United States Patent

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[73] Assignee **Phillips Petroleum Company**
Continuation of application Ser. No. 510,299, Nov. 29, 1965, now abandoned.

[54] **GAS LIQUEFACTION BY REFRIGERATION WITH PARALLEL EXPANSION OF THE REFRIGERANT**
6 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **62/11,** 62/40
[51] **Int. Cl.** **F25j 1/00,** F25j 1/02
[50] **Field of Search** ..... 62/9, 9 A, 111, 23, 40, 23 A

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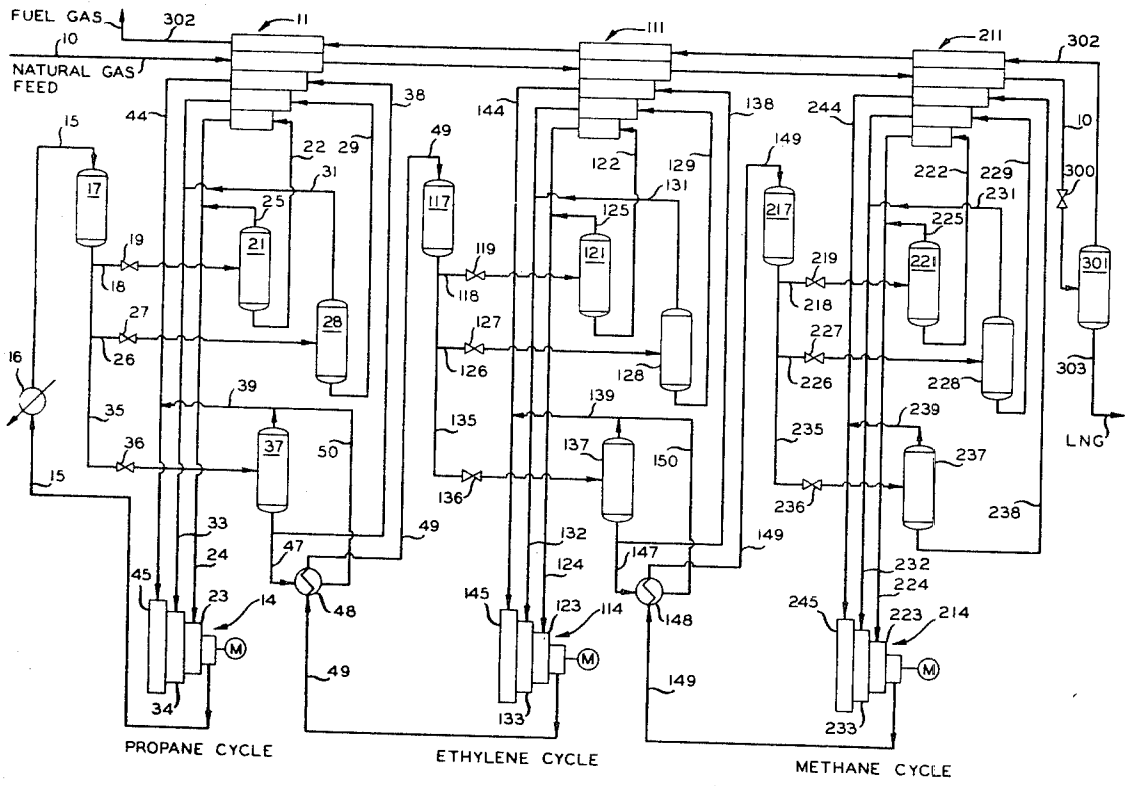
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ABSTRACT: A gaseous feed stream is cooled by a refrigerant which is expanded in parallel portions at different pressures. The lower pressure portion can be used in the same heat exchange zone as the higher pressure portion as well as in its own heat exchange zone. The lower pressure portion can be expanded first to the same pressure as the higher pressure portion and the vapor thus evolved combined with the vapor from the higher pressure portion for compression.



