Integrated NGL Recovery and Liquefied Natural Gas Production

BACKGROUND OF THE INVENTION

The present invention relates to the separation of methane from admixture with ethane and heavier hydrocarbons and has particular, but not exclusive, application to an integrated process in which natural gas liquids (NGL) are recovered and liquefied natural gas (LNG) produced from natural gas (NG).

Natural gas comprises primarily methane and minor constituents that include heavier hydrocarbons. Liquefied natural gas contains mostly methane. The hydrocarbons heavier than methane are usually condensed and recovered as natural gas liquids and fractionated to yield valuable hydrocarbon products.

A typical NG liquefaction system comprises a scrub column fed with raw natural gas or pipeline gas and producing a methane-rich overhead vapor and NGL as bottoms liquid. A portion of methane-rich overhead vapor is partially condensed to provide reflux for the column and the remainder liquefied to provide the LNG product. The bottoms liquid is fractionated to obtain individual hydrocarbons and/or hydrocarbon cuts (fractions) as valuable products.

Efficiency of liquefaction improves with increasing pressure and accordingly the NG liquefaction pressure should be significantly above the critical pressure of methane in order to minimize power consumption of the LNG process. However, recovery of heavy hydrocarbons by the scrub column becomes more difficult with increasing pressure and it is not possible to separate a mixture at a pressure above its critical pressure. Hence, the scrub column has to operate significantly below the critical pressure of methane in order to achieve satisfactory separation. A common solution is to expand the scrub column feed and then to compress the overhead vapor. Work obtained from the isentropic expansion of the feed can be used to at least partially drive the overhead compressor(s). Such solution is shown in US-A-4065278 (published December 27, 1977).

Expansion of the scrub column feed followed by compression of the overhead vapor can be avoided by recycling heavy components obtained from NGL fractionation to the top or near the top of the scrub column as absorber liquid. For example, Chen-Hwa Chiu (Oil and Gas Journal, Nov. 24, 1997, 56-63) reports that the use of a heavy alkane recycle, such as all or part of a C_4 NGL fraction, to the scrub column of a LNG process can raise the critical pressure of the separated mixture and thus the operating pressure for the scrub column. In an exemplified process, there is partial or total recycle of C_4 NGL fraction recovered from a debutanizer.

WO 01101307/US-A-2003005722/US-B-6,742,358 (published December 2, 2002/January 9, 2003/June 1, 2004) discloses LNG processes in which top reflux to the scrub column is provided by condensing vapor withdrawn from an intermediate location of the column. It also discloses processes in which the vapor and liquid fractions of partially condensed feed gas are separately fractionated and bottoms liquid from fractionation of the vapor fraction provides intermediate or top reflux to the fractionation of the liquid fraction. In all of these processes, vapor overhead from the scrub column is compressed before liquefaction.

DE-A-10205366 (published August 21, 2003) discloses an LNG process in which ethane-rich vapor overhead from the scrub column is cooled and passed to a second column for the removal of residual higher hydrocarbons. The bottoms liquid of the second column provides reflux to the scrub column. Preferably, a C_4/C_5 NGL fraction provides reflux to the second column. The rectification and adsorption functions of the two columns can be combined into a single column.

US-A-6662589/EP-A-1469266 (published December 16, 2003/October 20, 2004) discloses an LNG process in which a NGL fraction comprising components heavier than ethane is fed to the scrub column as absorber liquid at a location between the natural gas feed and feed of a methane-rich reflux stream. In the

exemplified embodiment, the reflux stream is obtained by partial condensation of the overhead vapor from the scrub column. The scrub column overhead is not compressed prior to liquefaction to provide the LNG product.

WO 2004/010064 (published January 29, 2004) discloses an LNG process in which a C_4/C_5 NGL fraction is directly or indirectly fed to the scrub column to provide additional reflux. The fraction is fed to the column at or above the feed of reflux provided by partial condensation of the column vapor overhead.

Critical pressure of the mixture in the scrub column can be increased also by refluxing the column with an ethane-rich stream. This also allows good C_2-C_3 separation and high propane (C_3) recovery from NGL.

WO-A-0188447/US-A-6,401,486 (published November 22, 2001/June 11, 2002) discloses an LNG process in which top reflux for the scrub column is provided by condensation of a vapor containing mostly methane and ethane with very little propane. The scrub column overhead vapor is totally liquefied to provide the LNG product and the scrub column bottoms is fractionated in an NGL purifying column. The vapor condensed to provide said top reflux can be derived from:

(i) vapor overhead from the NGL fractionation and optionally flashed vapor obtained by flashing the liquefied, and preferably sub-cooled, scrub column overhead to near atmospheric pressure ;

(ii) a slipstream of the feed gas portion;

(iii) flashed vapor obtained by flashing the liquefied, and preferably sub-cooled, scrub column overhead to near atmospheric pressure; or

(iv) a portion of the liquefied, and preferably sub-cooled, scrub column overhead.

