Systems and methods for the enhanced recovery of ethane and heavier hydrocarbons using an absorbing agent. Typical absorbing agents include one or more C3+ alkanes. The systems and methods separate components of a feed gas containing methane and heavier hydrocarbons, which maximizes ethane recovery, without requiring appreciable increases in capital and operating costs, and improves the safety margin with respect to the risk of CO₂ freeze-out.
SYSTEMS AND METHODS FOR ENHANCED RECOVERY OF NGL HYDROCARBONS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] Not applicable.

FIELD OF THE INVENTION

[0003] The present invention generally relates to systems and methods for enhanced recovery of natural gas liquid ("NGL") hydrocarbons. More particularly, the present invention relates to the enhanced recovery of ethane and heavier hydrocarbons using an absorbing agent.

BACKGROUND OF THE INVENTION

[0004] Natural gas, as a clean energy source, comprises a variety of hydrocarbon constituents from methane, ethane, propane to much heavier components. Ethane, propane and heavier components from the natural gas. A high recovery of ethane is needed because of its increased demand as petrochemical feedstock.

[0005] Cryogenic expansion using a turbo-expander has become the preferred process for high ethane recovery with or without the aid of external refrigeration, depending upon the composition (richness) of the gas. In a conventional turbo-expander process, the feed gas is pre-cooled and partially condensed by a heat exchanger with other process streams and/or by external propane refrigeration. The condensed liquid includes less volatile components and is then separated and fed to a fractionation column (e.g., a demethanizer), which is operated at a medium or low pressure to recover the heavy hydrocarbon constituents desired. The remaining non-condensed vapor portion is subjected to turbo-expansion at a lower pressure, resulting in further cooling and additional liquid condensation. With the expander discharge pressure typically the same as the demethanizer pressure, the resultant two-phase stream is fed to the top section of the demethanizer with the cold liquids acting as the reflux to enhance recovery of heavy hydrocarbon components. The remaining vapor combines with the column overhead as a residue gas, which is then recompressed to pipeline pressure after being heated to recover available refrigeration.

[0006] Because the demethanizer described above operates mainly as a stripping column, the expander discharge vapor leaving the column overhead, which is not subject to rectification, still contains a significant amount of heavy components. These heavy components could be recovered if they were brought to a lower temperature, or subject to a rectification step. The lower temperature option can be achieved by a higher expansion ratio and/or a lower column pressure, but the compression horsepower would be too high to be economical. Ongoing efforts to achieve a higher liquid recovery of NGL generally fall into one of the following three categories: (1) adding a rectification section to reduce the amount of heavy components escaping through the overhead; (2) providing a colder and leaner reflux stream; and (3) introducing a stripping gas to improve the separation efficiency of the demethanizer.

[0007] In U.S. Pat. Nos. 4,157,904 and 4,278,457, which describe a split-vapor process that became the most recognized process for high ethane recovery using a rectification section (category (1)), the non-condensed vapor is split into two portions with the major one passing through a turbo-expander, as usual, while the remaining portion is substantially subcooled and introduced near the top of the demethanizer. The colder reflux flow permits an improved ethane recovery in spite of less flow being expanded via the turbo-expander. The achievable recovery level, however, is ultimately limited by the composition of the vapor stream used for the top reflux due to equilibrium constraints. Ethane recovery is therefore, typically 90% when the expansion ratio is high. Multiple variations, such as U.S. Pat. No. 4,519,824 and U.S. Pat. No. 5,555,748, were proposed later to marginally improve the split-vapor process, however, the energy consumption can increase sharply when higher ethane recovery is targeted using this split-vapor process.

[0008] In category (2), a substantially ethane-free reflux is introduced and permits in excess of 98% recovery of ethane and heavier components. The reflux consists of recycling a portion of the residue gas stream that is condensed and deeply subcooled. However, condensing the recycled residue gas can require a significant amount of refrigeration and compression power. The use of a portion of the residue gas compressor discharge for recycle into a demethanizer is disclosed in U.S. Pat. Nos. 4,687,499 and 5,568,737. A variation with a booster compressor is disclosed for a low residue gas pressure scenario in the '737 patent. U.S. Pat. Nos. 4,851,020 and 4,889,545 utilize the cold residue gas from the demethanizer overhead as the recycle stream. This process requires a compressor operating at a cryogenic temperature. Two problems can arise from using the residue gas to generate a reflux stream: (1) residue gas being mostly methane and lighter components makes condensation difficult and requires significantly higher compression power; and (2) it can increase the CO₂ freeze-up risk in the demethanizer.

