PROCESS FOR SEPARATING HYDROCARBON GAS CONSTITUENTS

SPECIFICATION

BACKGROUND OF THE INVENTION

This invention relates to a process for the separation of a gas containing hydrocarbons. The applicants claim the benefits under Title 35, United States Code, Section 119(e) of prior U.S. Provisional Application Number 60/045,874 which was filed on May 7, 1997.

Ethylene, ethane, propylene, propane and/or heavier hydrocarbons can be recovered from a variety of gases, such as natural gas, refinery gas, and synthetic gas streams obtained from other hydrocarbon materials such as coal, crude oil, naphtha, oil shale, tar sands, and lignite. Natural gas usually has a major proportion of methane and ethane, i.e., methane and ethane together comprise at least 50 mole percent of the gas. The gas also contains relatively lesser amounts of heavier hydrocarbons such as propane, butanes, pentanes and the like, as well as hydrogen, nitrogen, carbon dioxide and other gases.

The present invention is generally concerned with the recovery of ethylene, ethane, propylene, propane and heavier hydrocarbons from such gas streams. A typical analysis of a gas stream to be processed in accordance with this invention would be, in approximate mole percent, 67.0% methane, 15.6% ethane and other C_2 components, 7.7% propane and other C_3 components, 1.8% iso-butane, 1.7% normal butane, 1.0% pentanes plus, 2.2% carbon dioxide, with the balance made up of nitrogen. Sulfur containing gases are also sometimes present.

The historically cyclic fluctuations in the prices of both natural gas and its natural gas liquid (NGL) constituents have at times reduced the incremental value of ethane, ethylene, and heavier components as liquid products. This has resulted in a demand for processes that can provide more efficient recoveries of these products, and for processes that can provide efficient recoveries with lower capital investment.

Available processes for separating these materials include those based upon cooling and refrigeration of gas, oil absorption, and refrigerated oil absorption. Additionally, cryogenic processes have become popular because of the availability of economical equipment that produces power while simultaneously expanding and extracting heat from the gas being processed. Depending upon the pressure of the gas source, the richness (ethane, ethylene, and heavier hydrocarbons content) of the gas, and the desired end products, each of these processes or a combination thereof may be employed.

The cryogenic expansion process is now generally preferred for natural gas liquids recovery because it provides maximum simplicity with ease of start up, operating flexibility, good efficiency, safety, and good reliability. U.S. Pat. Nos. 4,157,904, 4,171,964, 4,278,457, 4,519,824, 4,687,499, 4,854,955, 4,869,740, 4,889,545, 5,275,005, 5,555,748, and 5,568,737 describe relevant processes (although the description of the present invention in some cases is based on different processing conditions than those described in the cited U.S. Patents).

In a typical cryogenic expansion recovery process, a feed gas stream under pressure is cooled by heat exchange with other streams of the process and/or external sources of refrigeration such as a propane compression-refrigeration system. As the gas is cooled, liquids may be condensed and collected in one or more separators as high-pressure liquids containing some of the desired C_2+ components. Depending on the richness of the gas and the amount of liquids formed, the high-pressure liquids may be expanded to a lower pressure and fractionated. The vaporization occurring during expansion of the liquids results in further cooling of the stream. Under some conditions, pre-cooling the high pressure liquids prior to the expansion may be desirable in order to further lower the temperature resulting from the expansion. The expanded stream, comprising a mixture of liquid and vapor, is fractionated in a distillation (demethanizer) column. In the column, the expansion cooled stream(s) is (are) distilled to separate residual methane, nitrogen, and other volatile gases as overhead vapor from the desired C_2 components, C_3 components, and heavier hydrocarbon components as bottom liquid product.

If the feed gas is not totally condensed (typically it is not), the vapor

remaining from the partial condensation can be split into two or more streams. One portion of the vapor is passed through a work expansion machine or engine, or an expansion valve, to a lower pressure at which additional liquids are condensed as a result of further cooling of the stream. The pressure after expansion is essentially the same as the pressure at which the distillation column is operated. The combined vapor-liquid phases resulting from the expansion are supplied as feed to the column.

The remaining portion of the vapor is cooled to substantial condensation by heat exchange with other process streams, e.g., the cold fractionation tower overhead. Some or all of the high-pressure liquid may be combined with this vapor portion prior to cooling. The resulting cooled stream is then expanded through an appropriate expansion device, such as an expansion valve, to the pressure at which the demethanizer is operated. During expansion, a portion of the liquid will vaporize, resulting in cooling of the total stream. The flash expanded stream is then supplied as top feed to the demethanizer. Typically, the vapor portion of the expanded stream and the demethanizer overhead vapor combine in an upper separator section in the fractionation tower as residual methane product gas. Alternatively, the cooled and expanded stream may be supplied to a separator to provide vapor and liquid streams. The vapor is combined with the tower overhead and the liquid is supplied to the column as a top column feed.

In the ideal operation of such a separation process, the residue gas leaving the process will contain substantially all of the methane in the feed gas with essentially none of the heavier hydrocarbon components and the bottoms fraction leaving the demethanizer will contain substantially all of the heavier hydrocarbon components with essentially no methane or more volatile components. In practice, however, this ideal situation is not obtained for two main reasons. The first reason is that the conventional demethanizer is operated largely as a stripping column. The methane product of the process, therefore, typically comprises vapors leaving the top fractionation stage of the column, together with vapors not subjected to any rectification step. Considerable losses of C_2 components occur because the top liquid feed contains substantial quantities of C_2 components and heavier hydrocarbon components, resulting in corresponding equilibrium quantities of C_2 components and

heavier hydrocarbon components in the vapors leaving the top fractionation stage of the demethanizer. The loss of these desirable components could be significantly reduced if the rising vapors could be brought into contact with a significant quantity of liquid (reflux) capable of absorbing the C_2 components and heavier hydrocarbon components from the vapors.

The second reason that this ideal situation cannot be obtained is that carbon dioxide contained in the feed gas fractionates in the demethanizer and can build up to concentrations of as much as 5% to 10% or more in the tower even when the feed gas contains less than 1% carbon dioxide. At such high concentrations, formation of solid carbon dioxide can occur depending on temperatures, pressures, and the liquid solubility. It is well known that natural gas streams usually contain carbon dioxide, sometimes in substantial amounts. If the carbon dioxide concentration in the feed gas is high enough, it becomes impossible to process the feed gas as desired due to blockage of the process equipment with solid carbon dioxide (unless carbon dioxide removal equipment is added, which would increase capital cost substantially). The present invention provides a means for generating a liquid reflux stream that will improve the recovery efficiency for the desired products while simultaneously substantially mitigating the problem of carbon dioxide icing.

In accordance with the present invention, it has been found that C_2 recoveries in excess of 95 percent can be obtained. Similarly, in those instances where recovery of C_2 components is not desired, C_3 recoveries in excess of 95% can be maintained. In addition, the present invention makes possible essentially 100 percent separation of methane (or C_2 components) and lighter components from the C_2 components (or C_3 components) and heavier components at reduced energy requirements compared to the prior art while maintaining the same recovery levels and improving the safety factor with respect to the danger of carbon dioxide icing. The present invention, although applicable for leaner gas streams at lower pressures and warmer temperatures, is particularly advantageous when processing richer feed gases at pressures in the range of 600 to 1000 psia or higher under conditions requiring column overhead temperatures of -110°F or colder.

For a better understanding of the present invention, reference is made to the following examples and drawings. Referring to the drawings:

FIG. 1 is a flow diagram of a cryogenic expansion natural gas processing plant of the prior art according to U.S. Pat. No. 4,278,457;

FIG. 2 is a flow diagram of a cryogenic expansion natural gas processing plant of an alternative prior art system according to U.S. Pat. No. 5,568,737;

FIG. 3 is a flow diagram of a natural gas processing plant in accordance with the present invention;

FIG. 4 is a concentration-temperature diagram for carbon dioxide showing the effect of the present invention;

FIG. 5 is a flow diagram illustrating an alternative means of application of the present invention to a natural gas stream;

FIG. 6 is a concentration-temperature diagram for carbon dioxide showing the effect of the present invention with respect to the process of FIG. 5;

FIG. 7 is a flow diagram illustrating another alternative means of application of the present invention to a natural gas stream;

FIG. 8 is a concentration-temperature diagram for carbon dioxide showing the effect of the present invention with respect to the process of FIG. 7; and

FIGS. 9 through 17 are flow diagrams illustrating alternative embodiments of the present invention.

In the following explanation of the above figures, tables are provided summarizing flow rates calculated for representative process conditions. In the tables appearing herein, the values for flow rates (in pound moles per hour) have been rounded to the nearest whole number for convenience. The total stream rates shown in the tables include all non-hydrocarbon components and hence are generally larger than the sum of the stream flow rates for the hydrocarbon components. Temperatures indicated are approximate values rounded to the nearest degree. It should also be noted that the process design calculations performed for the purpose of comparing the processes depicted in the figures are based on the assumption of no heat leak from (or to) the surroundings to (or from) the process. The quality of commercially available

insulating materials makes this a very reasonable assumption and one that is typically made by those skilled in the art.

DESCRIPTION OF THE PRIOR ART

Referring now to FIG. 1, in a simulation of the process according to U.S. Pat. No. 4,278,457, feed gas enters the plant at 88°F and 840 psia as stream **31**. If the feed gas contains a concentration of sulfur compounds which would prevent the product streams from meeting specifications, the sulfur compounds are removed by appropriate pretreatment of the feed gas (not illustrated). In addition, the feed stream is usually dehydrated to prevent hydrate (ice) formation under cryogenic conditions. Solid desiccant has typically been used for this purpose.