In options (i), (iii) and (iv), additional reflux to the scrub column can be provided by condensing a slipstream of the feed gas portion but there is no teaching of providing reflux derived from both NGL fractionation and partially condensed

scrub column overhead. In these processes, it is unnecessary to compress the scrub column overhead prior to liquefaction.

EP-A-0178207/US-A-4,690,702 (published April 15, 1986/September 1, 1987); DE-A-3802553/US-A-4,952,305(published August 3, 1989/August 28, 1990); and EP-A-0535752/US-A-5,291,736 (published April 7, 1993/March 8, 1994) all disclose LNG processes in which reflux to the scrub column is provided by a mixture of methane and ethane obtained by condensing vapor overhead from an NGL fractionation. None of these patents show reflux obtained by partially condensing the overhead product.

It has now been found that the NGL and natural gas product recovery can be improved by combining the benefits of the reflux obtained by partially condensing the scrub column overhead with the benefits of ethane-rich reflux and absorber liquid in an efficient manner, from the standpoint of thermodynamic efficiency, simplicity of equipment, and the recovery of valuable components such as propane and butane.

BRIEF SUMMARY OF THE INVENTION

In its broadest aspect, the present invention provides a process for recovery of components heavier than methane from a feed of methane in admixture with ethane and heavier hydrocarbon(s), the process comprising:

introducing the feed into a scrub column at a first location;

withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separating the bottoms stream into an ethane-enriched stream and one or more streams enriched in components heavier than ethane; and

introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream.

In a preferred embodiment of this invention, the ethane-enriched stream, preferably deethanizer overhead, obtained from NGL fractionation is condensed, pumped, combined with the reflux stream obtained by partially condensing the scrub column overhead vapor and recycled to the scrub column, preferably to a scrub column reflux drum. This allows the scrub column to operate at a higher pressure by increasing the mixture's critical pressure and also improves ethane-propane separation. The ethane-enriched stream can be fully condensed using mixed refrigerant (MR) refrigeration available in the main heat exchanger of the LNG process to maximize the benefit.

Use of a heavy recycle stream, particularly pentane and isopentane, can also be beneficial. Such a stream can be introduced either to the reflux drum or directly to the scrub column. The heavy and light recycles can be combined and cooled separately or, preferably, mixed with the reflux stream obtained by condensing the scrub column overhead vapor. Reflux obtained by condensing the overhead vapor is typically more than about 80% of the total liquid reflux (including any heavy recycle stream) to the scrub column. In the preferred implementation cooling takes place in the warm bundle of the main LNG process heat exchanger.

DETAILED DESCRIPTION OF THE INVENTION

As mentioned above, the present invention provides, in its broadest process aspect, a process for recovery of components heavier than methane from

a feed of methane in admixture with ethane and heavier hydrocarbon(s), the comprising:

introducing the feed into a scrub column at a first location;

withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separating the bottoms stream into an ethane-enriched stream and one or more streams enriched in components heavier than ethane; and

introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream.

In a corresponding apparatus aspect, the present invention provides an apparatus for recovery of components heavier than methane from a feed of methane in admixture with ethane and heavier hydrocarbon(s) by a process of the aforementioned aspect, said apparatus comprising:

a scrub column;

conduit means for introducing the feed into the scrub column at a first location;

conduit means for withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

heat exchanger means for cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separation means for separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

conduit means for introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separation means for separating the bottoms stream into an ethane-enriched stream and one or more streams enriched in components heavier than ethane; and

conduit means for introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream.

In a preferred process aspect, the invention provides a process for obtaining liquefied methane from a feed of methane in admixture with ethane and heavier hydrocarbon(s), said process comprising:

introducing the feed into a scrub column at a first location;

withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

liquefying the second overhead vapor stream;

introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separating the bottoms stream into an ethane-enriched stream and one or more streams enriched in components heavier than ethane; and

introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream.

In a preferred apparatus aspect, the present invention provides an apparatus for obtaining liquefied methane from a feed of methane in admixture

with ethane and heavier hydrocarbon(s) by a process according to said preferred process aspect, said apparatus comprising:

a scrub column;

conduit means for introducing the feed into the scrub column at a first location;

conduit means for withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

heat exchanger means for cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separation means for separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

heat exchange means for liquefying said second overhead vapor stream;

conduit means for introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separation means for separating the bottoms stream into an ethane-enriched stream and one or more streams enriched in components heavier than ethane; and

conduit means for introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream.