[0009] In category (3), U.S. Pat. No. 5,992,175 introduces a stripping gas method that draws the liquid stream from the lower section of the demethanizer tower as a refrigerant to chill gas and the returns the compressed gas to the tower as stripping gas to enhance separation. Since the refrigerant is generated internally, the need for external refrigeration system is eliminated. However, the stripping gas method alone cannot achieve very high ethane recovery.

SUMMARY OF THE INVENTION

[0010] The present invention therefore, meets the above needs and overcomes one or more deficiencies in the prior art by providing systems and methods for the enhanced recovery of ethane and heavier hydrocarbons using an absorbing agent.

[0011] In one embodiment, the present invention includes a method for recovering ethane and heavier hydrocarbons from a hydrocarbon feed gas, which comprises: i) cooling an absorbing agent and an inlet stream comprising the feed gas in a heat exchanger to produce a cooled absorbing agent and a chilled inlet stream; ii) separating the chilled inlet stream in a separator to produce a liquid hydrocarbon stream and an overhead vapor stream; iii) combining the cooled absorbing agent with a portion of the overhead vapor stream to form a combined stream; iv) cooling the combined stream into a
reflux exchanger to produce a subcooled liquid stream; iv) expanding another portion of the overhead vapor stream in an expander to produce a demethanizer feed stream; and v) introducing the liquid hydrocarbon stream, the subcooled liquid stream and the demethanizer feed stream into a demethanizer column, wherein the ethane and heavier hydrocarbons are recovered as a bottom product in the demethanizer column and methane and lighter hydrocarbons are recovered as a top product in the demethanizer column.

In another embodiment, the present invention includes a method for recovering ethane and heavier hydrocarbons from a hydrocarbon feed gas, which comprises: i) combining a residue gas recycle stream and an absorbing agent to form an enriched residue gas recycle stream; ii) cooling the enriched residue gas recycle stream and an inlet stream comprising the feed gas in a heat exchanger to produce a chilled enriched residue gas recycle stream and a chilled inlet stream; iii) separating the chilled inlet stream in a separator to produce a liquid hydrocarbon stream and an overhead vapor stream; iv) cooling the chilled enriched residue gas recycle stream in a reflux exchanger to produce a subcooled liquid stream; v) expanding the overhead vapor stream in an expander to produce a demethanizer feed stream; and vi) introducing the liquid hydrocarbon stream, the subcooled liquid stream and the demethanizer feed stream into a demethanizer column, wherein the ethane and heavier hydrocarbons are recovered as a bottom product in the demethanizer column and methane and lighter hydrocarbons are recovered as a top product in the demethanizer column.

In yet another embodiment, the present invention includes a method for recovering ethane and heavier hydrocarbons from a hydrocarbon feed gas, which comprises: i) combining a portion of an inlet stream comprising the feed gas and an absorbing agent to form an enriched split feed stream; ii) cooling another portion of the inlet stream comprising the feed gas and the enriched split feed stream in a heat exchanger to produce a chilled enriched split feed stream and a chilled inlet stream or cooling the another portion of the inlet stream comprising the feed gas and the enriched inlet stream in the heat exchanger to produce the chilled enriched split feed stream and the chilled inlet stream; iii) separating the chilled inlet stream in a separator to produce a liquid hydrocarbon stream and an overhead vapor stream; iv) cooling the chilled enriched split feed stream in a reflux exchanger to produce a subcooled liquid stream or cooling an overhead vapor separator stream in the reflux exchanger to produce the subcooled liquid stream; v) expanding the overhead vapor stream in an expander to produce a demethanizer feed stream; and vi) introducing the liquid hydrocarbon stream, the subcooled liquid stream and the demethanizer feed stream into a demethanizer column, wherein the ethane and heavier hydrocarbons are recovered as a bottom product in the demethanizer column and methane and lighter hydrocarbons are recovered as a top product in the demethanizer column.

In yet another embodiment, the present invention includes a method for recovering ethane and heavier hydrocarbons from a hydrocarbon feed gas, which comprises: i) cooling an absorbing agent and an inlet stream comprising the feed gas in a heat exchanger to produce a cooled absorbing agent and a chilled inlet stream; ii) contracting the chilled inlet stream with the cooled absorbing agent in an absorber to produce a liquid hydrocarbon stream and an enriched overhead vapor stream; iii) cooling a portion of the enriched overhead vapor stream in a reflux exchanger to produce a subcooled liquid stream; iv) expanding another portion of the enriched overhead vapor stream in an expander to produce a demethanizer feed stream; and v) introducing the liquid hydrocarbon stream, the subcooled liquid stream and the demethanizer feed stream into a demethanizer column, wherein the ethane and heavier hydrocarbons are recovered as a bottom product in the demethanizer column and methane and lighter hydrocarbons are recovered as a top product in the demethanizer column.

