressure – psia	590.0	580.0	560.0	560.0	570.0	555.0	328.3
Flowrate (MMSCFD)	276.9	276.9	276.9	27.3	249.6	27.3	197.2
Methane Mole Fraction	0.69804	0.69804	0.69804	0.28907	0.74272	0.28907	0.74272
Nitrogen Mole Fraction	0.28029	0.28029	0.28029	0.49130	0.25724	0.49130	0.25724
CO ₂ Mole Fraction	0.00002	0.00002	0.00002	0.00000	0.00002	0.00000	0.00002
Helium Mole Fraction	0.02165	0.02165	0.02165	0.21963	0.00002	0.21963	0.00002
	5-8	5-9	5-10				
Temperature -°F	88.3	108.1	182.4				
Temperature -°C	31.3	42.3	83.6				
Pressure – psia	200.0	328.3	491.7				
Flowrate (MMSCFD)	52.4	249.6	249.6				
Methane Mole Fraction	0.74272	0.74272	0.74272				
Nitrogen Mole Fraction	0.25724	0.25724	0.25724				
CO ₂ Mole Fraction	0.00002	0.00002	0.00002				
Helium Mole Fraction	0.00002	0.00002	0.00002				

[0077] The system **500** may be used with a helium concentrator as described with respect to Fig. 4. The helium concentrator will increase the concentration of the helium in the helium product stream **102**, but may increase the sensitivity of the system **500** to fouling from CO₂ in the feed gas stream **122**, as discussed with respect to Fig. 6.

[0078] Fig. 6 is a plot **600** of a CO₂ freezing curve **602**. The x-axis **604** represents the temperature of the system in deg. F, while the y-axis **606** represents the concentration of the CO₂ on a logarithmic scale. The CO₂ freezing curve **602** divides the graph into two zones **608** and **610**. The first zone **608** represents conditions under which solid CO₂ will form, while the second zone **610** represents conditions under which solid CO₂ will not form. The embodiments discussed with respect to Figs. 3 and 5 utilize a minimum fluid temperature **612** of about -197.5 °F (-127.5 °C) in the cryogenic stripper column **206** for raw helium extraction. This

corresponds to a maximum CO₂ content **614** in the liquid product stream **214** from the bottom of the cryogenic stripper column **206** of about 0.415 mol% before the formation of solid CO₂ in the cryogenic stripper column **206**.

[0079] In contrast, the embodiment discussed with respect to Fig. 4, using the
5 helium concentrator **402**, utilizes a minimum fluid temperature **616** of about -288.6 °F (-178.1 °C). This corresponds to a maximum CO₂ content **618** of about 0.00029 mol% CO₂ (3 ppmv) in the helium concentrator liquid **416**, corresponding to about 25 ppmv in the feed gas.

Method for Extracting Helium

10 [0080] Fig. 7 is a block diagram of a method **700** for extracting helium from a natural gas stream, for example, using the systems described with respect to Figs. 1-5. The method **700** starts at block **702** where the compressed feed gas is flowed through a cold box to chill the stream and condense out liquids. Depending on the content of helium and other non-condensable gases, the chilled stream may be a
15 two phase flow.

[0081] At block **704**, the chilled stream can be metered into a cryogenic stripper column. The metering is performed to control the flow into the column and adjust the composition of the materials coming from the column. Accordingly, this does not have to be a J-T valve or other pressure drop. The column remains under
20 high pressure, which may help to prevent fouling from CO₂ solid formation.

[0082] At block **706** a helium enriched fraction can be removed from the top or gas phase of the cryogenic stripper column as shown in Figs. 3 and 5, or the top of a helium concentrator and shown in Fig. 4. As discussed with respect to the examples above, the concentration of helium may range from about 20 mole fraction to about
25 50 mole fraction. As block **708**, the helium enriched stream may be run through various cold boxes to chill a feed stream, such as the cold box **202** used to chill a feed stream to the cryogenic stripper column **206** and the second cold box **404** (Fig. 4) used to chill a feed stream to a separation vessel **414**. At block **710**, the helium enriched stream may be sent out as a product stream, for example, to a cryogenic
30 purification plant used to generate high purity helium (> 99.9 %).