As indicated above, it is preferred that the feed is a cooled natural gas feed and the second overhead vapor is liquefied to provide a liquefied natural gas product.

The ethane-enriched second reflux stream can be fed to the scrub column separately from the methane-rich first reflux stream but it is preferred that it is mixed with the methane-rich first reflux stream before introducing into the scrub column. The ethane-enriched stream can be partially or fully condensed before mixing with the methane-rich first reflux stream. The mixing suitably takes place upstream of or in a reflux drum or by feeding the first two-phase stream to the

bottom of an absorption column to which the ethane-enriched second reflux stream is fed as reflux.

The ethane-enriched stream, alone or after admixture with one or more other process streams preferably is condensed at temperature below that of the feed to the scrub column and the condensed stream pumped prior to introduction into the scrub column as the ethane-enriched second reflux stream. Said temperature usually is below -32°F (-35.5°C).

Usually, the ethane-enriched stream (130) is the vapor overhead of a deethanizer. Methane can be removed from the ethane-enriched stream whereby the second reflux stream consists essentially of ethane. Preferably, the second reflux stream contains less than about 0.05% of propane.

Usually, the methane-rich first reflux stream will constitute at least about 80% of the total reflux (i.e. liquid fed to the scrub column above the first location) and the second reflux stream will be less than about 20% of the total reflux.

Preferably more than 90%, especially more than 96%, of propane and/or butane contained in the feed is recovered from the bottoms stream as product.

As illustrated in Figure 6, the first overhead stream can be partially condensed in two stages and liquid fraction from each condensation fed to the scrub column as reflux.

In a preferred embodiment, a process of the invention comprises

introducing the feed into a scrub column at a first location;

withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separating the bottoms stream into an ethane-enriched stream and two or more streams enriched in components heavier than ethane including an absorber liquid stream enriched in component(s) heavier than ethane;

introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream; and .

introducing the absorber liquid into the scrub column, at a location selected from the second location, the third location and a fourth location above the first location.

In a corresponding preferred apparatus embodiment, an apparatus of the invention comprises:

a scrub column;

conduit means for introducing the feed into the scrub column at a first location;

conduit means for withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

heat exchanger means for cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separation means for separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

conduit means for introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separation means for separating the bottoms stream into an ethane-enriched stream and two or more streams enriched in components heavier than ethane including an absorber liquid stream enriched in component(s) heavier than ethane;

conduit means for introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream; and

conduit means for introducing the absorber liquid into the scrub column, at a location selected from the second location, the third location and a fourth location above the first location.

All of the features discussed above in connection with the broadest aspects apply to this preferred embodiment.

The absorber liquid can comprise C_4 hydrocarbon(s) but preferably comprises C_{5+} hydrocarbon(s)

The absorber liquid can be fed to the scrub column separately from either the ethane-enriched second reflux stream or the methane-rich first reflux stream. However, it is preferred that it is combined with at least one of the methane-rich first reflux stream and the ethane-enriched second reflux stream (136) before introducing into the scrub column. For example, it can be combined with at least one of the first two-phase stream and the ethane-enriched second reflux stream upstream of or in a reflux drum or the first two-phase stream can be fed to the bottom of an absorption column to which the absorber liquid and optionally the ethane-enriched second reflux stream is fed as reflux. The absorber liquid can be combined with the first overhead vapor stream before partial condensation of said stream to form the first two-phase stream and/or combined with gaseous ethane-enriched stream before condensation of said stream to provide the second reflux stream.

A combined absorber liquid and gaseous ethane-enriched stream can phase separated and the liquid fraction fed to the scrub column above the first location. The liquid fraction can be combined with the first overhead stream before partial condensation of that overhead stream to provide the first two-phase stream. The vapor fraction can be condensed and the condensed stream fed to

the scrub column above the first location, added to the second overhead vapor prior to liquefaction, or combined with the first overhead stream before partial condensation of that overhead stream to provide the first two-phase stream. Both the condensed vapor fraction and the liquid fraction can be combined with the first overhead stream before partial condensation of that overhead stream to provide the first two-phase stream.

Usually, the absorber liquid will constitute less than about 10% of the total reflux (i.e. liquid fed to the scrub column above the first location).