Additional aspects, advantages and embodiments of the invention will become apparent to those skilled in the art from the following description of the various embodiments and related drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention is described below with reference to the accompanying drawings in which like elements are referenced with like reference numerals, and in which:

**FIG. 1** is a schematic flow diagram illustrating one embodiment of an NGL enhanced recovery system in accordance with the present invention, wherein an overhead vapor stream is enriched with an absorbing agent.

**FIG. 2** is a schematic flow diagram illustrating another embodiment of an NGL enhanced recovery system in accordance with the present invention, wherein a residue gas recycle stream is enriched with an absorbing agent.

**FIG. 3** is a schematic flow diagram illustrating another embodiment of an NGL enhanced recovery system in accordance with the present invention, wherein an inlet stream comprising feed gas is split and a portion of the inlet stream is enriched with an absorbing agent.

**FIG. 4** is a schematic flow diagram illustrating another embodiment of an NGL enhanced recovery system in accordance with the present invention, wherein an absorbing agent is used to contact the feed gas in a chilled inlet stream to generate a liquid hydrocarbon stream and an enriched overhead vapor stream.

**FIG. 5** is a schematic flow diagram illustrating another embodiment of an NGL enhanced recovery system in accordance with the present invention, wherein a recycled absorbing agent stream is produced as a split stream from the bottom of a deethanizer column.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

The subject matter of the present invention is described with specificity, however, the description itself is not intended to limit the scope of the invention. The subject matter thus, might also be embodied in other ways, to include different steps or combinations of steps similar to the ones described herein, in conjunction with other present or future technologies. Moreover, although the term “step” may be used herein to describe different elements of methods employed, the term should not be interpreted as implying any particular order among or between various steps herein disclosed unless otherwise expressly limited by the description to a particular order. While the following description refers to the oil and gas industry, the systems and methods of the present invention are not limited thereto and may also be applied in other industries to achieve similar results.

The following description refers to FIGS. 1-5, which includes systems and methods for the enhanced recovery of ethane and heavier hydrocarbons (e.g. C2+ and C3+).
using an absorbing agent. The systems and methods separate components of a feed gas containing methane and heavier hydrocarbons, which maximizes ethane recovery, without requiring appreciable increases in capital and operating costs and improves the safety margin with respect to the risk of CO₂ freeze-out. As a result, the present invention provides significant improvements in the efficiency and operability of systems and methods for the enhanced recovery of ethane and heavier hydrocarbons using an absorbing agent. The most preferable absorbing agent for ethane (C₂+) recovery consists of propane and heavier components because the heavier components enhance absorption of ethane in the rectification section of the demethanizer. Similarly, the most preferable absorbing agent for propane (C₃+) recovery consists of butanes and heavier components. The addition of the absorbing agent to the reflux raises the critical temperature and pressure of the system, thereby allowing more efficient and/or economical separation to be performed. The enriched reflux can be condensed at a lower pressure and thus, reduce compression horsepower. The presence of an absorbing agent in the reflux also enhances hydrocarbon separation and helps avoid potential solid formation problems in a cryogenic separation process. To the extent that temperatures and pressures are used in connection with the following description, those conditions are merely illustrative and are not meant to limit the invention.

[0024] Referring now to FIG. 1, a schematic flow diagram illustrates one embodiment of an NGL enhanced recovery system 100 in accordance with the present invention wherein an overhead vapor stream is enriched with an absorbing agent.

[0025] Feed gas, typically comprising a clean, filtered, dehydrated natural gas or refinery fuel gas stream is introduced into the NGL enhanced recovery system 100 through inlet stream 2. One or more C₃+ components are introduced into the enhanced recovery system 100 through an absorbing agent 8. The source of the absorbing agent 8 can be an external additive or, preferably, can be one or more recycled products from fractionation columns downstream from a demethanizer column.

[0026] The inlet stream 2 and absorbing agent 8 are cooled to a predetermined temperature in a heat exchanger 110. The cooling is preferably by indirect heat exchange with at least a residue stream 33, a side reboiling stream 27, a demethanizer reboiling stream 46, and combinations thereof to at least partially condense the inlet stream 2. A shortage in the refrigeration, if any, can be effectively supplemented by either the enhanced stripping gas scheme disclosed in U.S. Pat. No. 5,992,175, or conventional refrigeration means that are well known in the art.