The feed stream **31** is split into two portions, stream **32** and stream **35**. Stream **35**, containing about 26 percent of the total feed gas, enters heat exchanger **15** and is cooled to -16°F by heat exchange with a portion of the cool residue gas at -23°F (stream **41**) and with external propane refrigerant. Note that in all cases exchangers **10** and **15** are representative of either a multitude of individual heat exchangers or single multi-pass heat exchangers, or any combination thereof. (The decision as to whether to use more than one heat exchanger for the indicated cooling services will depend on a number of factors including, but not limited to, feed gas flow rate, heat exchanger size, stream temperatures, etc.)

The partially cooled stream **35a** then enters heat exchanger **16** and is directed in heat exchange relation with the demethanizer overhead vapor stream **39**, resulting in further cooling and substantial condensation of the gas stream. The substantially condensed stream **35b** at -142°F is then flash expanded through an appropriate expansion device, such as expansion valve **17**, to the operating pressure (approximately 250 psia) of the fractionation tower **18**. During expansion a portion of the stream is vaporized, resulting in cooling of the total stream. In the process illustrated in FIG. 1, the expanded stream **35c** leaving expansion valve **17** reaches a temperature of -158°F and is supplied to separator section **18a** in the upper region of

fractionation tower **18**. The liquids separated therein become the top feed to demethanizing section **18b**.

Returning to the second portion (stream **32**) of the feed gas, the remaining 74 percent of the feed gas enters heat exchanger **10** where it is cooled to -50°F and partially condensed by heat exchange with a portion of the cool residue gas at -23°F (stream **42**), demethanizer reboiler liquids at 10°F, demethanizer side reboiler liquids at -70°F, and external propane refrigerant. The cooled stream **32a** enters separator **11** at –50°F and 825 psia where the vapor (stream **33**) is separated from the condensed liquid (stream **34**).

The vapor from separator **11** (stream **33**) enters a work expansion machine **12** in which mechanical energy is extracted from this portion of the high pressure feed. The machine **12** expands the vapor substantially isentropically from a pressure of about 825 psia to a pressure of about 250 psia, with the work expansion cooling the expanded stream **33a** to a temperature of approximately -128°F. The typical commercially available expanders are capable of recovering on the order of 80-85% of the work theoretically available in an ideal isentropic expansion. The work recovered is often used to drive a centrifugal compressor (such as item **13**), that can be used to re-compress the residue gas (stream **39b**), for example. The expanded and partially condensed stream **33a** is supplied as feed to distillation column **18** at an intermediate point. The separator liquid (stream **34**) is likewise expanded to approximately 250 psia by expansion valve **14**, cooling stream **34** to -102°F (stream **34a**) before it is supplied to the demethanizer in fractionation tower **18** at a lower mid-column feed point.

The demethanizer in fractionation tower **18** is a conventional distillation column containing a plurality of vertically spaced trays, one or more packed beds, or some combination of trays and packing. As is often the case in natural gas processing plants, the fractionation tower may consist of two sections. The upper section **18a** is a separator wherein the partially vaporized top feed is divided into its respective vapor and liquid portions, and wherein the vapor rising from the lower distillation or demethanizing section **18b** is combined with the vapor portion (if any) of the top feed to form the cold residue gas distillation stream **39**

which exits the top of the tower. The lower, demethanizing section **18b** contains the trays and/or packing and provides the necessary contact between the liquids falling downward and the vapors rising upward. The demethanizing section also includes reboilers which heat and vaporize a portion of the liquids flowing down the column to provide the stripping vapors which flow up the column to strip the liquid product, stream **40**, of methane. A typical specification for the bottom liquid product is to have a methane to ethane ratio of 0.015:1 on a volume basis. The liquid product stream **40** exits the bottom of the demethanizer at 31°F and flows to subsequent processing and/or storage.

The cold residue gas stream **39** passes countercurrently to a portion (stream **35a**) of the feed gas in heat exchanger **16** where it is warmed to –23°F (stream **39a**) as it provides further cooling and substantial condensation of stream **35b**. The cool residue gas stream **39a** is then divided into two portions, streams **41** and **42**. Streams **41** and **42** pass countercurrently to the feed gas in heat exchangers **15** and **10**, respectively, and are warmed to 80°F and 81°F (streams **41a** and **42a**, respectively) as the streams provide cooling and partial condensation of the feed gas. The two warmed streams **41a** and **42a** then recombine as residue gas stream **39b** at a temperature of 80°F. This recombined stream is then re-compressed in two stages. The first stage is compressor **13** driven by expansion machine **12**. The second stage is compressor **19** driven by a supplemental power source which compresses the residue gas (stream **39c**) to sales line pressure. After cooling in discharge cooler **20**, the residue gas product (stream **39e**) flows to the sales gas pipeline at 88°F and 835 psia.

A summary of stream flow rates and energy consumptions for the process illustrated in FIG. 1 is set forth in the following table:

TABLE I

(FIG. 1)

Stream Flow Summary - (Lb. Moles/Hr)

Stream	Methane		Ethane		Propane	Butanes+	Total
31	5516	1287	633	371	8235		
32	4069	949	467	274	6075		
35	1447	338	166	97	2160		
33	2235	199	38	8	2665		
34	1834	750	429	266	3410		
39	5487	64	3	0	5844		
40	29	1223	630	371	2391		

Recoveries*	
Ethane	95.00%
Propane	99.54%
Butanes+	99.95%
Horsepower	
Residue Compression	4,034
Refrigeration Compression	1,549

Total	5,583

* (Based on un-rounded flow rates)

The prior art illustrated in FIG. 1 is limited to the ethane recovery shown in Table I by the amount of substantially condensed feed gas which can be produced to serve as reflux for the upper rectification section of the demethanizer. The recovery of C_2 components and heavier hydrocarbon components can be improved up to a point either by increasing the amount of substantially condensed feed gas supplied as the top feed of the demethanizer, or by lowering the temperature of separator **11** to reduce the temperature of the work expanded feed gas and thereby reduce the temperature and quantity of vapor supplied to the mid-column feed point of

the demethanizer that must be rectified. Changes of this type can only be accomplished by removing more energy from the feed gas, either by adding supplemental refrigeration to cool the feed gas further, or by lowering the operating pressure of the demethanizer to increase the energy recovered by work expansion machine **12**. In either case, the utility (compression) requirements will increase inordinately while providing only marginal increases in C_2+ component recovery levels.

One way to achieve more efficient ethane recovery that is often used for rich feed gases such as this (where the recovery is limited by the energy that can be removed from the feed gas) is to substantially condense a portion of the re-compressed residue gas and recycle it to the demethanizer as its top (reflux) feed. In essence, this is an open compression-refrigeration cycle for the demethanizer using a portion of the volatile residue gas as the working fluid. FIG. 2 represents such an alternative prior art process in accordance with U.S. Pat. No. 5,568,737 that recycles a portion of the residue gas product to provide the top feed to the demethanizer. The process of FIG. 2 has been applied to the same feed gas composition and conditions as described above for FIG. 1.

In the simulation of this process, as in the simulation for the process of FIG. 1, operating conditions were selected to minimize energy consumption for a given recovery level. The feed stream **31** is split into two portions, stream **32** and stream **35**. Stream **35**, containing about 19 percent of the total feed gas, enters heat exchanger **15** and is cooled to -21°F by heat exchange with a portion of the cool residue gas at -40°F (stream **44**) and with external propane refrigerant. The partially cooled stream **35a** then enters heat exchanger **16** and is directed in heat exchange relation with a portion of the cold demethanizer overhead vapor at -152°F (stream **42**), resulting in further cooling and substantial condensation of the gas stream. The substantially condensed stream **35b** at -145°F is then flash expanded through expansion valve **17** to the operating pressure (approximately 276 psia) of fractionation tower **18**. During expansion a portion of the stream vaporizes, cooling the total stream to -154°F (stream **35c**). The expanded stream **35c** then enters the distillation column or demethanizer at a mid-column feed position. The distillation column is in

a lower region of fractionation tower **18**.

Returning to the second portion (stream **32**) of the feed gas, the remaining 81 percent of the feed gas enters heat exchanger **10** where it is cooled to -47°F and partially condensed by heat exchange with a portion of the cool residue gas at -40°F (stream **45**), demethanizer reboiler liquids at 19°F, demethanizer side reboiler liquids at -71°F, and external propane refrigerant. The cooled stream **32a** enters separator **11** at –47°F and 825 psia where the vapor (stream **33**) is separated from the condensed liquid (stream **34**).

The vapor from separator **11** (stream **33**) enters a work expansion machine **12** in which mechanical energy is extracted from this portion of the high pressure feed. The machine **12** expands the vapor substantially isentropically from a pressure of about 825 psia to the pressure of the demethanizer (about 276 psia), with the work expansion cooling the expanded stream to a temperature of approximately -119°F (stream **33a**). The separator liquid (stream **34**) is likewise expanded to approximately 276 psia by expansion valve **14**, cooling stream **34** to -95°F (stream **34a**) before it is supplied to the demethanizer in fractionation tower **18** at a lower mid-column feed point.

A portion of the high pressure residue gas (stream **46**) is withdrawn from the main residue flow (stream **39e**) to become the top distillation column feed (reflux). Recycle gas stream **46** passes through heat exchanger **21** in heat exchange relation with a portion of the cool residue gas (stream **43**) where it is cooled to 0°F (stream **46a**). Cooled recycle stream **46a** then passes through heat exchanger **22** in heat exchange relation with the other portion of the cold demethanizer overhead distillation vapor, stream **41**, resulting in further cooling and substantial condensation of the recycle stream. The substantially condensed stream **46b** at -145°F is then expanded through expansion valve **23**. As the stream is expanded to the demethanizer operating pressure of 276 psia, a portion of the stream is vaporized, cooling the total stream to a temperature of approximately -169°F (stream **46c**). The expanded stream **46c** is supplied to the tower as the top feed.