The following is a description by way of example only and with reference to the accompanying drawings of presently preferred embodiments of the invention. In the drawings:

Figure 1 shows one embodiment of the present invention;

Figure 2 shows a modification of the embodiment of Figure 1, in which the reflux drum (118) is replaced by an absorption column (218);

Figure 3 shows another modification of the embodiment of Figure 1, in which the ethane-enriched stream (130) and "absorber liquid" stream (140) are combined to form a single stream (330);

Figure 4 shows a modification of the embodiment of Figure 3, in which the combined second reflux and absorber liquid stream (330) is phase separated (430);

Figure 5 shows a modification of the embodiment of Figure 4, in which the separated vapor portion (436) is compressed, cooled and condensed and the resultant stream (536) combined with the liquid portion (438); and

Figure 6 shows another modification of the embodiment of Figure 4, in which the overhead vapor (116) from the scrub column (114) is condensed in two stages (612, 122) to provide separate reflux streams (619, 626) to the scrub column.

Referring to Figure 1, pretreated pressurized natural gas feed 110 containing primarily methane with heavier hydrocarbons in the C_2-C_6 range with

very little water, acid gases such as CO_2 and H_2S, and other contaminants such as mercury is cooled in a heat exchanger 112 to between about -20°F (-29°C) and about -40°F (-40 °C) and fed to the scrub column 114. Typically the feed 110 is at a pressure of between about 600 and about 900 psia (4 and 6.25 MPa) and at about ambient temperature. Heat exchanger 112 represents multiple stages of cooling by evaporating propane at different pressures. Any other means of cooling, such as vaporizing mixed refrigerant in a single exchanger, can be used. Stream 110, or a vapor portion of stream 110 downstream of the heat exchanger, 112 can be throttled or isentropically expanded into the column 114. Energy obtained from the expansion can be used to at least partially compress another vapor stream, for example process stream 116, 120, 150, or 156.

Scrub column 114 separates the feed into a bottoms liquid 126 & 127 enriched in heavier hydrocarbons and a "first" overhead vapor stream 116 enriched in methane. One portion 127 of the bottoms liquid is vaporized in reboiler 128 to provide boilup for the column 114. The reboiler 128 can use a portion of feed stream 110, or any other suitable process stream, to provide heat duty. The column may also have an intermediate reboiler, for which the feed stream portion also can provide heat duty. The remaining bottoms liquid 126, generally described as Natural Gas Liquid (NGL), is fed to NGL fractionation system 128. There, NGL is usually reduced in pressure and separated using known separation apparatus such as deethanizer, depropanizer, and/or debutanizer to provide two or more hydrocarbon fractions. The bottoms liquid 126 is separated into a stream (the ethane-enriched stream) containing methane and ethane with very little propane and factions containing primarily C_3, C_4, and C_{5+} hydrocarbons (i.e. n-pentane, isopentane and heavier). Typically, the ethane-enriched stream 130 is deethanizer overhead and contains less than about 0.05% propane.

The use of the ethane-enriched second reflux stream 136 allows high recovery of propane (96-99%) and butane (almost 100%) in the fractionation system.

A portion of C_{5+} hydrocarbons is withdrawn as "absorber" liquid 140, which is pumped to scrub column pressure (i.e. pressure sufficient to introduce it to the scrub column 114, including equipment pressure drops and static pressure) by pump 142, cooled in heat exchanger 144 against vaporizing propane, further cooled in the main heat exchanger 122, and introduced into a reflux drum 118, either mixed with the second reflux stream obtained from NGL fractionation or, as shown in ghost lines, directly. Heat exchanger 144 can be placed before or after the pump 142.

Mixing the absorber liquid 140 with the second reflux stream 136 prior to introduction into the reflux drum 118 is a preferred implementation as it allows equilibration and some absorption to take place in the conduit.

As shown in ghost lines, the absorber liquid 140 could be fed directly to the top or near the top of the scrub column 114, or, in a preferred implementation, combined with the first overhead vapor stream 116 upstream of the main heat exchanger 122.

Ethane-enriched stream 130 is cooled and partially condensed in the heat exchanger 132 against vaporizing propane, cooled and completely condensed in the main heat exchanger 122, pumped to the scrub column pressure by pump 134, preferably combined with the absorber liquid 140, and introduced into the reflux drum as stream 136. Any uncondensed vapor upstream of the pump 134 can be separated, condensed in the middle bundle of the main heat exchanger 122, and combined with the liquefied natural gas product 124.

Absorber liquid 140 can also be obtained from lighter products of NGL fractionation such as C_3 and C_4 hydrocarbons, either pure or blended together. It may contain mostly C_5 hydrocarbons without C_6 and heavier components that may be rejected in an additional distillation column.

Stream 130 can be nearly-pure ethane, methane being rejected in an additional distillation column. A portion of ethane or ethane-methane mixture can be recovered as product.

The first overhead vapor stream 116 is cooled and partially condensed in the warm bundle of the main heat exchanger 122 and introduced to the reflux drum 118. It can be compressed (not shown) prior to cooling in main heat exchanger 122. The liquid portion is returned to the scrub column as the "first" liquid reflux 119. The methane-enriched "second" vapor portion 120 is liquefied and preferably subcooled in the middle and cold bundle of the main heat exchanger to provide LNG product 124.