[0083] At block **712**, a liquid stream is removed from the bottom of the cryogenic stripper column, or both the cryogenic stripper column and a separation

vessel in a helium concentrator. At block **714**, the liquid stream may be flashed through one or more J-T valves to control a temperature in a cold box. The flashing may result in a low pressure vapor stream, as shown in the examples above, and, thus, one or more compression stages may be used to compress the vapor stream to a sales pressure, prior to sending the compressed gas out as a low BTU product stream.

[0084] The systems and methods described herein may allow for a nearly full helium recovery from natural gas within a controlled freeze zone (CFZ) or Ryan-Holmes process plant. The systems and methods can be heat-integrated, e.g., in a single cold box, within existing cryogenic designs. The systems and methods do not require a cryogenic feed, but may also be used for helium recovery from a residue gas from a NGL recovery plant or other warm feed gas process.

[0085] Using only a cryogenic stripper column **206**, as described with respect to Figs. 3 and 5, a raw helium product **102** stream up to 25% pure may be produced. In these embodiments, the feed gas can contain elevated CO₂ levels (up to 0.42 mol %), without forming solid CO₂. A higher concentration of helium may be produced in the raw helium product **102** stream, up to 50% purity, when a helium concentrator **402** is used, as described with respect to Fig. 4.

[0086] While the present techniques may be susceptible to various modifications and alternative forms, the exemplary embodiments discussed above have been shown only by way of example. However, it should again be understood that the techniques is not intended to be limited to the particular embodiments disclosed herein. Indeed, the present techniques include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