[0027] A chilled inlet stream 20 from the heat exchanger 110 flows into a separator 112 where it is separated into vapor and liquid phases. Liquid hydrocarbons collected at the bottom of separator 112 form a liquid hydrocarbon stream 82 that flows into a demethanizer column 118 through a level control valve 135. An overhead vapor stream 30, produced from separator 112, is split between line 31 and line 65, which are directed to a reflux exchanger 116 and an expander 115, respectively. The overhead vapor stream 30 in line 31 is mixed with a cooled absorbing agent 12 prior to passing through the reflux exchanger 116, wherein the combined stream 34 is totally condensed and subcooled in the reflux exchanger 116 by indirect heat exchange with an overhead vapor 37 from the demethanizer column 118. The overhead vapor stream 30 in line 65 is expanded in expander 115 and sent to the demethanizer column 118, preferably to a feed location below a subcooled liquid stream 35, as a demethanizer feed stream 80. During the expansion, the temperature of the overhead vapor stream 30 in line 65 is lowered and shaftwork is generated. This shaftwork is later recovered in a boost compressor 113 driven by the expander 115.

[0028] The subcooled liquid stream 35 is expanded through an expansion valve 133 before entering the top of the demethanizer column 118 as reflux. Ethane and heavier components are recovered in the demethanizer column 118 and exit as a bottom liquid stream 66 while methane and lighter components are recovered in the demethanizer column 118 and exit as the overhead vapor 37. The overhead vapor 37 is fed into the reflux exchanger 116, providing refrigeration for condensing and subcooling combined stream 34. A residue gas exits the reflux exchanger 116 as residue stream 33 where it is further warmed to near the temperature of the inlet stream 2 in the heat exchanger 110. A warmed residue gas stream 51 from the heat exchanger 110 is sent to the suction end of the boost compressor 113 and exits as a compressed stream 26. Depending upon the delivery pressure, a residue gas compressor 120 may be needed to further compress the compressed stream 26 into a residue gas stream 68 for final delivery.

[0029] Referring now to FIG. 2, a schematic flow diagram illustrates another embodiment of an NGL enhanced recovery system 200 in accordance with the present invention, wherein a residue gas recycle stream is enriched with an absorbing agent.

[0030] In this embodiment, a residue gas recycle stream 70 is split from the residue gas stream 68 exiting the residue gas compressor 120. An absorbing agent 8, typically comprising one of more C₃+ components, is mixed with the residue gas recycle stream 70 to form an enriched residue gas recycle stream 71. The source of the absorbing agent 8 can be an external additive or, preferably, can be one or more recycled products from fractionation columns downstream from a demethanizer column.

[0031] The inlet stream 2 and the enriched residue gas recycle stream 71 are cooled to a predetermined temperature in the heat exchanger 110. The cooling is preferably by indirect heat exchange with at least a residue stream 33, a side reboiling stream 27, a demethanizer reboiling stream 46, and combinations thereof to at least partially condense the inlet stream 2. A shortage in the refrigeration, if any, can be effectively supplemented by either the enhanced stripping gas scheme disclosed in U.S. Pat. No. 5,992,175, or conventional refrigeration means that are well known in the art.

[0032] A chilled inlet stream 20 from the heat exchanger 110 flows into the separator 112 where it is separated into vapor and liquid phases. Liquid hydrocarbons collected at the bottom of separator 112 form a liquid hydrocarbon stream 82 that flows into the demethanizer column 118 through the level control valve 135. A chilled enriched residue gas recycle stream 36 leaving the heat exchanger 110 is sent to the reflux exchanger 116, wherein it is totally condensed and subcooled in the reflux exchanger 116 by indirect heat exchange with the overhead vapor 37 from the demethanizer column 118. The overhead vapor stream in line 65 is expanded in expander 115 and sent to the demethanizer column 118, preferably to a feed location below the subcooled liquid stream 35, as a demethanizer feed stream 80. During the expansion, the temperature of overhead vapor stream in line 65 is lowered and shaftwork
is generated. This shaftwork is later recovered in a boost compressor 113 driven by the expander 115. [0033] The subcooled liquid stream 35 is expanded through the expansion valve 133 before entering the top of the demethanizer column 118 as reflux. Ethane and heavier components are recovered in the demethanizer column 118 and exit as the bottom liquid stream 66 while methane and lighter components are recovered in the demethanizer column 118 and exit as the overhead vapor 37. The overhead vapor 37 is fed to the reflux exchanger 116, providing refrigeration for condensing and subcooling the chilled enriched residue gas recycle stream 36. A residue gas exits the reflux exchanger 116 as residue stream 33 where it is further warmed to near the temperature of the inlet stream 2 in the heat exchanger 110. A warmed residue gas stream 51 from the heat exchanger 110 is sent to the suction end of the boost compressor 113 and exits as the compressed stream 26. Depending upon the delivery pressure, a residue gas compressor 120 may be needed to further compress the compressed stream 26 into the residue gas stream 68 for final delivery.

[0034] Referring now to FIG. 3, a schematic flow diagram illustrates another embodiment of an NGL enhanced recovery system 300 in accordance with the present invention, wherein a portion of an inlet stream containing the feed gas is split and is enriched with an absorbing agent.