In a preferred implementation, the partially condensed first overhead vapor stream 116 is combined with the second reflux stream 136 and/or the absorber liquid 140 in or upstream of the reflux drum 118 so that some equilibration takes place. Thus, the first liquid reflux (the liquid portion of the partially condensed first overhead vapor) gets mixed with the second liquid reflux 136 and/or the absorber liquid 140.

Typically, depending on natural gas feed composition, the second reflux stream 136 is less than about 20% of the total reflux (inclusive of any absorber liquid), and the absorber liquid 140 is less than about 10% of the total reflux. If the natural gas feed 110 does not contain components that are suitable for the absorber liquid 140 or does not contain them in sufficient quantity they can be introduced as an additional feed.

The second vapor stream 120 may be compressed (not shown) prior to introducing into main heat exchanger 122 and/or reduced in pressure before subcooling. If the LNG product 124 is stored at high pressure (PNGL) there is no need for subcooling in the cold bundle.

The main heat exchanger 122 is cooled by vaporizing a recycled mixed refrigerant (MR) stream 150, which is compressed, cooled by multiple stages of vaporizing propane, and separated into a liquid 152 and a lighter vapor 156 (compression, cooling, and phase separation not shown). Vapor 156 is condensed, cooled, and expanded through throttling valve 158. Liquid 152 is cooled, expanded through throttle valve 154, and combined with vaporizing condensed vapor 156. The combined MR streams are completely vaporized and leave the main heat exchanger 122 as stream 150. Throttling valves 154 and/or 156 can be replaced with isentropic dense fluid expanders, such as hydraulic turbines. Any other refrigeration system or a combination of systems, including pure fluid cascade and isentropic vapor expansion as described in US-A-6308531, can be used to refrigerate the main heat exchanger 122.

Figure 2 shows a modification of the embodiment of Figure 1, where the reflux drum 118 is replaced with an absorption column 218. Absorber liquid 140 and/or the second reflux stream 136, preferably both combined into stream 136, are fed to the top of the absorption column 218. They may also enter the column independently at the same location or at different locations with at least one of the two streams fed to the top of the absorption column 218. For example, absorber liquid 140 can be fed some stages below the top of the column or at the bottom of the column. The second overhead vapor stream 120 is withdrawn from the top of the column 218 and the first reflux stream 119 is withdrawn from the bottom of the column. Multiple stages in the column 218 improve the absorption of heavy components from the ascending vapor.

Figure 3 shows another modification of the embodiment of Figure 1, in which the ethane-enriched stream 130 and absorber liquid 140 are combined to form a single stream 330. Stream 330 is cooled and partially condensed in heat exchanger 332 against vaporizing propane, further cooled and completely condensed in the main heat exchanger 122, pumped to the scrub column pressure in pump 334, and introduced into the reflux drum. The mixing of streams 130 and 140 at a warmer temperature and condensing them together is

thermodynamically more efficient than the configurations shown in Figures 1 and 2. The benefit is similar to the benefit of the absorption column 218 as absorption takes place in heat exchangers 332 and 122. This configuration also eliminates passages in the main heat exchanger 122. As with the configuration of Figure 1, streams 116 and 330 can be combined downstream of the main heat exchanger 122 and before the reflux drum 118.

Figure 4 shows a modification of the embodiment of Figure 3, in which the combined ethane-enriched stream and absorber liquid stream 330 is fed to a phase separator 430. The liquid portion 438 is pumped by pump 432 to the pressure of the scrub column 114 and combined with the first overhead vapor 116 upstream of the main heat exchanger 122. The combined stream 416 exiting the main heat exchanger 122 is then fed to the reflux drum 118. The smaller vapor portion 436 is condensed in the main heat exchanger 122 and either pumped by pump 434 and introduced to the reflux drum 118, optionally combined with stream 416, or combined with liquefied natural gas upstream of the subcooling portion (cold bundle) of the main heat exchanger 122, where the liquid can be reduced in pressure prior to subcooling. Combining both streams 130 & 116 and the absorber liquid 140 upstream of the main heat exchanger 122 further increases thermodynamic efficiency of the process.

As an option, stream 438 can be cooled in a separate circuit in main heat exchanger 122 prior to introduction to the reflux drum 118. If stream 130 contains little methane, which can be rejected in the scrub column 114 or in an additional demethanizer column in the fractionation system, then stream 330 can be completely condensed and there is no need for the phase separator 430, there is no stream 436, and pump 434 can also be eliminated. Further, stream 438 could be fed directly the scrub column 114, for example to the second stage below the top of the column.