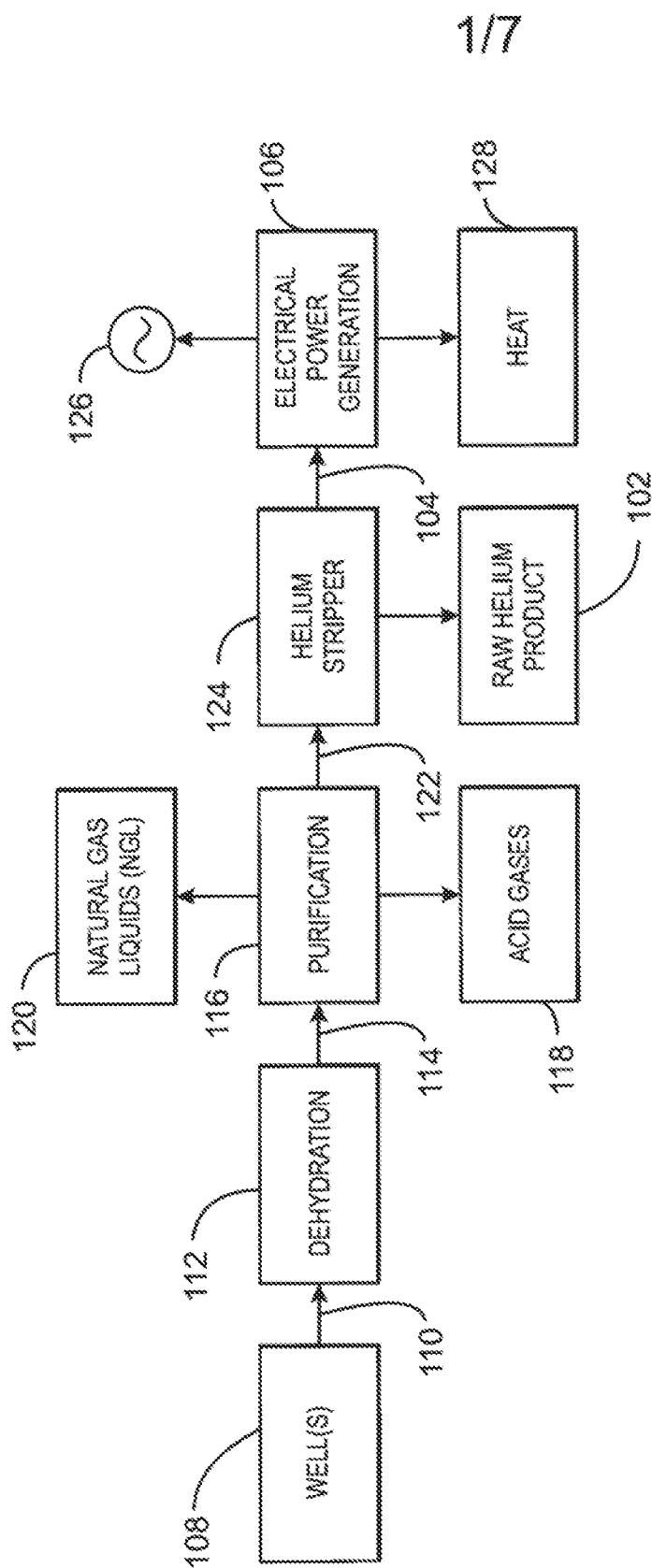
CLAIMS

What is claimed is:

1. A method for removing helium from natural gas (LNG), comprising:
 - flowing a compressed natural gas stream through a cold box to condense liquids;
 - metering the cooled stream into a cryogenic stripper column;
 - removing a raw helium product from the top of the cryogenic stripper column;
 - and
 - removing a liquid product stream from the bottom of the cryogenic stripper column, wherein the temperature in the cold box is controlled by:
 - flashing a first portion of the liquid product stream into the cold box to form a first flash gas stream;
 - flashing a second portion of the liquid product stream into the cold box to form a second flash gas stream; and
 - controlling the ratio of the first portion to the second portion to adjust the temperature in the cold box.
2. The method of claim 1, comprising feeding the raw helium product through the cold box to provide further cooling.
3. The method of claim 1, comprising feeding the raw helium product through a cryogenic concentrator to increase the helium concentration.
4. The method of claim 1, comprising:
 - compressing the first flash gas stream to substantially match a pressure of the second flash gas stream;
 - combining the first flash gas stream and the second flash gas stream to form a combined stream; and
 - compressing the combined stream to form a product stream.
5. The method claim 1, comprising producing a product stream comprising a low BTU natural gas.

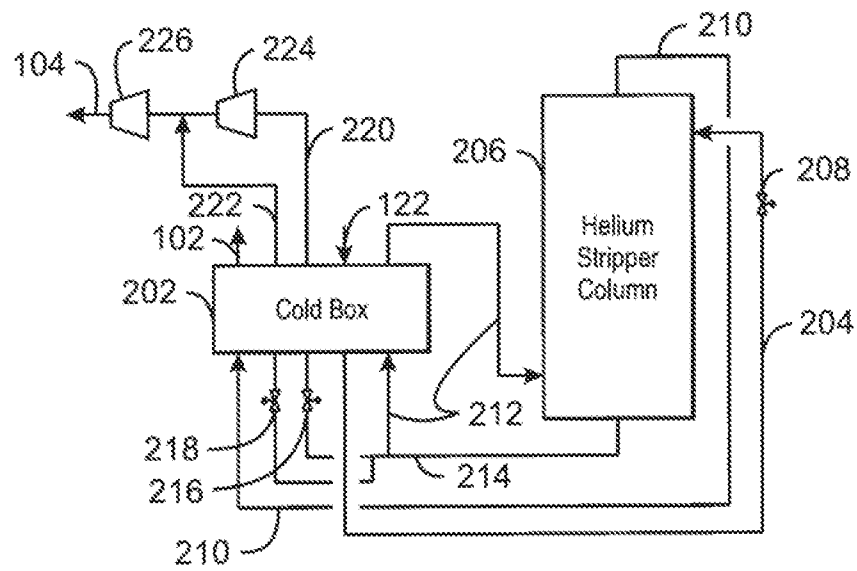
6. The method of claim 5, comprising generating electrical power from the product stream.