[0035] In this embodiment, the inlet stream 2 is split between line 4 and line 10, wherein the inlet stream 2 in line 10 includes the majority of the inlet stream 2. An absorbing agent 8, typically comprising one of more C3+ components, is mixed with the inlet stream 2 in line 4 to form an enriched split feed stream 15. Optionally, the enriched split feed stream 15 may be compressed in a compressor 122 to a predetermined pressure and cooled in a cooler 125 to form an enriched inlet stream 19. The source of the absorbing agent 8 can be an external additive or, preferably, can be one or more recycled products from fractionation columns downstream from a demethanizer column.

[0036] A portion of the inlet stream 2 in line 10 and the enriched inlet stream 19 are cooled to a predetermined temperature in the heat exchanger 110. The cooling is preferably by indirect heat exchange with at least a residue stream 33, a side reboiling stream 27, a demethanizer reboiling stream 46, and combinations thereof to at least partially condense the portion of inlet stream 2 in line 10. A shortage in the refrigeration, if any, can be effectively supplemented by either the enhanced stripping gas scheme disclosed in U.S. Pat. No. 5,992,175, or conventional refrigeration means that are known in the art.

[0037] A chilled inlet stream 20 from the heat exchanger 110 flows into separator 112 where it is separated into vapor and liquid phases. Liquid hydrocarbons collected at the bottom of the separator 112 form a liquid hydrocarbon stream 82 that flows into demethanizer column 118 through level control valve 135. A chilled enriched split feed stream 34a leaving the heat exchanger 110 is optionally sent to another separator 114. A bottom liquid separator stream 81 from the another separator 114 passes through another level control valve 136 and is mixed with the liquid hydrocarbon stream 82 from the separator 112 before flowing into the demethanizer column 118 through the level control valve 135. Overhead vapor separator stream 38 from the another separator 114 is sent to the reflux exchanger 116, wherein it is totally condensed and subcooled in the reflux exchanger 116 by indirect heat exchange with the overhead vapor 37 from the demethanizer column 118. The overhead vapor stream in line 65 is expanded in expander 115 and sent to demethanizer column 118, preferably to a feed location below the subcooled liquid stream 35, as a demethanizer feed stream 80. During the expansion, the temperature of the overhead vapor stream in line 65 is lowered and shaftwork is generated. This shaftwork is later recovered in a boost compressor 113 driven by the expander 115.

[0038] The subcooled liquid stream 35 is expanded through the expansion valve 133 before entering the top of the demethanizer column 118 as reflux. Ethane and heavier components are recovered in the demethanizer column 118 and exits as the bottom liquid stream 66 while methane and lighter components are recovered in the demethanizer column 118 and exits as the overhead vapor 37. The overhead vapor 37 is fed into the reflux exchanger 116, providing refrigeration for condensing and subcooling the overhead vapor separator stream 38. A residue gas exits the reflux exchanger 116 as residue stream 33 where it is further warmed to near the temperature of the inlet stream 2 in the heat exchanger 110. A warmed residue gas stream 51 from the heat exchanger 110 is sent to the suction end of the boost compressor 113 and exits as a compressed stream 26. Depending upon the delivery pressure, a residue gas compressor 120 may be needed to further compress the compressed stream 26 into a residue gas stream 68 for final delivery.

[0039] Referring now to FIG. 4, a schematic flow diagram illustrates another embodiment of an NGL enhanced recovery system 400 in accordance with the present invention, wherein an absorbing agent is used to contact the feed gas in a chilled inlet stream to generate a liquid hydrocarbon stream 27 to a demethanizer column and an enriched overhead vapor stream to an expander.

[0040] In this embodiment, the inlet stream 2 and an absorbing agent 8, typically comprising one of more C3+ components, are cooled to a predetermined temperature in a heat exchanger 110. The source of the absorbing agent 8 can be an external additive or, preferably, can be one or more recycled products from fractionator columns downstream from a demethanizer column. The cooling is preferably by indirect heat exchange with at least a residue stream 33, a side reboiling stream 27, a demethanizer reboiling stream 46, and combinations thereof to at least partially condense the inlet stream 2. A shortage in the refrigeration, if any, can be effectively supplemented by either the enhanced stripping gas scheme disclosed in U.S. Pat. No. 5,992,175, or conventional refrigeration means that are known in the art.