Figure 5 shows a modification of the embodiment of Figure 4, in which the separated vapor portion 436 is compressed to the pressure of the scrub column

114 in compressor 530, cooled and condensed in heat exchanger 532 and the resultant stream 536 combined with the liquid portion 438 to form stream 538. Heat exchanger 532 could be a series of heat exchangers, the first one using cooling water, the other(s) using vaporizing propane. Stream 438 can be warmed up to close-to ambient temperature prior to compression in an additional heat exchanger, and cooled back down following the compression in the aftercooler and the same additional heat exchanger for additional thermodynamic efficiency. Stream 536 may be a dense supercritical fluid.

Figure 6 shows another modification of the embodiment of Figure 4, in which the first overhead vapor 116 is partially condensed by cooling in heat exchanger 612, with, for example, either or both of the reflux stream 136 and the absorber liquid 140 but preferably by vaporizing propane. The resulting first two-phase stream is separated in phase separator 618 into a "second" overhead vapor stream 616, and a methane-rich liquid stream 619. The liquid stream 619 is returned to scrub column 114 as reflux. Stream 616, now at a temperature matching the temperatures at the bottom of the main heat exchanger 122, is mixed with stream 438, cooled in main heat exchanger 122, and fed to the reflux drum 628 as a two-phase stream 626. The overhead vapor stream 620 from the reflux drum 628 is liquefied in the main heat exchanger 122 and recovered as liquefied natural gas product 124. The liquid stream 629 from the reflux drum 628, optionally reheated in the main heat exchanger 122, is returned to the scrub column 114 at the same or different location than reflux stream 619.

Phase separator 618 and/or reflux drum 628 can be replaced with absorption columns having two-phase feed at the bottom and refluxes provided by cooled streams 136 and/or 140 at the top.

Individual features described in connection with any of the illustrated embodiments, or combinations of those features, can be incorporated as appropriate in any of the other illustrated embodiments. For example, the optional reheating of the reflux stream 629 in the main heat exchanger 122 described in

connection with Figure 6 can be applied to any of the embodiments of Figures 1 to 5. Additionally or alternatively, the provision of reflux to the scrub column 114 by a liquid fraction 619 derived from the first vapor overhead 116 of the embodiment of Figure 6 also can be applied to any of the embodiments of Figures 1 to 5.

EXAMPLE

Using the embodiment of Figure 3, 97,904 lbmol/h (44,408.5 kgmol/h) of a pre-purified natural gas stream 110 at 950 psia (6.5 MPa) is cooled in heat exchanger 112 by three stages of propane cooling to -32.3°F (-35.7°C) and fed to the scrub column 114. This feed stream 110 contains 0.6% nitrogen, 84.8% methane, 7.3% ethane, 4.4% propane, 0.7% isobutane, 1.5% butane, 0.3% isopentane, 0.2% pentane, and 0.2% hexanes. The column 114 operates at 840 psia (5.8 MPa) and has an intermediate reboiler heated by 40% of the stream 110 bypassing the first two stages of propane cooling and a bottom reboiler 128 at about 130°F (55°C). Column overhead 116 is cooled from -62.3°F (-52.4°C) to -77.5°F (-60.8°C) in the warm bundle of the main heat exchanger 122 and introduced into the reflux drum 118 as a two-phase stream containing about 15% of liquid. Scrub column bottoms stream 126 is sent to the fractionation systems 128, consisting of a series of distillation columns comprising deethanizer, depropanizer, and debutanizer. 96% of propane present in the feed stream 110 is recovered as depropanizer overhead. Nearly all of butane and isobutane is recovered as debutanizer overhead. Deethanizer overhead containing about 39% of methane, 61% of ethane, and only 0.05% of propane at a flow rate of 6,105 lbmol/h (2,769kgmol/h) and pressure of 420 psia (2.9 MPa) is mixed with stream 140 which constitutes 39% of the debutanizer bottoms liquid; the rest being recovered as C_{5+} product. Low propane content is important for high propane recovery. Stream 140 is a liquid at 17 psia (117 kPa) and a flow rate of 406 lbmol/h (184 kgmol/h), and contains about 51% isopentane, 36% pentane, 12% hexanes and less than 1% of lighter components. It is pumped, by a pump not shown in Figure 3, to 420 psia (2.9 MPa) prior to mixing with ethane-enriched stream 130. The combined stream 330 is cooled in heat exchanger 332 by