The liquid product (stream **40**) exits the bottom of tower **18** at 42°F and flows to subsequent processing and/or storage. The cold distillation stream **39**

from the upper section of the demethanizer is divided into two portions, streams **41** and **42**. Stream **41** passes countercurrently to recycle stream **46a** in heat exchanger **22** where it is warmed to –58°F (stream **41a**) as it provides cooling and substantial condensation of cooled recycle stream **46a**. Similarly, stream **42** passes countercurrently to stream **35a** in heat exchanger **16** where it is warmed to –28°F (stream **42a**) as it provides cooling and substantial condensation of stream **35a**. The two partially warmed streams **41a** and **42a** then recombine as stream **39a** at a temperature of –40°F. This recombined stream is divided into three portions, streams **43, 44,** and **45**. Stream **43** passes countercurrently to recycle stream **46** in exchanger **21** where it is warmed to 79°F (stream **43a**). The second portion, stream **44**, flows through heat exchanger **15** where it is heated to 79°F (stream **44a**) as it provides cooling to the first portion of the feed gas (stream **35**). The third portion, stream **45**, flows through heat exchanger **10** where it is heated to 81°F (stream **45a**) as it provides cooling to the second portion of the feed gas (stream **32**). The three heated streams **43a, 44a,** and **45a** recombine as warm distillation stream **39b**. The warm distillation stream at 80°F is then re-compressed in two stages. The first stage is compressor **13** driven by expansion machine **12**. The second stage is compressor **19** driven by a supplemental power source which compresses the residue gas (stream **39c**) to sales line pressure. After cooling in discharge cooler **20**, the cooled stream **39e** is split into the residue gas product (stream **47**) and the recycle stream **46** as described earlier. The residue gas product (stream **47**) flows to the sales gas pipeline at 88°F and 835 psia.

A summary of stream flow rates and energy consumptions for the process illustrated in FIG. 2 is set forth in the following table:

TABLE II

(FIG. 2)

Stream Flow Summary - (Lb. Moles/Hr)

Stream	Methane		Ethane		Propane	Butanes+	Total
31	5516	1287	633	371	8235		
32	4478	1045	514	301	6685		
35	1038	242	119	70	1550		
33	2607	244	47	10	3120		
34	1871	801	467	291	3565		
39	6160	72	0	0	6591		
46	673	8	0	0	720		
47	5487	64	0	0	5871		
40	29	1223	633	371	2364		

Recoveries*	
Ethane	95.00%
Propane	100.00%
Butanes+	100.00%
Horsepower	
Residue Compression	4,048
Refrigeration Compression	1,533
Total	5,581

* (Based on un-rounded flow rates)

Comparison of the recovery levels and utility usages displayed in Tables I and II shows that the refrigeration provided by the addition of recycle stream **46** was not effective for improving the ethane recovery efficiency in this case. Although the substantially condensed and expanded stream **46c** in the FIG. 2 process is significantly colder and significantly leaner (lower in concentration of C_2+ components) than the top feed for the FIG. 1 process (stream **35c**), the quantity of

stream **46c** is insufficient to absorb the C_2+ components in an effective manner from the vapors rising up tower **18**. As was the case for the FIG. 1 process, the recovery levels are still set by the amount of energy that can be extracted from the feed gas, meaning that the quantity of top feed (not its composition) is the determining factor that sets the ethane recovery efficiency for this case. The leaner top feed composition that is a feature of the FIG. 2 process could only improve the ethane recovery for this case if the quantity of the top feed was increased, which would increase the horsepower requirements above those listed in Table II.

DESCRIPTION OF THE INVENTION

Example 1

FIG. 3 illustrates a flow diagram of a process in accordance with the present invention. The feed gas composition and conditions considered in the process presented in FIG. 3 are the same as those in FIGS. 1 and 2. Accordingly, the FIG. 3 process can be compared with that of the FIG. 1 and FIG. 2 processes to illustrate the advantages of the present invention.

In the simulation of the FIG. 3 process, feed gas enters at 88°F and 840 psia as stream **31** and is split into two portions, stream **32** and stream **35**. Stream **32**, containing about 79 percent of the total feed gas, enters heat exchanger **10** and is cooled by heat exchange with a portion of the cool residue gas at -30°F (stream **42**), demethanizer reboiler liquids at 25°F, demethanizer side reboiler liquids at -71°F, and external propane refrigerant. The cooled stream **32a** enters separator **11** at –50°F and 825 psia where the vapor (stream **33**) is separated from the condensed liquid (stream **34**).

The vapor (stream **33**) from separator **11** enters a work expansion machine **12** in which mechanical energy is extracted from this portion of the high pressure feed. The machine **12** expands the vapor substantially isentropically from a pressure of about 825 psia to the operating pressure (approximately 305 psia) of fractionation tower **18**, with the work expansion cooling the expanded stream **33a** to a

temperature of approximately -117°F. The expanded and partially condensed stream **33a** is then supplied as feed to distillation column **18** at a mid-column feed point.

The condensed liquid (stream **34**) from separator **11** is flash expanded through an appropriate expansion device, such as expansion valve **14**, to the operating pressure of fractionation tower **18**, cooling stream **34** to a temperature of -95°F (stream **34a**). The expanded stream **34a** leaving expansion valve **14** is then supplied to fractionation tower **18** at a lower mid-column feed point.

Returning to the second portion (stream **35**) of the feed gas, the remaining 21 percent of the feed gas is combined with a portion of the high pressure residue gas (stream **46**) withdrawn from the main residue flow (stream **39e**). The combined stream **38** enters heat exchanger **15** and is cooled to -23°F by heat exchange with the other portion of the cool residue gas at -30°F (stream **41**) and with external propane refrigerant. The partially cooled stream **38a** then passes through heat exchanger **16** in heat exchange relation with the -143°F cold distillation stream **39** where it is further cooled to -136°F (stream **38b**). The resulting substantially condensed stream **38b** is then flash expanded through an appropriate expansion device, such as expansion valve **17**, to the operating pressure (approximately 305 psia) of fractionation tower **18**. During expansion a portion of the stream is vaporized, resulting in cooling of the total stream. In the process illustrated in FIG. 3, the expanded stream **38c** leaving expansion valve **17** reaches a temperature of -152°F and is supplied to fractionation tower **18** as the top column feed. The vapor portion (if any) of stream **38c** combines with the vapors rising from the top fractionation stage of the column to form distillation stream **39**, which is withdrawn from an upper region of the tower.

The liquid product (stream **40**) exits the bottom of tower **18** at 49°F and flows to subsequent processing and/or storage. The cold distillation stream **39** at -143°F from the upper section of the demethanizer passes countercurrently to the partially cooled combined stream **38a** in heat exchanger **16** where it is warmed to -30°F (stream **39a**) as it provides further cooling and substantial condensation of stream **38b**. The cool residue gas stream **39a** is then divided into two portions, streams **41** and **42**. Stream **41** passes countercurrently to the mixture of feed gas and

recycle gas in heat exchanger **15** and is warmed to 79°F (stream **41a**) as it provides cooling and partial condensation of the combined stream **38**. Stream **42** passes countercurrently to the feed gas in heat exchanger **10** and is warmed to 23°F (stream **42a**) as it provides cooling and partial condensation of the feed gas. The two warmed streams **41a** and **42a** then recombine as residue gas stream **39b** at a temperature of 51°F. This recombined stream is then re-compressed in two stages. The first stage is compressor **13** driven by expansion machine **12**. The second stage is compressor **19** driven by a supplemental power source which compresses the residue gas (stream **39c**) to sales line pressure. After cooling in discharge cooler **20**, the cooled stream **39e** is split into the residue gas product (stream **47**) and the recycle stream **46** as described earlier. The residue gas product (stream **47**) flows to the sales gas pipeline at 88°F and 835 psia.

A summary of stream flow rates and energy consumptions for the process illustrated in FIG. 3 is set forth in the following table:

TABLE III

(FIG. 3)

Stream Flow Summary - (Lb. Moles/Hr)

Stream	Methane		Ethane		Propane	Butanes+	Total
31	5516	1287	633	371	8235		
32	4357	1017	500	293	6505		
35	1159	270	133	78	1730		
33	2394	213	40	8	2853		
34	1963	804	460	285	3652		
39	6040	71	3	0	6444		
46	553	7	0	0	590		
38	1712	277	133	78	2320		
47	5487	64	3	0	5854		
40	29	1223	630	371	2381		

Recoveries*	
Ethane	95.00%
Propane	99.48%
Butanes+	99.93%
Horsepower	
Residue Compression	3,329
Refrigeration Compression	1,897
Total	5,226

* (Based on un-rounded flow rates)

Comparison of the recovery levels and utility usages displayed in Tables I and III shows that the present invention maintains essentially the same ethane, propane, and butanes+ recovery as the FIG. 1 process while reducing the horsepower (utility) requirements by about 6 percent. The quantity of the top tower feed for the FIG. 3 process (stream **38c**) is roughly the same as for the FIG. 1 process

(stream **35c**), but in the present invention a substantial fraction of the top feed is composed of residual methane, resulting in concentrations of C_2+ components in the top feed that are significantly lower for the FIG. 3 process. Thus, combining the residual methane in recycle stream **46** with a portion of the feed gas allows the present invention to provide a top reflux stream for demethanizer **18** that is leaner than the feed gas, but which is still of sufficient quantity to be effective in absorbing the C_2+ components in the vapors rising up through the tower.

Comparison of the recovery levels and utility usages displayed in Tables II and III shows that the present invention also maintains the same ethane recovery as the FIG. 2 process with a similar reduction of about 6 percent in the horsepower (utility) requirements. Although the FIG. 2 process has slightly better propane recovery (100.00% versus 99.48%) and butanes+ recovery (100.00% versus 99.93%) than the FIG. 3 process, the present invention as depicted in FIG. 3 requires significantly fewer equipment items than the FIG. 2 process, resulting in much lower capital investment. The fractionation tower **18** in the FIG. 3 process also requires fewer contact stages than the corresponding tower in FIG. 2, further reducing capital investment. The reduction in both operating and capital expenses achieved by the present invention is a result of using the mass of a portion of the feed gas to supplement the mass in the residual methane recycle stream, so that there is then sufficient mass in the top reflux feed to the demethanizer to use the refrigeration available in the recycle stream in an effective manner to absorb C_2+ components from the vapors rising up through the tower.