[0041] A chilled inlet stream 20 from the heat exchanger 110 flows into the bottom of an absorber 112a, which may contain one or more mass transfer stages. A cooled absorbing agent 12 from the heat exchanger 110 flows into the top of the absorber 112a to primarily recover desired heavy components in the form of a liquid hydrocarbon stream 82a, and enrich the enriched overhead vapor stream 30a. The liquid hydrocarbon stream 82a flows into a demethanizer column 118 through a level control valve 135. The enriched overhead vapor stream 30a is split between line 31 and line 65, which are directed to a reflux exchanger 116 and an expander 115, respectively. The enriched overhead vapor stream 30a in line 31 enters the reflux exchanger 116 wherein it is totally condensed and subcooled in the reflux exchanger 116 by indirect heat exchange with an overhead vapor 37 from the demethanizer column 118. The enriched overhead vapor stream 30a in line 65 is expanded in expander 115 and sent to the demetha-
nizer column 118, preferably to a feed location below a subcooled liquid stream 35, as a demethanizer feed stream 80. During the expansion, the temperature of the enriched overhead vapor stream 30u in line 65 is lowered and shaftwork is generated. This shaftwork is later recovered in a boost compressor 113 driven by the expander 115.

[0042] The subcooled liquid stream 35 is expanded through an expansion valve 133 before entering the top of the demethanizer column 118 as reflux. Ethane and heavier components are recovered in the demethanizer column 118 and exit as a bottom liquid stream 66 while methane and lighter components are recovered in the demethanizer column 118 and exit as the overhead vapor 37. The overhead vapor 37 is fed to the reflux exchanger 116, providing refrigeration for condensing and subcooling the enriched overhead vapor stream 30u in line 31. A residue gas exits the reflux exchanger 116 as residue stream 33 where it is further warmed to near the temperature of the inlet stream 2 in the heat exchanger 110. A warmed residue gas stream 51 from the heat exchanger 110 is sent to the suction end of the boost compressor 113 and exits as a compressed stream 26. Depending upon the delivery pressure, a residue gas compressor 120 may be needed to further compress the compressed stream 26 into a residue gas stream 68 for final delivery.

[0043] Referring now to FIG. 5, a schematic flow diagram illustrates another embodiment of an NGL enhanced recovery system 500 in accordance with the present invention, wherein a recycled absorbing agent stream is produced as a split stream from the bottom of a deethanizer column.

[0044] In this embodiment, a residue gas recycle stream 70 is split from the residue gas stream 68 exiting the residue gas compressor 120. An absorbing agent 8, typically comprising one of more C3+ components, is mixed with the residue gas recycle stream 70 to form an enriched residue gas recycle stream 71. The source of the absorbing agent 8 can be an external additive or, preferably, can be one or more recycled products from fractionation columns downstream from a demethanizer column.

[0045] The inlet stream 2 and the enriched residue gas recycle stream 71 are cooled to a predetermined temperature in the heat exchanger 110. The cooling is preferably by indirect heat exchange with at least a residue stream 33, a side reboiling stream 27, a demethanizer reboiling stream 46, and combinations thereof to at least partially condense the inlet stream 2. A shortage in the refrigeration, if any, can be effectively supplemented by either the enhanced stripping gas scheme disclosed in U.S. Pat. No. 5,992,175, or conventional refrigeration means that are known in the art.

[0046] A chilled inlet stream 20 from the heat exchanger 110 flows into the separator 112 where it is separated into vapor and liquid phases. Liquid hydrocarbons collected at the bottom of separator 112 form a liquid hydrocarbon stream 82 that flows into the demethanizer column 118 through the level control valve 135. A chilled enriched residue gas recycle stream 36 leaving the heat exchanger 110 is sent to the reflux exchanger 116, wherein it is totally condensed and subcooled in the reflux exchanger 116 by indirect heat exchange with the overhead vapor 37 from the demethanizer column 118. The overhead vapor stream in line 65 is expanded in expander 115 and sent to the demethanizer column 118, preferably to a feed location below the subcooled liquid stream 35, as a demethanizer feed stream 80. During the expansion, the temperature of overhead vapor stream in line 65 is lowered and shaftwork is generated. This shaftwork is later recovered in a boost compressor 113 driven by the expander 115.

[0047] The subcooled liquid stream 35 is expanded through the expansion valve 133 before entering the top of the demethanizer column 118 as reflux. Ethane and heavier components are recovered in the demethanizer column 118 and exit as the bottom liquid stream 66 while methane and lighter components are recovered in the demethanizer column 118 and exit as the overhead vapor 37. The overhead vapor 37 is fed to the reflux exchanger 116, providing refrigeration for condensing and subcooling the chilled enriched residue gas recycle stream 36. A residue gas exits the reflux exchanger 116 as residue stream 33 where it is further warmed to near the temperature of the inlet stream 2 in the heat exchanger 110. A warmed residue gas stream 51 from the heat exchanger 110 is sent to the suction end of the boost compressor 113 and exits as the compressed stream 26. Depending upon the delivery pressure, a residue gas compressor 120 may be needed to further compress the compressed stream 26 into the residue gas stream 68 for final delivery.