propane to -32.3°F (-35.7°C) and completely condensed by further cooling to -77.5°F (-60.8°C) in the warm bundle of the main heat exchanger 122. The condensed stream is pumped to the scrub column pressure in pump 334 and introduced to the reflux drum 118. Liquid reflux 119 is returned to the top of the scrub column 114 at -74.2°F (-59.0°C); there is a heat effect of pumping and mixing in the phase separator. Stream 120, which contains 91.3% methane, 7.8% ethane, 0.7% nitrogen, 0.2% propane, and only trace amounts of heavier hydrocarbons, is at -74.2°F (-59.0°C) and has a flow rate of 83,571 lbmol/h (37,907 kgmol/h). It is cooled down to -161.6°F (-107.6°C) in the middle and cold bundles of the main heat exchanger 122 and then let down to the storage pressure of 15.3 psia (105.5 kPa) as liquid stream 124. The main heat exchanger 122 is cooled, as described with reference to Figure 1, by mixed refrigerant comprising nitrogen, methane, ethane, and propane.

It will be appreciated that the invention is not restricted to the details described above with reference to the preferred embodiments but that numerous modifications and variations can be made without departing from the scope of the invention as defined by the following claims.

CLAIMS:

1. A process for recovery of components heavier than methane from a feed of methane in admixture with ethane and heavier hydrocarbon(s) comprising:

introducing the feed into a scrub column at a first location;

withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream enriched in components heavier than methane;

cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

introducing the methane-rich first reflux stream at a second location in the scrub column above the first location; and

separating the bottoms stream into an ethane-enriched stream and one or more streams enriched in components heavier than ethane;

characterized in that an ethane-enriched second reflux stream is derived from the ethane-enriched stream and introduced into the scrub column at a location selected from the second location and a third location above the first location.

2. A process of Claim 1, wherein the feed is a cooled natural gas feed.

3. A process of Claim 1 or Claim 2, wherein the methane-rich first reflux stream constitutes at least about 80% of the total reflux (i.e. liquid fed to the scrub column above the first location).

4. A process of any one of the preceding claims, wherein the second reflux stream is less than about 20% of the total reflux (i.e. liquid fed to the scrub column above the first location).

5. A process of any one of the preceding claims, wherein the ethane-enriched stream is condensed at temperature below that of the feed to the scrub column and the condensed stream pumped prior to introduction into the scrub column as the ethane-enriched second reflux stream.

6. A process of any one of the preceding claims, wherein the ethane-enriched second reflux stream is fed to the scrub column separately from the methane-rich first reflux stream.

7. A process of any one of Claims 1 to 5, wherein the ethane-enriched second reflux stream is mixed with the methane-rich first reflux stream before introducing into the scrub column.

8. A process of Claim 7, wherein the ethane-enriched second reflux stream is combined with the first two-phase stream at a location selected from upstream of and in a reflux drum.

9. A process of Claim 7, wherein the first two-phase stream is fed to the bottom of an absorption column to which the ethane-enriched second reflux stream is fed as reflux.

10. A process of any one of Claims 7 to 9, wherein the ethane-enriched stream is fully condensed before mixing with the methane-rich first reflux stream.

11. A process of any one of the preceding claims, wherein the ethane-enriched stream is the vapor overhead of a deethanizer.

12. A process of any one of the preceding claims, wherein an absorber liquid derived from the one or more streams enriched in components heavier than ethane is introduced into the scrub column at a location selected from the second location, the third location and a fourth location above the first location.

13. A process of Claim 12, wherein the absorber liquid comprises pentane and isopentane.

14. A process of Claim 12 or Claim 13, wherein the absorber liquid comprises C_4 hydrocarbon(s).

15. A process of any one of Claims 12 to 14, wherein the absorber liquid comprises C_{5+} hydrocarbon(s).

16. A process of any one of Claims 12 to 16, wherein the absorber liquid is fed to the scrub column separately from either the ethane-enriched second reflux stream or the methane-rich first reflux stream .

17. A process of any one of Claims 12 to 15, wherein the absorber liquid is combined with at least one of the methane-rich first reflux stream and the ethane-enriched second reflux stream before introducing into the scrub column.

18. A process of Claim 17, wherein the absorber liquid is combined with at least one of the first two-phase stream and the ethane-enriched second reflux stream at a location selected from upstream of and in a reflux drum.

19. A process of Claim 17, wherein the first two-phase stream is fed to the bottom of an absorption column to which at least one of the absorber liquid and the ethane-enriched second reflux stream is fed as reflux.

20. A process of Claim 19, wherein the absorber liquid is combined with the first overhead vapor stream before partial condensation of said stream to form the first two-phase stream.

21. A process of any one of Claims 12 to 15, wherein the absorber liquid is combined with the gaseous ethane-enriched stream before condensation of said stream to provide the second reflux stream.