A further advantage of the present invention over the prior art processes is a reduced likelihood of carbon dioxide icing. FIG. 4 is a graph of the relation between carbon dioxide concentration and temperature. Line **71** represents the equilibrium conditions for solid and liquid carbon dioxide in hydrocarbon mixtures like those found on the fractionation stages of demethanizer **18** in FIGS. 1 through 3. (This graph is similar to the one given in the article "Shortcut to CO_2 Solubility" by Warren E. White, Karl M. Forency, and Ned P. Baudat, *Hydrocarbon Processing*, V. 52, pp. 107-108, August 1973, but the relationship depicted in FIG. 4 for the liquid-solid equilibrium line has been calculated using an equation of state to

properly account for the influence of hydrocarbons heavier than methane.) A liquid temperature on or to the right of line 71, or a carbon dioxide concentration on or above this line, signifies an icing condition. Because of the variations which normally occur in gas processing facilities (e.g., feed gas composition, conditions, and flow rate), it is usually desired to design a demethanizer with a considerable safety factor between the expected operating conditions and the icing conditions. Experience has shown that the conditions of the liquids on the fractionation stages of a demethanizer, rather than the conditions of the vapors, govern the allowable operating conditions in most demethanizers. For this reason, the corresponding vapor-solid equilibrium line is not shown in FIG. 4.

Also plotted in FIG. 4 are lines representing the conditions for the liquids on the fractionation stages of demethanizer 18 in the FIG. 1 and FIG. 2 processes (lines 72 and 73, respectively). For FIG. 1, there is a safety factor of 1.17 between the anticipated operating conditions and the icing conditions. That is, an increase of 17 percent in the carbon dioxide content of the liquid could cause icing. For the FIG. 2 process, however, a portion of the operating line lies to the right of the liquid-solid equilibrium line, indicating that the FIG. 2 process cannot be operated at these conditions without encountering icing problems. As a result, it is not possible to use the FIG. 2 process under these conditions, so its potential for improved efficiency over the FIG. 1 process could not actually be realized in practice without removal of at least some of the carbon dioxide from the feed gas. This would, of course, substantially increase capital cost.

Line 74 in FIG. 4 represents the conditions for the liquids on the fractionation stages of demethanizer 18 in the present invention as depicted in FIG. 3. In contrast to the FIG. 1 and FIG. 2 processes, there is a safety factor of 1.33 between the anticipated operating conditions and the icing conditions for the FIG. 3 process. Thus, the present invention could tolerate nearly double the increase in the concentration of carbon dioxide that the FIG. 1 process could tolerate without risk of icing. Further, whereas the FIG. 2 process cannot be operated to achieve the recovery levels given in Table II because of icing, the present invention could in fact be

operated at even higher recovery levels than those given in Table III without risk of icing.

The shift in the operating conditions of the FIG. 3 demethanizer as indicated by line 74 in FIG. 4 can be understood by comparing the distinguishing features of the present invention to the prior art processes of FIGS. 1 and 2. The shape of the operating line for the FIG. 1 process (line 72) is very similar to the shape of the operating line for the present invention. The major difference is that the operating temperatures of the fractionation stages in the demethanizer in the FIG. 3 process are significantly warmer than those of the corresponding fractionation stages in the demethanizer in the FIG. 1 process, effectively shifting the operating line of the FIG. 3 process away from the liquid-solid equilibrium line. The warmer temperatures of the fractionation stages in the FIG. 3 demethanizer are the result of operating the tower at substantially higher pressure than the FIG. 1 process. However, the higher tower pressure does not cause a loss in C_2+ component recovery levels because the recycle stream 46 in the FIG. 3 process is in essence an open direct-contact compression-refrigeration cycle for the demethanizer using a portion of the volatile residue gas as the working fluid, supplying needed refrigeration to the process to overcome the loss in recovery that normally accompanies an increase in demethanizer operating pressure.

The prior art FIG. 2 process is similar to the present invention in that it also employs an open compression-refrigeration cycle to supply additional refrigeration to its demethanizer. However, in the present invention, the volatile residue gas working fluid is enriched with heavier hydrocarbons from the feed gas. As a result, the liquids on the fractionation stages in the upper section of the FIG. 3 demethanizer contain higher concentrations of C_4+ hydrocarbons than those of the corresponding fractionation stages in the demethanizer in the FIG. 2 process. The effect of these heavier hydrocarbon components (along with the higher operating pressure of the tower) is to raise the bubble point temperatures of the tray liquids. This produces warmer operating temperatures for the fractionation stages in the FIG. 3 demethanizer, once again shifting the operating line of the FIG. 3 process away from the liquid-solid equilibrium line.

Example 2

FIG. 3 represents the preferred embodiment of the present invention for the temperature and pressure conditions shown because it typically requires the least equipment and the lowest capital investment. An alternative method of enriching the recycle stream is shown in another embodiment of the present invention as illustrated in FIG. 5. The feed gas composition and conditions considered in the process presented in FIG. 5 are the same as those in FIGS. 1 through 3. Accordingly, FIG. 5 can be compared with the FIGS. 1 and 2 processes to illustrate the advantages of the present invention, and can likewise be compared to the embodiment displayed in FIG. 3.

In the simulation of the FIG. 5 process, feed gas enters at 88°F and 840 psia as stream **31** and is cooled in heat exchanger **10** by heat exchange with a portion of the cool residue gas at -55°F (stream **42**), demethanizer reboiler liquids at 22°F, demethanizer side reboiler liquids at -71°F, and external propane refrigerant. The cooled stream **31a** enters separator **11** at -45°F and 825 psia where the vapor (stream **33**) is separated from the condensed liquid (stream **34**).

The vapor (stream **33**) from separator **11** enters a work expansion machine **12** in which mechanical energy is extracted from this portion of the high pressure feed. The machine **12** expands the vapor substantially isentropically from a pressure of about 825 psia to the operating pressure (approximately 297 psia) of fractionation tower **18**, with the work expansion cooling the expanded stream **33a** to a temperature of approximately -114°F. The expanded and partially condensed stream **33a** is then supplied as feed to distillation column **18** at a mid-column feed point.

The condensed liquid (stream **34**) from separator **11** is divided into two portions, streams **36** and **37**. Stream **37**, containing about 67 percent of the total condensed liquid, is flash expanded to the operating pressure (approximately 297 psia) of fractionation tower **18** through an appropriate expansion device, such as expansion valve **14**, cooling stream **37** to a temperature of -90°F (stream **37a**). The expanded stream **37a** leaving expansion valve **14** is then supplied to fractionation tower **18** at a lower mid-column feed point.

A portion of the high pressure residue gas (stream **46**) is withdrawn from the main residue flow (stream **39e**) and cooled to -25°F in heat exchanger **15** by heat exchange with the other portion of the cool residue gas at -55°F (stream **41**). The partially cooled recycle stream **46a** is then combined with the other portion of the liquid from separator **11**, stream **36** containing about 33 percent of the total condensed liquid. The combined stream **38** then passes through heat exchanger **16** in heat exchange relation with the -142°F cold distillation stream **39** and is cooled to -135°F (stream **38a**). The resulting substantially condensed stream **38a** is then flash expanded through an appropriate expansion device, such as expansion valve **17**, to the operating pressure (approximately 297 psia) of fractionation tower **18**. During expansion a portion of the stream is vaporized, resulting in cooling of the total stream. In the process illustrated in FIG. 5, the expanded stream **38b** leaving expansion valve **17** reaches a temperature of -151°F and is supplied to fractionation tower **18** as the top column feed. The vapor portion (if any) of stream **38b** combines with the vapors rising from the top fractionation stage of the column to form distillation stream **39**, which is withdrawn from an upper region of the tower.

The liquid product (stream **40**) exits the bottom of tower **18** at 46°F and flows to subsequent processing and/or storage. The cold distillation stream **39** at -142°F from the upper section of the demethanizer passes countercurrently to the combined stream **38** in heat exchanger **16** where it is warmed to -55°F (stream **39a**) as it provides cooling and substantial condensation of stream **38a**. The cool residue gas stream **39a** is then divided into two portions, streams **41** and **42**. Stream **41** passes countercurrently to the recycle gas in heat exchanger **15** and is warmed to 79°F (stream **41a**) as it provides cooling of recycle stream **46**. Stream **42** passes countercurrently to the feed gas in heat exchanger **10** and is warmed to 81°F (stream **42a**) as it provides cooling and partial condensation of the feed gas. The two warmed streams **41a** and **42a** then recombine as residue gas stream **39b** at a temperature of 81°F. This recombined stream is then re-compressed in two stages. The first stage is compressor **13** driven by expansion machine **12**. The second stage is compressor **19** driven by a supplemental power source which compresses the residue gas (stream **39c**) to sales line pressure. After cooling in discharge cooler **20**, the cooled stream **39e** is

split into the residue gas product (stream 47) and the recycle stream 46 as described earlier. The residue gas product (stream 47) flows to the sales gas pipeline at 88°F and 835 psia.