[0048] The bottom liquid stream 66 from the demethanizer column 118 enters a deethanizer column 119 through another expansion valve 137. An ethane-rich stream 84 is generated from the top of the deethanizer column 119 and a stream 85 containing propane and heavier components is recovered from the bottom of the deethanizer column 119. The stream 85 is split into C3+ product stream 86 and a recycled absorbing agent stream 87 using techniques well known in the art. The recycled absorbing agent stream 87 is transferred by a pump 121 at a predetermined pressure through a cooler 138 to form the absorbing agent 8, which is mixed with the residue gas recycle stream 70 to form the enriched residue gas recycle stream 71.

EXAMPLE

[0049] Table 1 below includes the exemplary feed conditions used for the three systems compared in Table 2.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Feed Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C.</td>
<td>4.5</td>
</tr>
<tr>
<td>Pressure, psia</td>
<td>641</td>
</tr>
<tr>
<td>Mol Flow (MMSCFD)</td>
<td>1,500</td>
</tr>
<tr>
<td>Mass Flow (kg/hr)</td>
<td>1,304,368</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Composition (mol %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
</tr>
<tr>
<td>CO2</td>
</tr>
<tr>
<td>Methane</td>
</tr>
<tr>
<td>Ethane</td>
</tr>
<tr>
<td>Propane</td>
</tr>
<tr>
<td>i-Butane</td>
</tr>
<tr>
<td>n-Butane</td>
</tr>
<tr>
<td>i-Pentane</td>
</tr>
<tr>
<td>n-Pentane</td>
</tr>
<tr>
<td>n-Hexane</td>
</tr>
<tr>
<td>n-Heptane</td>
</tr>
<tr>
<td>n-Octane</td>
</tr>
</tbody>
</table>

[0050] Table 2 below compares the simulated performance of the split feed compression system described in U.S. Pat. No. 6,354,105 and two embodiments of an NGL enhanced recovery system described above in reference to FIGS. 2 and 3. Without an absorbing agent, the split feed compression system requires a new split feed compressor of 6,359 hp compared to 4,868 hp for the split feed compression system.
with an absorbing agent (FIG. 3). Overall, the total compression power is reduced by 2,141 hp. The residue gas recycle system with an absorbing agent (FIG. 2) only requires a split feed compressor with 3,607 hp. Overall, the total compression power is reduced by 2,755 hp. The demethanizer operating pressure is increased to 384 psia to maintain the same residue gas compression power.

<table>
<thead>
<tr>
<th></th>
<th>Demethanizer Pressure, psia</th>
<th>Liquid Recovery</th>
<th>Ethane Recovery (%)</th>
<th>Compression Power, hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split Feed Compression</td>
<td>366</td>
<td>366</td>
<td>80.0</td>
<td>14,324</td>
</tr>
<tr>
<td>w/o absorbing agent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split Feed Compression</td>
<td>384</td>
<td>80.0</td>
<td></td>
<td>4,772</td>
</tr>
<tr>
<td>w/ absorbing agent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue Gas Recycle</td>
<td>38,898</td>
<td>3,607</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compression</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propane Refrigeration</td>
<td>14,324</td>
<td>14,372</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethane Refrigeration</td>
<td>4,772</td>
<td>4,513</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue Gas Compression</td>
<td>38,690</td>
<td>38,898</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split Feed Compression</td>
<td>6,259</td>
<td>4,868</td>
<td></td>
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<tr>
<td>New Equipment</td>
<td></td>
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<tr>
<td>New Compressor Discharge, psia</td>
<td>1120</td>
<td>985</td>
<td>960</td>
<td></td>
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<tr>
<td>New BAHX Duty (MMBtu/h)</td>
<td>96.5</td>
<td>95.4</td>
<td>66.4</td>
<td></td>
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</table>

5. The method of claim 1, further comprising processing the methane and lighter hydrocarbons in the reflux exchanger, the heat exchanger and a boost compressor to produce a residue gas stream.

6. A method for recovering ethane and heavier hydrocarbons from a hydrocarbon feed gas, which comprises: combining a residue gas recycle stream and an absorbing agent to form an enriched residue gas recycle stream; cooling the enriched residue gas recycle stream and an inlet stream comprising the feed gas in a heat exchanger to produce a chilled enriched residue gas recycle stream and a chilled inlet stream; separating the chilled inlet stream in a separator to produce a liquid hydrocarbon stream and an overhead vapor stream; expanding the overhead vapor stream in an expander to produce a demethanizer feed stream; introducing the liquid hydrocarbon stream, the subcooled liquid stream and the demethanizer feed stream into a demethanizer column wherein the ethane and heavier hydrocarbons are recovered as a bottom product in the demethanizer column and methane and lighter hydrocarbons are recovered as a top product in the demethanizer column.