7. The method of claim 1, comprising providing the raw helium product to a marketplace through a pipeline.
8. A system for recovering helium from a natural gas stream, comprising:
 - a cold box configured to chill a feed stream;
 - a cryogenic stripper column configured to separate the feed stream into a gaseous top stream and a liquid bottom stream, wherein the gaseous top stream comprises an enhanced concentration of helium; and
 - a Joule-Thompson (J-T) valve configured to flash at least a portion of the liquid bottom stream into a first gaseous stream into a heat exchanger in a cold box to chill the feed stream.
9. The system of claim 8, comprising a cryogenic distillation.
10. The system of claim 8, comprising a Ryan-Holmes cryogenic distillation.
11. The system of claim 8, comprising a warm-gas processing plant.
12. The system of claim 8, comprising a helium concentrator, wherein the helium concentrator comprises:
 - a second cold box configured to chill an overhead gas stream from a cryogenic stripper column to form a second chilled stream;
 - a J-T valve configured to flash the second chilled stream to form a two phase stream; and
 - a separation vessel configured to separate gas and liquid components from the two phase stream.
13. The system of claim 8, comprising a product heat exchanger configured to chill plant streams in a cryogenic purification plant using cold from the liquid bottom stream.
14. The system of claim 8, comprising a second J-T valve configured to flash a second portion of the liquid bottoms stream into a second gaseous stream, wherein the ratio of the flows through the J-T valve and the second J-T valve is used to control the temperature of the cold box.