A summary of stream flow rates and energy consumptions for the process illustrated in FIG. 5 is set forth in the following table:

TABLE IV

(FIG. 5)

Stream Flow Summary - (Lb. Moles/Hr)

Stream	Methane		Ethane		Propane	Butanes+	Total
31	5516	1287	633	371	8235		
33	3324	320	63	13	3989		
34	2192	967	570	358	4246		
36	723	319	188	118	1400		
37	1469	648	382	240	2846		
39	6706	78	5	0	7151		
46	1219	14	1	0	1300		
38	1942	333	189	118	2700		
47	5487	64	4	0	5851		
40	29	1223	629	371	2384		

Recoveries*	
Ethane	95.00%
Propane	99.40%
Butanes+	99.92%
Horsepower	
Residue Compression	3,960
Refrigeration Compression	1,515
Total	5,475

* (Based on un-rounded flow rates)

A comparison of Tables III and IV shows that this embodiment of the present invention (FIG. 5) is capable of achieving essentially the same product recoveries as the previously shown embodiment of FIG. 3, although requiring higher horsepower (utility) requirements. When the present invention is employed as in Example 2 using a portion of the condensed liquid to enrich the recycle stream,

however, the advantage with regard to avoiding carbon dioxide icing conditions is further enhanced compared to the FIG. 3 embodiment. FIG. 6 is another graph of the relation between carbon dioxide concentration and temperature, with line 71 as before representing the equilibrium conditions for solid and liquid carbon dioxide in hydrocarbon mixtures like those found on the fractionation stages of demethanizer 18 in FIGS. 1, 2, 3, and 5. Line 75 in FIG. 6 represents the conditions for the liquids on the fractionation stages of demethanizer 18 in the present invention as depicted in FIG. 5, and shows a safety factor of 1.45 between the anticipated operating conditions and the icing conditions for the FIG. 5 process. Thus, this embodiment of the present invention could tolerate an increase of 45 percent in the concentration of carbon dioxide without risk of icing. In practice, this improvement in the icing safety factor could be used to advantage by operating the demethanizer at lower pressure (i.e., with colder temperatures on the fractionation stages) to raise the C_2+ component recovery levels without encountering icing problems. The shape of line 75 in FIG. 6 is very similar to that of line 74 in FIG. 4. The primary difference is the somewhat warmer operating temperatures of the fractionation stages in the FIG. 5 demethanizer due to the effect on the liquid bubble point temperatures from higher concentrations of heavier hydrocarbons in this embodiment when the condensed liquid is used to enrich the recycle stream.

Example 3

A third embodiment of the present invention is shown in FIG. 7, wherein additional equipment is used to further improve the recovery efficiency of the present invention. The feed gas composition and conditions considered in the process illustrated in FIG. 7 are the same as those in FIGS. 1, 2, 3, and 5.

In the simulation of the FIG. 7 process, the feed gas splitting, cooling, and separation scheme and the recycle enrichment scheme are essentially the same as those used in FIG. 3. The difference lies in the disposition of the condensed liquids leaving separator 11 (stream 34). Rather than flash expanding the liquid stream and feeding it directly to the fractionation tower at a lower mid-column feed point, the

so-called auto-refrigeration process can be employed to cool a portion of the liquids so that they can become an effective upper mid-column feed stream.

The feed gas enters at 88°F and 840 psia as stream **31** and is split into two portions, stream **32** and stream **35**. Stream **32**, containing about 79 percent of the total feed gas, enters heat exchanger **10** and is cooled by heat exchange with a portion of the cool residue gas at -26°F (stream **42**), demethanizer reboiler liquids at 23°F, demethanizer side reboiler liquids at -57°F, and external propane refrigerant. The cooled stream **32a** enters separator **11** at –38°F and 825 psia where the vapor (stream **33**) is separated from the condensed liquid (stream **34**).

The vapor (stream **33**) from separator **11** enters a work expansion machine **12** in which mechanical energy is extracted from this portion of the high pressure feed. The machine **12** expands the vapor substantially isentropically from a pressure of about 825 psia to the operating pressure (approximately 299 psia) of fractionation tower **18**, with the work expansion cooling the expanded stream **33a** to a temperature of approximately -106°F. The expanded and partially condensed stream **33a** is then supplied as feed to distillation column **18** at a mid-column feed point.

The condensed liquid (stream **34**) from separator **11** is directed to heat exchanger **22** where it is cooled to -115°F (stream **34a**). The subcooled stream **34a** is then divided into two portions, streams **36** and **37**. Stream **37** is flash expanded through an appropriate expansion device, such as expansion valve **23**, to slightly above the operating pressure of fractionation tower **18**. During expansion a portion of the liquid vaporizes, cooling the total stream to a temperature of -122°F (stream **37a**). The flash expanded stream **37a** is then routed to heat exchanger **22** to supply the cooling of stream **34** as described earlier. The resulting warmed stream **37b**, at a temperature of -45°F, is thereafter supplied to fractionation tower **18** at a lower mid-column feed point. The other portion of subcooled liquid (stream **36**) is also flash expanded through an appropriate expansion device, such as expansion valve **14**. During the flash expansion to the operating pressure of the demethanizer (approximately 299 psia), a portion of the liquid vaporizes, cooling the total stream to a temperature of -123°F (stream **36a**). The flash expanded stream **36a** is then supplied to fractionation tower **18** at an upper mid-column feed point, above the feed

point of work expanded stream **33a**.

Returning to the second portion (stream **35**) of the feed gas, the remaining 21 percent of the feed gas is combined with a portion of the high pressure residue gas (stream **46**) withdrawn from the main residue flow (stream **39e**). The combined stream **38** enters heat exchanger **15** and is cooled to -19°F by heat exchange with the other portion of the cool residue gas at -26°F (stream **41**) and with external propane refrigerant. The partially cooled stream **38a** then passes through heat exchanger **16** in heat exchange relation with the -144°F cold distillation stream **39** where it is further cooled to -137°F (stream **38b**). The resulting substantially condensed stream **38b** is then flash expanded through an appropriate expansion device, such as expansion valve **17**, to the operating pressure (approximately 299 psia) of fractionation tower **18**. During expansion a portion of the stream is vaporized, resulting in cooling of the total stream. In the process illustrated in FIG. 7, the expanded stream **38c** leaving expansion valve **17** reaches a temperature of -153°F and is supplied to fractionation tower **18** as the top column feed. The vapor portion (if any) of stream **38c** combines with the vapors rising from the top fractionation stage of the column to form distillation stream **39**, which is withdrawn from an upper region of the tower.

The liquid product (stream **40**) exits the bottom of tower **18** at 46°F and flows to subsequent processing and/or storage. The cold distillation stream **39** at -144°F from the upper section of the demethanizer passes countercurrently to the partially cooled combined stream **38a** in heat exchanger **16** where it is warmed to -26°F (stream **39a**) as it provides further cooling and substantial condensation of stream **38b**. The cool residue gas stream **39a** is then divided into two portions, streams **41** and **42**. Stream **41** passes countercurrently to the mixture of feed gas and recycle gas in heat exchanger **15** and is warmed to 79°F (stream **41a**) as it provides cooling and partial condensation of the combined stream **38**. Stream **42** passes countercurrently to the feed gas in heat exchanger **10** and is warmed to 79°F (stream **42a**) as it provide cooling and partial condensation of the feed gas. The two warmed streams **41a** and **42a** then recombine as residue gas stream **39b** at a temperature of 79°F. This recombined stream is then re-compressed in two stages. The first stage is

compressor **13** driven by expansion machine **12**. The second stage is compressor **19** driven by a supplemental power source which compresses the residue gas (stream **39c**) to sales line pressure. After cooling in discharge cooler **20**, the cooled stream **39e** is split into the residue gas product (stream **47**) and the recycle stream **46** as described earlier. The residue gas product (stream **47**) flows to the sales gas pipeline at 88°F and 835 psia.

A summary of stream flow rates and energy consumptions for the process illustrated in FIG. 7 is set forth in the following table:

TABLE V

(FIG. 7)

Stream Flow Summary - (Lb. Moles/Hr)

Stream	Methane		Ethane		Propane	Butanes+	Total
31	5516	1287	633	371	8235		
32	4357	1017	500	293	6505		
35	1159	270	133	78	1730		
33	2898	309	64	14	3515		
34	1459	708	436	279	2990		
36	622	302	186	119	1275		
37	837	406	250	160	1715		
39	6041	71	3	0	6435		
46	554	7	0	0	590		
38	1713	277	133	78	2320		
47	5487	64	3	0	5845		
40	29	1223	630	371	2390		

Recoveries*	
Ethane	95.00%
Propane	99.50%
Butanes+	99.93%
Horsepower	
Residue Compression	3,516
Refrigeration Compression	1,483
Total	4,999

* (Based on un-rounded flow rates)

A comparison of Tables III and V shows that this embodiment of the present invention (FIG. 7) is capable of achieving essentially the same product recoveries as the previously shown embodiment of FIG. 3, while requiring even lower

horsepower (utility) requirements (i.e., about 10 percent lower than the prior art processes depicted in FIGS. 1 and 2). In addition, the advantage with regard to avoiding carbon dioxide icing conditions is further enhanced compared to the FIG. 3 and FIG. 5 embodiments. FIG. 8 is another graph of the relation between carbon dioxide concentration and temperature, with line **71** as before representing the equilibrium conditions for solid and liquid carbon dioxide in hydrocarbon mixtures like those found on the fractionation stages of demethanizer **18** in FIGS. 1, 2, 3, 5, and 7. Line **76** in FIG. 8 represents the conditions for the liquids on the fractionation stages of demethanizer **18** in the present invention as depicted in FIG. 7, and shows a safety factor of 1.84 between the anticipated operating conditions and the icing conditions for the FIG. 7 process. Thus, this embodiment of the present invention could tolerate an increase of 84 percent in the concentration of carbon dioxide without risk of icing. In practice, this improvement in the icing safety factor could be used to advantage by operating the demethanizer at lower pressure (i.e., with colder temperatures on the fractionation stages) to raise the C_2+ component recovery levels without encountering icing problems. The carbon dioxide concentrations for line **76** in FIG. 8 are significantly lower than those of line **74** in FIG. 4. This is due to the absorption of carbon dioxide by the heavy hydrocarbon components in the upper mid-column feed, stream **36a**, preventing the carbon dioxide from concentrating as much in the upper section of the demethanizer in the FIG. 7 process as it does in the previous embodiments.