7. The method of claim 6, wherein the absorbing agent comprises one or more C3+ alkanes.

8. The method of claim 6, wherein the hydrocarbon feed gas comprises methane and heavier hydrocarbons.

9. The method of claim 6, wherein the enriched residue gas recycle stream and the inlet stream are cooled in the heat exchanger by indirect heat exchange with a residue stream, a side reboiling stream and a demethanizer reboiling stream.

10. The method of claim 6, further comprising processing the methane and lighter hydrocarbons in the reflux exchanger, the heat exchanger and a boost compressor to produce a residue gas stream.
11. The method of claim 10, wherein a portion of the residue gas stream is used to form the residue gas recycle stream.

12. The method of claim 6, further comprising processing the ethane and heavier hydrocarbons in a demethanizer column, wherein an ethane-rich stream is recovered as another top product in the demethanizer column and another stream comprising propane and heavier components is recovered as another bottom product in the demethanizer column.

13. The method of claim 12, wherein a portion of the another stream is recycled to form the absorbing agent.

14. A method for recovering ethane and heavier hydrocarbons from a hydrocarbon feed gas, which comprises: combining a portion of an inlet stream comprising the feed gas and an absorbing agent to form an enriched split feed stream;
cooling another portion of the inlet stream comprising the feed gas and the enriched split feed stream in a heat exchanger to produce a chilled enriched split feed stream and a chilled inlet stream or cooling the another portion of the inlet stream comprising the feed gas and an enriched inlet stream in the heat exchanger to produce the chilled enriched split feed stream and the chilled inlet stream;
separating the chilled inlet stream in a separator to produce a liquid hydrocarbon stream and an overhead vapor stream;
cooling the chilled enriched split feed stream in a reflux exchanger to produce a subcooled liquid stream or cooling an overhead vapor separator stream in the reflux exchanger to produce the subcooled liquid stream;
expanding the overhead vapor stream in an expander to produce a demethanizer feed stream; and
introducing the liquid hydrocarbon stream, the subcooled liquid stream and the demethanizer feed stream into a demethanizer column, wherein the ethane and heavier hydrocarbons are recovered as a bottom product in the demethanizer column and methane and lighter hydrocarbons are recovered as a top product in the demethanizer column.

15. The method of claim 14, wherein the absorbing agent comprises one or more C3+ alkanes.

16. The method of claim 14, wherein the hydrocarbon feed gas comprises methane and heavier hydrocarbons.

17. The method of claim 14, wherein the another portion of the inlet stream and the enriched split feed stream or the enriched inlet stream are cooled in the heat exchanger by indirect heat exchange with a residue stream, a side reboiling stream and a demethanizer reboiling stream.

18. The method of claim 14, further comprising processing the methane and lighter hydrocarbons in the reflux exchanger, the heat exchanger and a boost compressor to produce a residue gas stream.

19. The method of claim 14, further comprising compressing and cooling the enriched split feed stream to produce the enriched inlet stream.

20. The method of claim 14, further comprising:
separating the chilled enriched split feed stream in another separator to produce the overhead vapor separator stream and a bottom liquid separator stream; and combining the bottom liquid separator stream and the liquid hydrocarbon stream.

21. A method for recovering ethane and heavier hydrocarbons from a hydrocarbon feed gas, which comprises:
cooling an absorbing agent and an inlet stream comprising the feed gas in a heat exchanger to produce a cooled absorbing agent and a chilled inlet stream;
contracting the chilled inlet stream with the cooled absorbing agent in an absorber to produce a liquid hydrocarbon stream and an enriched overhead vapor stream;
cooling a portion of the enriched overhead vapor stream in a reflux exchanger to produce a subcooled liquid stream; expanding another portion of the enriched overhead vapor stream in an expander to produce a demethanizer feed stream; and
introducing the liquid hydrocarbon stream, the subcooled liquid stream and the demethanizer feed stream into a demethanizer column, wherein the ethane and heavier hydrocarbons are recovered as a bottom product in the demethanizer column and methane and lighter hydrocarbons are recovered as a top product in the demethanizer column.

22. The method of claim 21, wherein the absorbing agent comprises one or more C3+ alkanes.

23. The method of claim 21, wherein the hydrocarbon feed gas comprises methane and heavier hydrocarbons.

24. The method of claim 21, wherein the absorbing agent and the inlet stream are cooled in the heat exchanger by indirect heat exchange with a residue stream, a side reboiling stream and a demethanizer reboiling stream.

25. The method of claim 21, further comprising processing the methane and lighter hydrocarbons in the reflux exchanger, the heat exchanger and a boost compressor to produce a residue gas stream.