15. The system of claim 8, comprising a compressor configured to boost the pressure of the first gaseous stream to a sales pressure.
16. The system of claim 14, comprising a compressor configured to boost the pressure of the second gaseous stream to match a pressure of the first gaseous stream.
17. The system of claim 8, comprising an electrical generation plant configured to burn a low-BTU natural gas comprising at least the first gaseous stream.
18. A method for using low-BTU natural gas from a field, comprising:
 - harvesting a low-BTU natural gas from a well;
 - dehydrating the low-BTU natural gas to remove at least a portion of a water vapor;
 - removing at least a portion of natural gas liquids from the low-BTU natural gas;
 - removing at least a portion of acid gases from the low-BTU natural gas;
 - removing at least a portion of helium from the low-BTU natural gas in a cryogenic stripper column, wherein the energy to lower a temperature for the helium removal is provided by flashing at least a portion of a liquid bottoms stream from the cryogenic stripper column through a cold box; and
 - providing the low-BTU natural gas to customers.
19. The method of claim 18, comprising adjusting the temperature of the cold box by controlling a ratio between two portions of the liquid bottoms stream that are each being flashed, wherein one portion is flashing at a first pressure, and another portion is flashing at a lower pressure.
20. The method of claim 19, comprising removing a further portion of the helium from the low-BTU natural gas using a helium concentrator.