22. A process of Claim 21, wherein the combined absorber liquid and gaseous ethane-enriched stream is phase separated and the liquid fraction is fed to the scrub column above the first location.

23. A process of Claim 22, wherein the vapor fraction is condensed and fed to the scrub column above the first location.

24. A process of Claim 22 or Claim 23, wherein the liquid fraction is combined with the first overhead stream before partial condensation of that overhead stream to provide the first two-phase stream.

25. A process of Claim 22 or Claim 23, wherein the condensed vapor fraction is combined with the first overhead stream before partial condensation of that overhead stream to provide the first two-phase stream.

26. A process of Claims 12 to 25, wherein the absorber liquid is less than about 10% of the total reflux (i.e. liquid fed to the scrub column above the first location).

27. A process of any one of the preceding claims, wherein the second reflux stream contains less than about 0.05% of propane.

28. A process of any one of the preceding claims, wherein methane is removed from the ethane-enriched stream whereby the second reflux stream consists essentially of ethane.

29. An apparatus for recovery of components heavier than methane from a feed of methane in admixture with ethane and heavier hydrocarbon(s) by a process of Claim 1, said apparatus comprising:

a scrub column (114);

conduit means (110) for introducing the feed into the scrub column at a first location;

conduit means (116) for withdrawing from the scrub column a first overhead vapor stream depleted in components heavier than methane and a bottoms stream (126) enriched in components heavier than methane;

heat exchanger means (122) for cooling and partially condensing the first overhead vapor stream to form a first two-phase stream;

separation means (118; 218) for separating the first two-phase stream to provide a second overhead vapor stream and a methane-rich first reflux stream;

conduit means (119) for introducing the methane-rich first reflux stream at a second location in the scrub column above the first location;

separation means (128) for separating the bottoms stream into an ethane-enriched stream and one or more streams enriched in components heavier than ethane; and

conduit means (130, 136 & 119) for introducing into the scrub column, at a location selected from the second location and a third location above the first location, an ethane-enriched second reflux stream derived from the ethane-enriched stream.

30. An apparatus of Claim 29, comprising heat exchange means (132 & 122) for condensing the ethane-enriched stream at temperature below that of the feed to the scrub column and pumping means (134) for pumping the condensed stream prior to introduction into the scrub column (114) as the ethane-enriched second reflux stream.

31. An apparatus of Claim 29 or Claim 30, comprising a reflux drum (118) from which a mixture of the ethane-enriched second reflux stream and the methane-rich first reflux stream is fed to the scrub column (114).

32 The apparatus of Claim 29 or Claim 30, comprising an absorption column (218) which receives the first two-phase stream as a bottom feed and the

ethane-enriched second reflux stream as reflux and from which the bottoms liquid is fed to the scrub column (114).

33 An apparatus of any one of Claims 29 to 32, comprising conduit means (140, 136 & 119) for introducing into the scrub column (114), at a location selected from the second location, the third location and a fourth location above the first location, an absorber liquid enriched in component(s) heavier than ethane and provided by the separation means (128) for separating the bottoms stream of the scrub column.

34. An apparatus of Claim 33, comprising a reflux drum (118) from which a mixture of the absorber liquid and at least one of the methane-rich first reflux stream and the ethane-enriched second reflux stream is fed to the scrub column (114).

35. An apparatus of Claim 33, comprising an absorption column (218) which receives the first two-phase stream as a bottom feed and at least one of the absorber liquid and the ethane-enriched second reflux stream as reflux and from which the bottoms liquid is fed to the scrub column (114).

36. An apparatus of any one of Claims 33 to 35, comprising means (438) for combining the absorber liquid with the first overhead vapor stream before partial condensation of said stream to form the first two-phase stream.

37. An apparatus of any one of Claims 33 to 36, comprising means (140 & 330) for combining the absorber liquid with the gaseous ethane-enriched stream before condensation of said stream to provide the second reflux stream.

38. An apparatus of Claim 37, comprising separator means (430) for phase separating the combined absorber liquid and gaseous ethane-enriched stream and conduit means (438 & 416) for feeding the liquid fraction to the scrub column (114) above the first location.

39. An apparatus of Claim 38, comprising heat exchange means (122; 532) for condensing the vapor fraction and conduit means (436; 536, 538 & 516) for feeding the condensed vapor to the scrub column (114) above the first location.

40. An apparatus of Claim 38 or Claim 39, comprising means (438) for combining the liquid fraction with the first overhead stream before partial condensation of that overhead stream to provide the first two-phase stream.

41. An apparatus of Claim 39 or Claim 40, comprising means (532 & 538) for combining the condensed vapor fraction with the first overhead stream before partial condensation of that overhead stream to provide the first two-phase stream.