Other Embodiments

In accordance with this invention, the enriching of the recycle stream with heavier hydrocarbons can be accomplished in a number of ways. In the embodiments of FIGS. 3 and 7, this enrichment is accomplished by blending a portion of the feed gas with the recycle gas prior to any cooling of the feed gas. In the embodiment of FIG. 5, the enrichment is accomplished by blending the recycle gas with a portion of the condensed liquid that results after cooling the feed gas. As illustrated in FIG. 9, the enrichment could instead be accomplished by blending the

recycle gas with a portion (stream **35**) of the vapor remaining after cooling and partial condensation of the feed gas. In addition, the enrichment shown in FIG. 9 could be enhanced by also blending all or a portion of the condensed liquid (stream **36**) that results after cooling of the feed gas. The remaining portion, if any, of the condensed liquid (stream **37**) may be used for feed gas cooling or other heat exchange service before or after the expansion step prior to flowing to the demethanizer. In some embodiments, vapor splitting may be effected in a separator. Alternatively, the separator **11** in the processes shown in FIG. 9 may be unnecessary if the feed gas is relatively lean.

As depicted in FIG. 10, the enrichment can also be accomplished by blending the recycle gas with a portion of the feed gas before cooling, or after cooling but prior to any separation of liquids that may be condensed from the feed gas. Any liquid that is condensed (stream **34**) from the feed gas may be expanded and fed to the demethanizer, or may be used for feed gas cooling or other heat exchange service before or after the expansion step prior to flowing to the demethanizer. The separator **11** in the processes shown in FIG. 10 may be unnecessary if the feed gas is relatively lean.

Depending on the relative temperatures and quantities of individual streams, two or more of the feed streams, or portions thereof, may be combined and the combined stream then fed to a mid-column feed position. For example, as depicted in FIG. 9, the remaining portion of the condensed liquid (stream **37**) can be flash expanded by expansion valve **14**, and then all or a portion of the flash expanded stream **37a** combined with at least a portion of the work expanded stream **33a** to form a combined stream that is then supplied to column **18** at a mid-column feed position. Similarly, as depicted in FIGS. 10 and 11, all or a portion of the flash expanded stream (stream **34a** in FIG. 10, stream **36a** in FIG. 11) can be combined with at least a portion of the work expanded stream **33a** to form a combined stream that is then supplied to column **18** at a mid-column feed position.

The examples of the present invention depicted in FIGS. 3, 5, 7, 9, 10, and 11 illustrate withdrawal of recycle stream **46** after distillation stream **39** has been heated by heat exchange with the feed streams and has been compressed to pipeline

pressure. Depending on plant size, equipment cost and availability, etc., it may be advantageous to withdraw recycle stream **46** after heating but prior to compression, as depicted in FIG. 12. In such an embodiment, a separate compressor **24** and discharge cooler **25** can be used to raise the pressure of recycle stream **46b** so that it can then combine with a portion (stream **35**) of the feed gas. Alternatively, as depicted in FIG. 13, recycle stream **46** may be withdrawn from distillation stream **39** prior to either heating or compression. Recycle stream **46** can be used to supply a portion of the feed gas cooling, then flow to a separate compressor **24** and discharge cooler **25** to raise the pressure of recycle stream **46d** so that it can combine with a portion (stream **35**) of the feed gas.

The examples presented heretofore have all contemplated use of the present invention when the pressures of the feed gas and the residue gas are substantially the same. In situations where this is not the case, however, boosting of the lower pressure stream can be employed in accordance with the present invention. Some of the alternative means of applying the present invention in these situations are illustrated in FIGS. 14 through 16, showing boosting of the recycle gas, the feed gas, and the condensed liquids, respectively.

In accordance with this invention, the use of external refrigeration to supplement the cooling available to the feed gas from other process streams may be unnecessary, particularly in the case of a feed gas leaner than that used in Example 1. The use and distribution of demethanizer liquids for process heat exchange, and the particular arrangement of heat exchangers for feed gas cooling must be evaluated for each particular application, as well as the choice of process streams for specific heat exchange services.

The high pressure liquid in FIG. 3 (stream **34**) and the first portion of high pressure liquid in FIG. 5 (stream **37**) may be used for feed gas cooling or other heat exchange service before or after the expansion step prior to flowing to the demethanizer. As depicted in FIG. 17, the work expanded stream **33a** may also be used for feed gas cooling or other heat exchange service prior to flowing to the column.

The process of the present invention is also applicable for processing

gas streams when it is desirable to recover only the C_3 components and heavier hydrocarbon components (rejection of C_2 components and lighter components to the residue gas). Because of the warmer process operating conditions associated with propane recovery (ethane rejection) operation, the feed gas cooling scheme is usually different than for the ethane recovery cases illustrated in FIGS. 3, 5, 7, and 9 through 16. FIG. 17 illustrates a typical application of the present invention when recovery of only the C_3 components and heavier hydrocarbon components is desired. When operating as a deethanizer (ethane rejection), the tower reboiler temperatures are significantly warmer than when operating as a demethanizer (ethane recovery). Generally this makes it impossible to reboil the tower using plant feed gas as is typically done for ethane recovery operation. Therefore, an external source for reboil heat is normally employed. For example, a portion of compressed residue gas (stream **39d**) can sometimes be used to provide the necessary reboil heat. In some instances, a portion of the liquid downflow from the upper, colder section of the tower can be withdrawn and used for feed gas cooling in exchanger **10** and then returned to the tower in a lower, warmer section of the tower, maximizing heat recovery from the tower and minimizing external heat requirements.

It will also be recognized that the relative amount of feed found in each branch of the column feed streams will depend on several factors, including gas pressure, feed gas composition, the amount of heat which can economically be extracted from the feed, and the quantity of horsepower available. More feed to the top of the column may increase recovery while decreasing power recovered from the expansion machine thereby increasing the recompression horsepower requirements. Increasing feed lower in the column reduces the horsepower consumption but may also reduce product recovery. The mid-column feed positions depicted in FIGS. 3, 5, and 7 are the preferred feed locations for the process operating conditions described. However, the relative locations of the mid-column feeds may vary depending on inlet composition or other factors such as desired recovery levels and amount of liquid formed during feed gas cooling. FIGS. 3, 5, and 7 are the preferred embodiments for the compositions and pressure conditions shown. Although individual stream expansion is depicted in particular expansion devices, alternative expansion means

may be employed where appropriate. For example, conditions may warrant work expansion of the substantially condensed stream (**38b** in FIGS. 3 and 7, **38a** in FIG. 5).

While there have been described what are believed to be preferred embodiments of the invention, those skilled in the art will recognize that other and further modifications may be made thereto, e.g. to adapt the invention to various conditions, types of feed or other requirements without departing from the spirit of the present invention as defined by the following claims.

CLAIMS

1. In a process for the separation of a gas stream containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in which process

(a) said gas stream is cooled under pressure to provide a cooled stream;

(b) said cooled stream is expanded to a lower pressure whereby it is further cooled; and

(c) said further cooled stream is fractionated at said lower pressure whereby the components of said relatively less volatile fraction are recovered;

the improvement wherein prior to cooling, said gas is divided into gaseous first and second streams; and

(1) a distillation stream is withdrawn from an upper region of a fractionation tower and is warmed;

(2) said warmed distillation stream is compressed to higher pressure and thereafter divided into said volatile residue gas fraction and a compressed recycle stream;

(3) said compressed recycle stream is combined with said gaseous first stream to form a combined stream;

(4) said combined stream is cooled to condense substantially all of it;

(5) said substantially condensed combined stream is expanded to said lower pressure and supplied to said fractionation tower at a top feed position;

(6) said gaseous second stream is cooled under pressure sufficiently to partially condense it;



(7) said partially condensed second stream is separated thereby to provide a vapor stream and a condensed stream;

(8) said vapor stream is expanded to said lower pressure and supplied at a first mid-column feed position to a distillation column in a lower region of said fractionation tower;

(9) at least a portion of said condensed stream is expanded to said lower pressure and is supplied to said distillation column at a second mid-column feed position; and

(10) the quantity and pressure of said combined stream and the quantities and temperatures of said feed streams to the column are effective to maintain tower overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

2. In a process for the separation of a gas stream containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in which process

(a) said gas stream is cooled under pressure to provide a cooled stream;

(b) said cooled stream is expanded to a lower pressure whereby it is further cooled; and

(c) said further cooled stream is fractionated at said lower pressure whereby the components of said relatively less volatile fraction are recovered;

the improvement wherein said gas stream is cooled sufficiently to partially condense it; and

(1) said partially condensed gas stream is separated thereby to provide a vapor stream and a condensed stream;

(2) a distillation stream is withdrawn from an upper region of a fractionation tower and is warmed;

(3) said warmed distillation stream is compressed to higher pressure and thereafter divided into said volatile residue gas fraction and a compressed recycle stream;

(4) said compressed recycle stream is combined with at least a portion of said condensed stream to form a combined stream;

(5) said combined stream is cooled to condense substantially all of it;

(6) said substantially condensed combined stream is expanded to said lower pressure and supplied to said fractionation tower at a top feed position;

(7) said vapor stream is expanded to said lower pressure and supplied at a mid-column feed position to a distillation column in a lower region of said fractionation tower;

(8) the quantity and pressure of said combined stream and the quantities and temperatures of said feed streams to the column are effective to maintain tower overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

3. In a process for the separation of a gas stream containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in which process

(a) said gas stream is cooled under pressure to provide a cooled stream;

(b) said cooled stream is expanded to a lower pressure whereby it is further cooled; and

(c) said further cooled stream is fractionated at said lower pressure whereby the components of said relatively less volatile fraction are recovered;

the improvement wherein following cooling, said cooled stream

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is divided into first and second streams; and

(1) a distillation stream is withdrawn from an upper region of a fractionation tower and is warmed;

(2) said warmed distillation stream is compressed to higher pressure and thereafter divided into said volatile residue gas fraction and a compressed recycle stream;