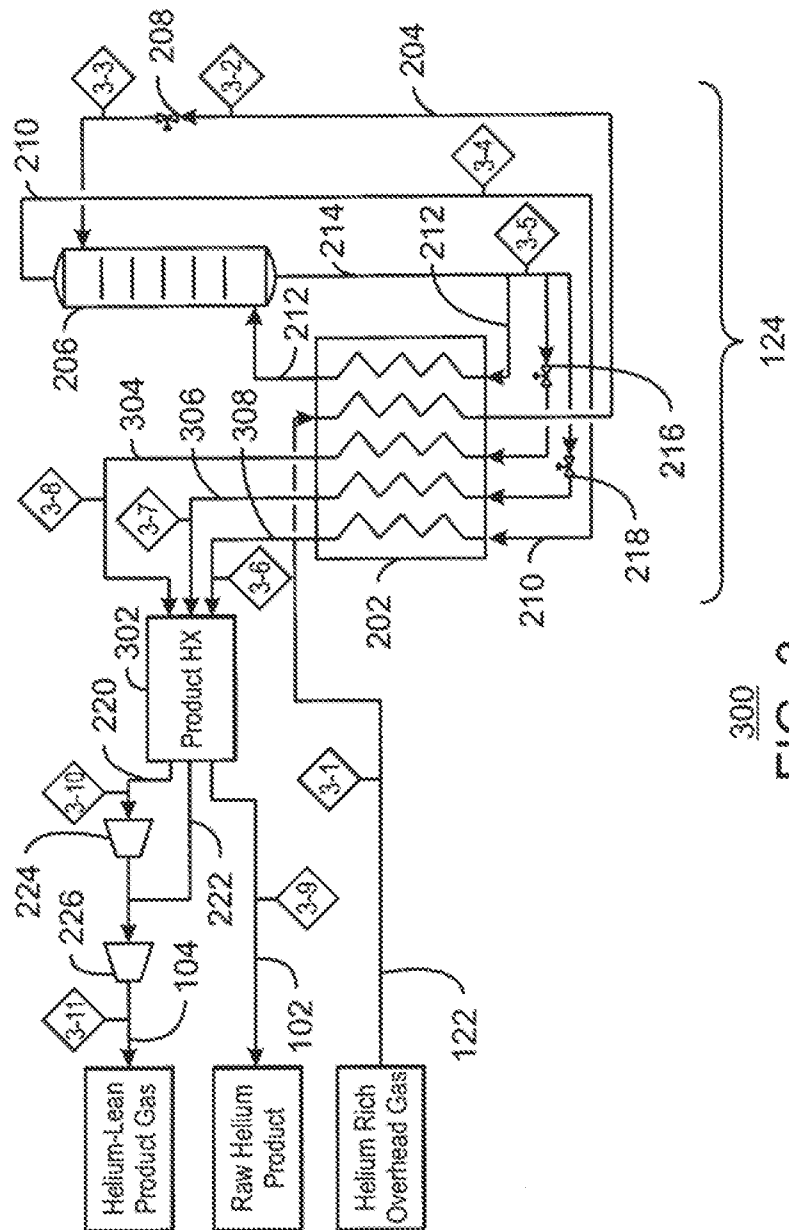
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FIG. 1

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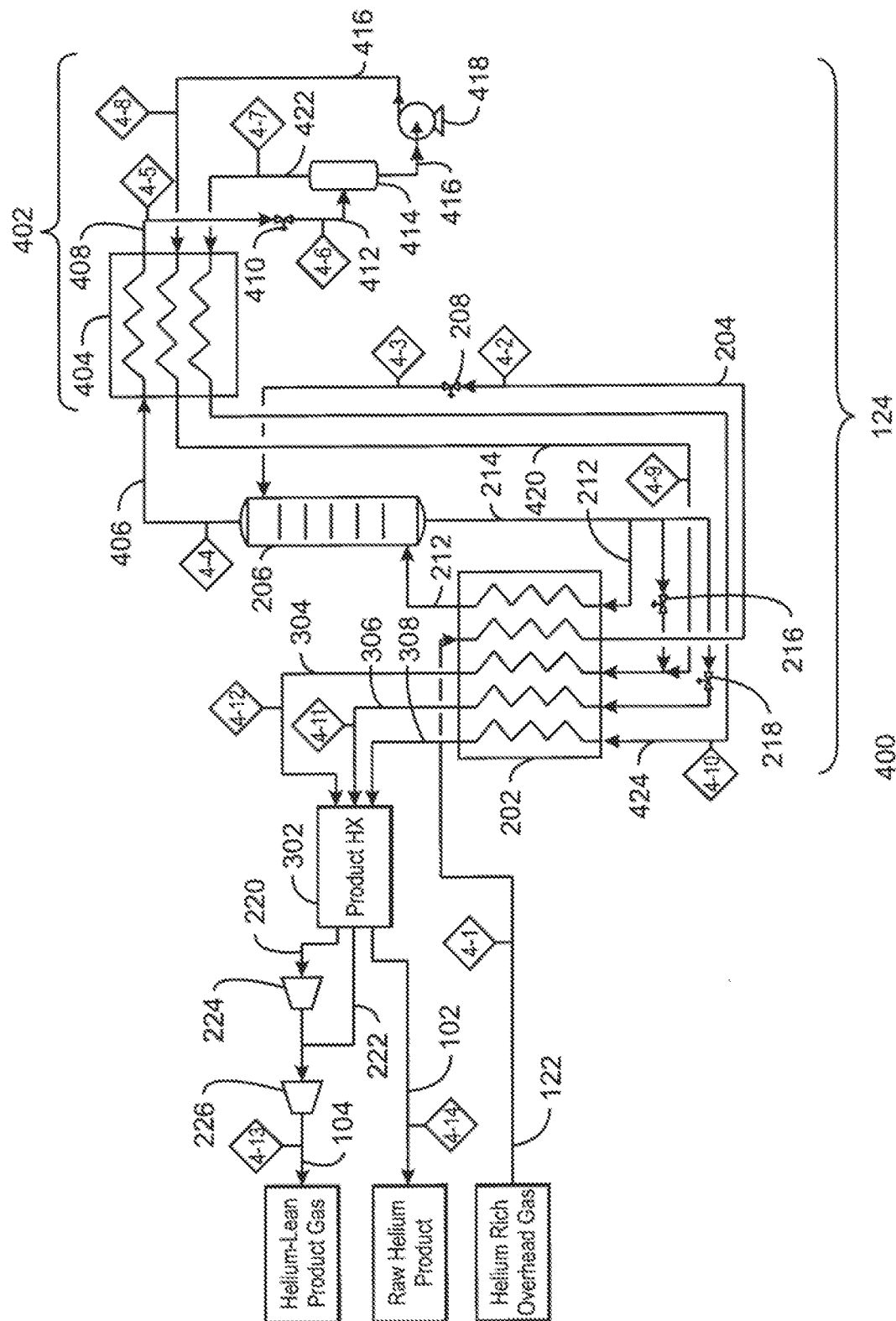
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FIG. 2