(3) said compressed recycle stream is combined with said first stream to form a combined stream;

(4) said combined stream is cooled to condense substantially all of it;

(5) said substantially condensed combined stream is expanded to said lower pressure and supplied to said fractionation tower at a top feed position;

(6) said second stream is expanded to said lower pressure and supplied at a mid-column feed position to a distillation column in a lower region of said fractionation tower; and

(7) the quantity and pressure of said combined stream and the quantities and temperatures of said feed streams to the column are effective to maintain tower overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

4. In a process for the separation of a gas stream containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in which process

(a) said gas stream is cooled under pressure to provide a cooled stream;

(b) said cooled stream is expanded to a lower pressure whereby it is further cooled; and

(c) said further cooled stream is fractionated at said lower

pressure whereby the components of said relatively less volatile fraction are recovered;

the improvement wherein said gas stream is cooled sufficiently to partially condense it; and

(1) said partially condensed gas stream is separated thereby to provide a vapor stream and a condensed stream;

(2) said vapor stream is thereafter divided into gaseous first and second streams;

(3) a distillation stream is withdrawn from an upper region of a fractionation tower and is warmed;

(4) said warmed distillation stream is compressed to higher pressure and thereafter divided into said volatile residue gas fraction and a compressed recycle stream;

(5) said compressed recycle stream is combined with said gaseous first stream to form a combined stream;

(6) said combined stream is cooled to condense substantially all of it;

(7) said substantially condensed combined stream is expanded to said lower pressure and supplied to said fractionation tower at a top feed position;

(8) said gaseous second stream is expanded to said lower pressure and supplied at a first mid-column feed position to a distillation column in a lower region of said fractionation tower;

(9) at least a portion of said condensed stream is expanded to said lower pressure and is supplied to said distillation column at a second mid-column feed position; and

(10) the quantity and pressure of said combined stream and the quantities and temperatures of said feed streams to the column are effective to maintain tower overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

5. In a process for the separation of a gas stream containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in which process

(a) said gas stream is cooled under pressure to provide a cooled stream;

(b) said cooled stream is expanded to a lower pressure whereby it is further cooled; and

(c) said further cooled stream is fractionated at said lower pressure whereby the components of said relatively less volatile fraction are recovered;

the improvement wherein said gas stream is cooled sufficiently to partially condense it; and

(1) said partially condensed gas stream is separated thereby to provide a vapor stream and a condensed stream;

(2) said vapor stream is thereafter divided into gaseous first and second streams;

(3) a distillation stream is withdrawn from an upper region of a fractionation tower and is warmed;

(4) said warmed distillation stream is compressed to higher pressure and thereafter divided into said volatile residue gas fraction and a compressed recycle stream;

(5) said compressed recycle stream is combined with said gaseous first stream and at least a portion of said condensed stream to form a combined stream;

(6) said combined stream is cooled to condense substantially all of it;

(7) said substantially condensed combined stream is expanded to said lower pressure and supplied to said fractionation tower at a top feed position;

(8) said gaseous second stream is expanded to said lower pressure and supplied at a mid-column feed position to a distillation column in a lower region of said fractionation tower;

(9) the quantity and pressure of said combined stream and the quantities and temperatures of said feed streams to the column are effective to maintain tower overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

6. In a process for the separation of a gas stream containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in which process

(a) said gas stream is cooled under pressure to provide a cooled stream;

(b) said cooled stream is expanded to a lower pressure whereby it is further cooled; and

(c) said further cooled stream is fractionated at said lower pressure whereby the components of said relatively less volatile fraction are recovered;

the improvement wherein prior to cooling, said gas is divided into gaseous first and second streams; and

(1) a distillation stream is withdrawn from an upper region of a fractionation tower and is warmed;

(2) said warmed distillation stream is compressed to higher pressure and thereafter divided into said volatile residue gas fraction and a compressed recycle stream;

(3) said compressed recycle stream is combined with said gaseous first stream to form a combined stream;

(4) said combined stream is cooled to condense substantially all of it;



(5) said substantially condensed combined stream is expanded to said lower pressure and supplied to said fractionation tower at a top feed position;

(6) said gaseous second stream is cooled under pressure and then expanded to said lower pressure and supplied at a mid-column feed position to a distillation column in a lower region of said fractionation tower; and

(7) the quantity and pressure of said combined stream and the quantities and temperatures of said feed streams to the column are effective to maintain tower overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

7. In a process for the separation of a gas stream containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in which process

(a) said gas stream is cooled under pressure to provide a cooled stream;

(b) said cooled stream is expanded to a lower pressure whereby it is further cooled; and

(c) said further cooled stream is fractionated at said lower pressure whereby the components of said relatively less volatile fraction are recovered;

the improvement wherein following cooling, said cooled stream is divided into first and second streams; and

(1) a distillation stream is withdrawn from an upper region of a fractionation tower and is warmed;

(2) said warmed distillation stream is compressed to higher pressure and thereafter divided into said volatile residue gas fraction and a compressed recycle stream;

(3) said compressed recycle stream is combined with said

first stream to form a combined stream;

(4) said combined stream is cooled to condense substantially all of it;

(5) said substantially condensed combined stream is expanded to said lower pressure and supplied to said fractionation tower at a top feed position;

(6) said second stream is cooled sufficiently to partially condense it;

(7) said partially condensed second stream is separated thereby to provide a vapor stream and a condensed stream;

(8) said vapor stream is expanded to said lower pressure and supplied at a first mid-column feed position to a distillation column in a lower region of said fractionation tower;

(9) at least a portion of said condensed stream is expanded to said lower pressure and is supplied to said distillation column at a second mid-column feed position; and

(10) the quantity and pressure of said combined stream and the quantities and temperatures of said feed streams to the column are effective to maintain tower overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

8. The improvement according to claims 1, 2, 3, 4, 5, 6 or 7 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

9. The improvement according to claims 1, 2, 3, 4, 5, 6 or 7 wherein

(a) said distillation stream is divided into said volatile

residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

10. The improvement according to claims 2 or 5 wherein at least a portion of said condensed stream is expanded to said lower pressure and then supplied to said distillation column at a second mid-column feed position.

11. The improvement according to claim 10 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

12. The improvement according to claim 10 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

13. The improvement according to claims 1, 4 or 7 wherein

(a) said condensed stream is cooled and then divided into first and second liquid portions prior to said expansion;

(b) said first liquid portion is expanded to said lower pressure and supplied to said column at a mid-column feed position; and

(c) said second liquid portion is expanded to said lower pressure and supplied to said column at a higher mid-column feed position.

14. The improvement according to claim 13 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

15. The improvement according to claim 13 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

16. The improvement according to claim 13 wherein said expanded first liquid portion is heated prior to being supplied to said distillation column.

17. The improvement according to claim 16 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

18. The improvement according to claim 16 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

19. The improvement according to claim 13 wherein said first liquid portion is expanded, directed in heat exchange relation with said condensed stream and is then supplied to said column at a mid-column feed position.

20. The improvement according to claim 19 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

21. The improvement according to claim 19 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

22. The improvement according to claims 1, 2 or 7 wherein at least a portion of said vapor stream is heated after expansion to said lower pressure.

23. The improvement according to claim 22 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

24. The improvement according to claim 22 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

25. The improvement according to claims 3, 4, 5 or 6 wherein at least a portion of said second stream is heated after expansion to said lower pressure.

26. The improvement according to claim 25 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said

compressed recycle stream.

27. The improvement according to claim 25 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

28. The improvement according to claims 1, 4 or 7 wherein at least a portion of said expanded condensed stream is heated prior to being supplied to said distillation column.

29. The improvement according to claim 28 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

30. The improvement according to claim 28 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

31. The improvement according to claims 2 or 5 wherein at least a portion of said condensed stream is expanded to said lower pressure, heated and then supplied to said distillation column at a second mid-column feed position.

32. The improvement according to claim 31 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

33. The improvement according to claim 31 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

34. The improvement according to claims 1 or 7 wherein at least portions of said expanded vapor stream and said expanded condensed stream are combined to form a second combined stream, whereupon said second combined stream is supplied to said column at a mid-column feed position.

35. The improvement according to claim 34 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

36. The improvement according to claim 34 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

37. The improvement according to claim 2 wherein at least a portion of said condensed stream is expanded to said lower pressure and combined with at least a portion of said expanded vapor stream to form a second combined stream, whereupon said second combined stream is supplied to said column at a mid-column feed position.

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38. The improvement according to claim 37 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

39. The improvement according to claim 37 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

40. The improvement according to claim 4 wherein at least portions of said expanded second stream and said expanded condensed stream are combined to form a second combined stream, whereupon said second combined stream is supplied to said column at a mid-column feed position.

41. The improvement according to claim 40 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

42. The improvement according to claim 40 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

43. The improvement according to claim 5 wherein at least a portion of said condensed stream is expanded to said lower pressure and combined

with at least a portion of said expanded second stream to form a second combined stream, whereupon said second combined stream is supplied to said column at a mid-column feed position.

44. The improvement according to claim 43 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

45. The improvement according to claim 43 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

46. The improvement according to claims 1 or 7 wherein

(a) said condensed stream is cooled and then divided into first and second liquid portions prior to said expansion;

(b) said first liquid portion is expanded to said lower pressure and supplied to said column at a mid-column feed position;

(c) said second liquid portion is expanded to said lower pressure and combined with at least a portion of said expanded vapor stream to form a second combined stream; and

(d) said second combined stream is supplied to said column at a higher mid-column feed position.

47. The improvement according to claim 46 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said

compressed recycle stream.

48. The improvement according to claim 46 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

49. The improvement according to claim 46 wherein said expanded first liquid portion is heated prior to being supplied to said distillation column.

50. The improvement according to claim 49 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

51. The improvement according to claim 49 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

52. The improvement according to claim 46 wherein said first liquid portion is expanded, directed in heat exchange relation with said condensed stream and is then supplied to said column at a mid-column feed position.