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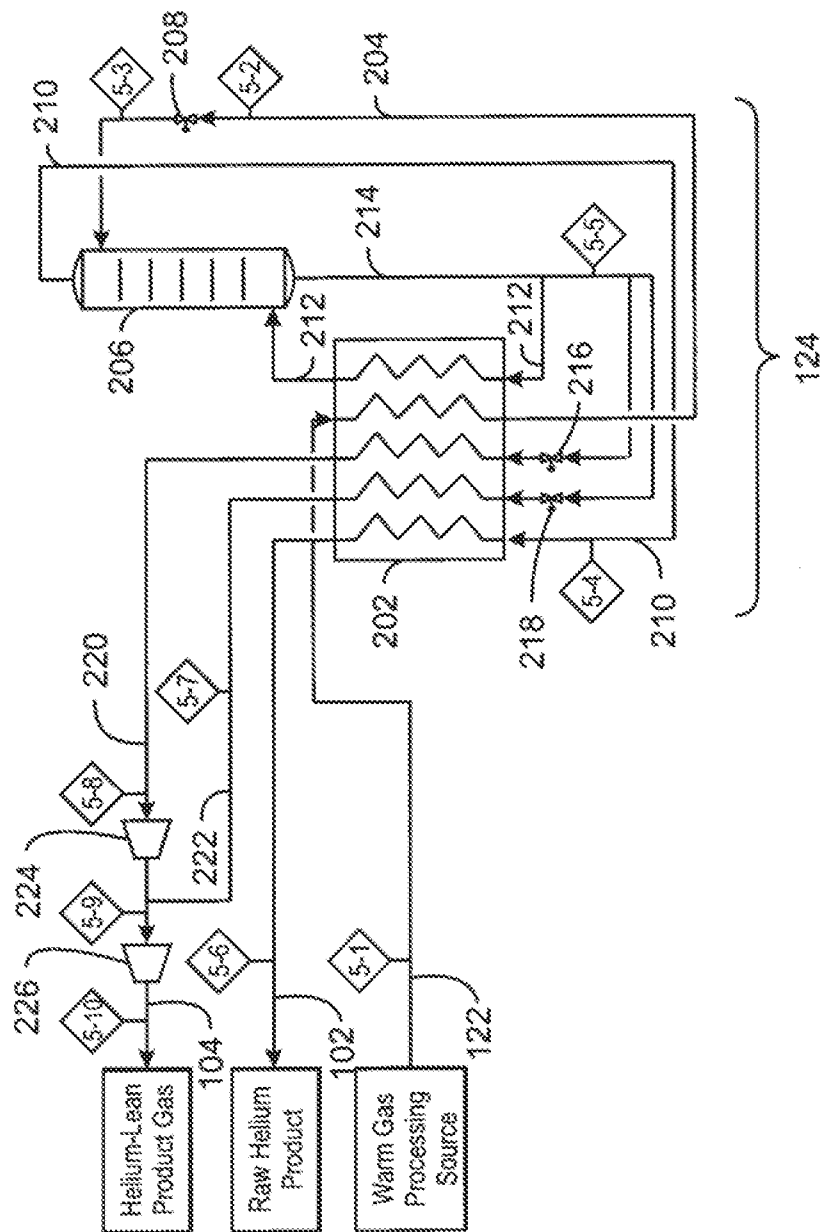
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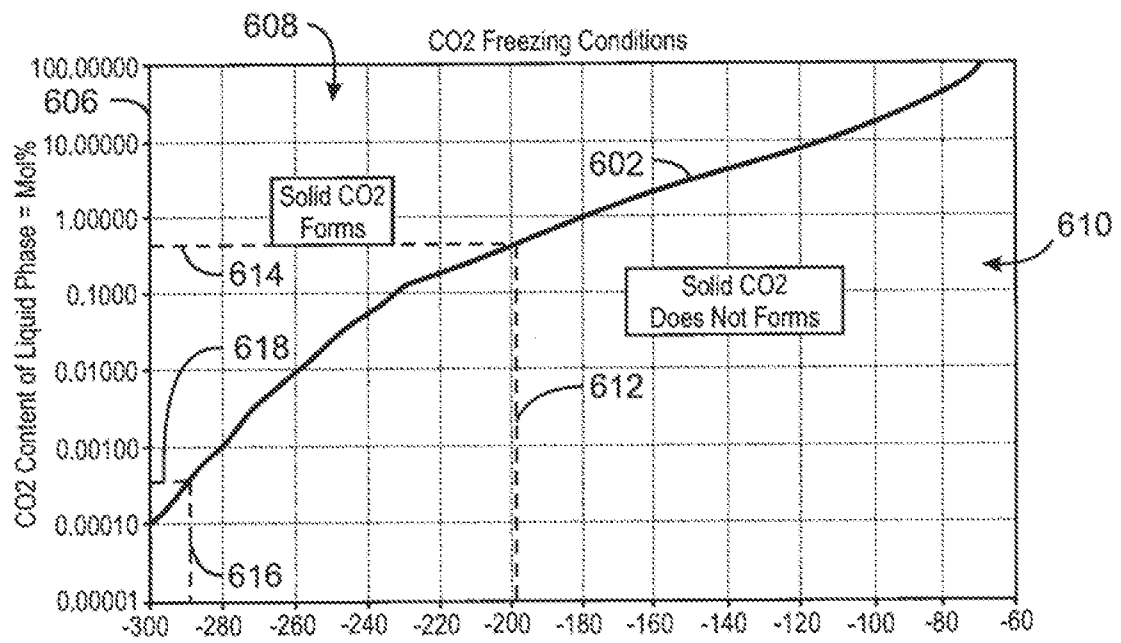
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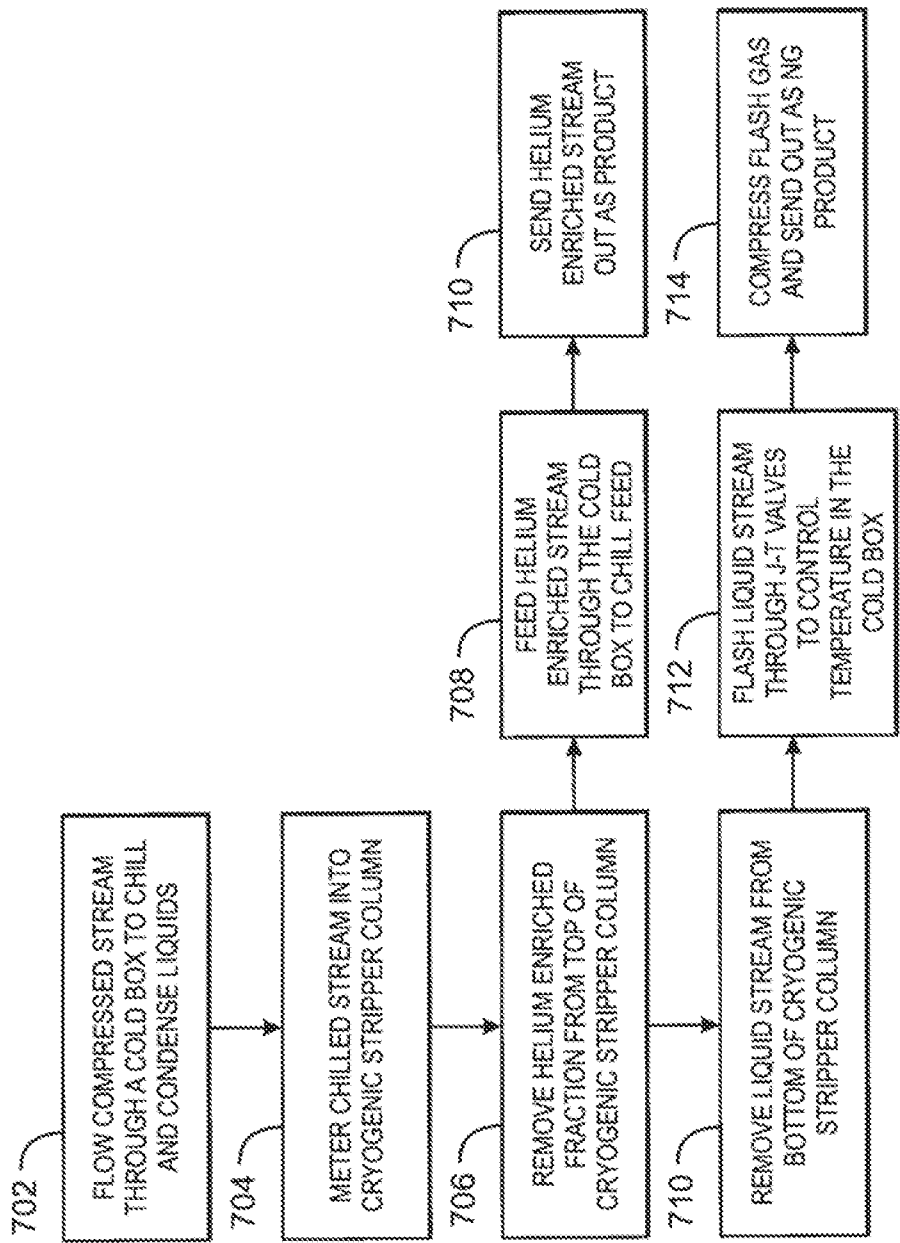


500
FIG. 5

6/7



600
FIG. 6



700
FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2012/042945

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F25J 3/00 (2012.01)

USPC - 62/620

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - B01D 3/06, 40; 8/00; F25J 3/00 (2012.01)

USPC - 62/619, 620, 639; 95/53, 247

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Orbit.com, Google Patents, Google, ProQuest

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 2007/0157662 A1 (ROBERTS et al) 12 July 2007 (12.07.2007) entire document	8, 9, 11-13, 15 1-7, 10, 14, 16-20
Y	US 2008/0134718 A1 (HOWARD et al) 12 June 2008 (12.06.2008) entire document	1-7, 14, 16, 19, 20
Y	US 4,717,408 A (HOPEWELL) 05 January 1988 (05.01.1988) entire document	10
Y	US 2006/0065119 A1 (LANDRUM) 30 March 2006 (30.03.2006) entire document	5-7, 17-20
Y	US 2010/0132405 A1 (NILSEN) 03 June 2010 (03.06.2010) entire document	4, 16
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☐ Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search

20 August 2012

Date of mailing of the international search report

28 AUG 2012

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