53. The improvement according to claim 52 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said



compressed recycle stream.

54. The improvement according to claim 52 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

55. The improvement according to claim 4 wherein

(a) said condensed stream is cooled and then divided into first and second liquid portions prior to said expansion;

(b) said first liquid portion is expanded to said lower pressure and supplied to said column at a mid-column feed position;

(c) said second liquid portion is expanded to said lower pressure and combined with at least a portion of said expanded second stream to form a second combined stream; and

(d) said second combined stream is supplied to said column at a higher mid-column feed position.

56. The improvement according to claim 55 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

57. The improvement according to claim 55 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

58. The improvement according to claim 55 wherein said expanded first liquid portion is heated prior to being supplied to said distillation column.

59. The improvement according to claim 58 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

60. The improvement according to claim 58 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

61. The improvement according to claim 55 wherein said first liquid portion is expanded, directed in heat exchange relation with said condensed stream and is then supplied to said column at a mid-column feed position.

62. The improvement according to claim 61 wherein

(a) said warmed distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to compression; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

63. The improvement according to claim 61 wherein

(a) said distillation stream is divided into said volatile residue gas fraction and a recycle stream prior to heating; and

(b) said recycle stream is thereafter compressed to form said compressed recycle stream.

64. In an apparatus for the separation of a gas containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in said apparatus there being

(a) a first cooling means to cool said gas under pressure connected to provide a cooled stream under pressure;

(b) a first expansion means connected to receive at least a portion of said cooled stream under pressure and to expand it to a lower pressure, whereby said stream is further cooled; and

(c) a fractionation tower connected to said first expansion means to receive said further cooled stream therefrom;

the improvement wherein said apparatus includes

(1) first dividing means prior to said first cooling means to divide said feed gas into a first gaseous stream and a second gaseous stream;

(2) heating means connected to said fractionation tower to receive a distillation stream which rises in the fractionation tower and to heat it;

(3) compressing means connected to said heating means to receive said heated distillation stream and to compress it;

(4) second dividing means connected to said compressing means to receive said heated compressed distillation stream and to divide it into said volatile residue gas fraction and a compressed recycle stream;

(5) combining means connected to combine said compressed recycle stream and said first gaseous stream into a combined stream;

(6) second cooling means connected to said combining means to receive said combined stream and to cool it sufficiently to substantially condense it;

(7) second expansion means connected to said second cooling means to receive said substantially condensed combined stream and to expand it to said lower pressure; said second expansion means being further connected to said fractionation tower to supply said expanded condensed combined stream to the tower

at a top feed position;

(8) said first cooling means being connected to said first dividing means to receive said second gaseous stream and to cool it under pressure sufficiently to partially condense it;

(9) separation means connected to said first cooling means to receive said partially condensed second stream and to separate it into a vapor and a condensed stream;

(10) said first expansion means being connected to said separation means to receive said vapor stream and to expand it to said lower pressure; said first expansion means being further connected to a distillation column in a lower region of said fractionation tower to supply said expanded vapor stream to said distillation column at a first mid-column feed position;

(11) third expansion means being connected to said separation means to receive said condensed stream and to expand it to said lower pressure; said third expansion means being further connected to said distillation column to supply said expanded condensed stream to said distillation column at a second mid-column feed position; and

(12) control means adapted to regulate the pressure of said combined stream and the quantities and temperatures of said combined stream, said second stream and said condensed stream to maintain column overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

65. In an apparatus for the separation of a gas containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in said apparatus there being

(a) a first cooling means to cool said gas under pressure connected to provide a cooled stream under pressure;

(b) a first expansion means connected to receive at least a

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portion of said cooled stream under pressure and to expand it to a lower pressure, whereby said stream is further cooled; and

(c) a fractionation tower connected to said first expansion means to receive said further cooled stream therefrom;

the improvement wherein said apparatus includes

(1) first cooling means adapted to cool said feed gas under pressure sufficiently to partially condense it;

(2) separation means connected to said first cooling means to receive said partially condensed feed stream and to separate it into a vapor and a condensed stream;

(3) heating means connected to said fractionation tower to receive a distillation stream which rises in the fractionation tower and to heat it;

(4) compressing means connected to said heating means to receive said heated distillation stream and to compress it;

(5) dividing means connected to said compressing means to receive said heated compressed distillation stream and to divide it into said volatile residue gas fraction and a compressed recycle stream;

(6) combining means connected to combine said compressed recycle stream and at least a portion of said condensed stream into a combined stream;

(7) second cooling means connected to said combining means to receive said combined stream and to cool it sufficiently to substantially condense it;

(8) second expansion means connected to said second cooling means to receive said substantially condensed combined stream and to expand it to said lower pressure; said second expansion means being further connected to said fractionation tower to supply said expanded condensed combined stream to the tower at a top feed position;

(9) said first expansion means being connected to said separation means to receive said vapor stream and to expand it to said lower pressure; said first expansion means being further connected to a distillation column in a lower

region of said fractionation tower to supply said expanded vapor stream to said distillation column at a mid-column feed position; and

(10) control means adapted to regulate the pressure of said combined stream and the quantities and temperatures of said combined stream and said vapor stream to maintain column overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

66. In an apparatus for the separation of a gas containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in said apparatus there being

(a) a first cooling means to cool said gas under pressure connected to provide a cooled stream under pressure;

(b) a first expansion means connected to receive at least a portion of said cooled stream under pressure and to expand it to a lower pressure, whereby said stream is further cooled; and

(c) a fractionation tower connected to said first expansion means to receive said further cooled stream therefrom;

the improvement wherein said apparatus includes

(1) first dividing means prior to said first cooling means to divide said feed gas into a first gaseous stream and a second gaseous stream;

(2) heating means connected to said fractionation tower to receive a distillation stream which rises in the fractionation tower and to heat it;

(3) compressing means connected to said heating means to receive said heated distillation stream and to compress it;

(4) second dividing means connected to said compressing means to receive said heated compressed distillation stream and to divide it into said volatile residue gas fraction and a compressed recycle stream;

(5) combining means connected to combine said

compressed recycle stream and said first gaseous stream into a combined stream;

(6) second cooling means connected to said combining means to receive said combined stream and to cool it sufficiently to substantially condense it;

(7) second expansion means connected to said second cooling means to receive said substantially condensed combined stream and to expand it to said lower pressure; said second expansion means being further connected to said fractionation tower to supply said expanded condensed combined stream to the tower at a top feed position;

(8) said first cooling means being connected to said first dividing means to receive said second gaseous stream and to cool it under pressure;

(9) said first expansion means being connected to said first cooling means to receive said cooled second stream and to expand it to said lower pressure; said first expansion means being further connected to a distillation column in a lower region of said fractionation tower to supply said expanded second stream to said distillation column at a mid-column feed position; and

(10) control means adapted to regulate the pressure of said combined stream and the quantities and temperatures of said combined stream and said second stream to maintain column overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.

67. In an apparatus for the separation of a gas containing methane, C_2 components, C_3 components and heavier hydrocarbon components into a volatile residue gas fraction and a relatively less volatile fraction containing said C_2 components, C_3 components and heavier hydrocarbon components or said C_3 components and heavier hydrocarbon components, in said apparatus there being

(a) a first cooling means to cool said gas under pressure connected to provide a cooled stream under pressure;

(b) a first expansion means connected to receive at least a portion of said cooled stream under pressure and to expand it to a lower pressure,

whereby said stream is further cooled; and

(c) a fractionation tower connected to said first expansion means to receive said further cooled stream therefrom;

the improvement wherein said apparatus includes

(1) first dividing means prior to said first cooling means to divide said feed gas into a first gaseous stream and a second gaseous stream;

(2) heating means connected to said fractionation tower to receive a distillation stream which rises in the fractionation tower and to heat it;

(3) compressing means connected to said heating means to receive said heated distillation stream and to compress it;

(4) second dividing means connected to said compressing means to receive said heated compressed distillation stream and to divide it into said volatile residue gas fraction and a compressed recycle stream;

(5) combining means connected to combine said compressed recycle stream and said first gaseous stream into a combined stream;

(6) second cooling means connected to said combining means to receive said combined stream and to cool it sufficiently to substantially condense it;

(7) second expansion means connected to said second cooling means to receive said substantially condensed combined stream and to expand it to said lower pressure; said second expansion means being further connected to said fractionation tower to supply said expanded condensed combined stream to the tower at a top feed position;

(8) said first cooling means being connected to said first dividing means to receive said second gaseous stream and to cool it under pressure sufficiently to partially condense it;

(9) separation means connected to said first cooling means to receive said partially condensed second stream and to separate it into a vapor and a condensed stream;

(10) said first expansion means being connected to said separation means to receive said vapor stream and to expand it to said lower pressure;

said first expansion means being further connected to a distillation column in a lower region of said fractionation tower to supply said expanded vapor stream to said distillation column at a first mid-column feed position;

(11) heat exchange means being connected to said separation means to receive said condensed stream and cool it;

(12) third dividing means connected to said heat exchange means to receive said cooled condensed stream and divide it into a first liquid stream and a second liquid stream;

(13) third expansion means being connected to said third dividing means to receive said first liquid stream and to expand it to said lower pressure; said third expansion means being further connected to said heat exchange means to heat said expanded first liquid stream and thereby supply said cooling to said condensed stream; said heat exchange means being further connected to said distillation column to supply said heated expanded first liquid stream to said distillation column at a second mid-column feed position;

(14) fourth expansion means being connected to said third dividing means to receive said second liquid stream and to expand it to said lower pressure; said fourth expansion means being further connected to said distillation column at an upper mid-column feed position; and

(15) control means adapted to regulate the pressure of said combined stream and the quantities and temperatures of said combined stream, said second stream, said first liquid stream and said second liquid stream to maintain column overhead temperature at a temperature whereby the major portions of the components in said relatively less volatile fraction are recovered.