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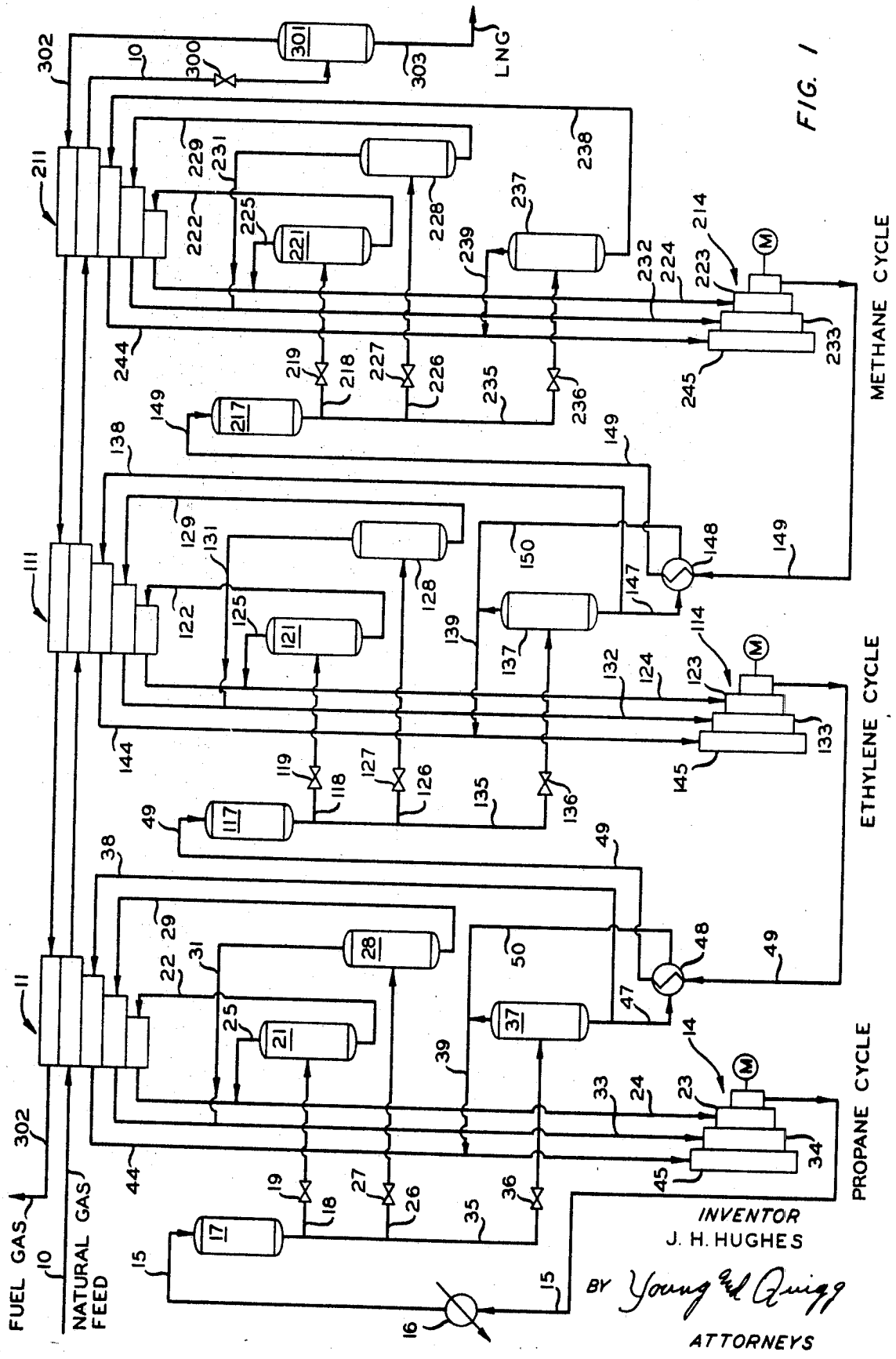


FIG. 1

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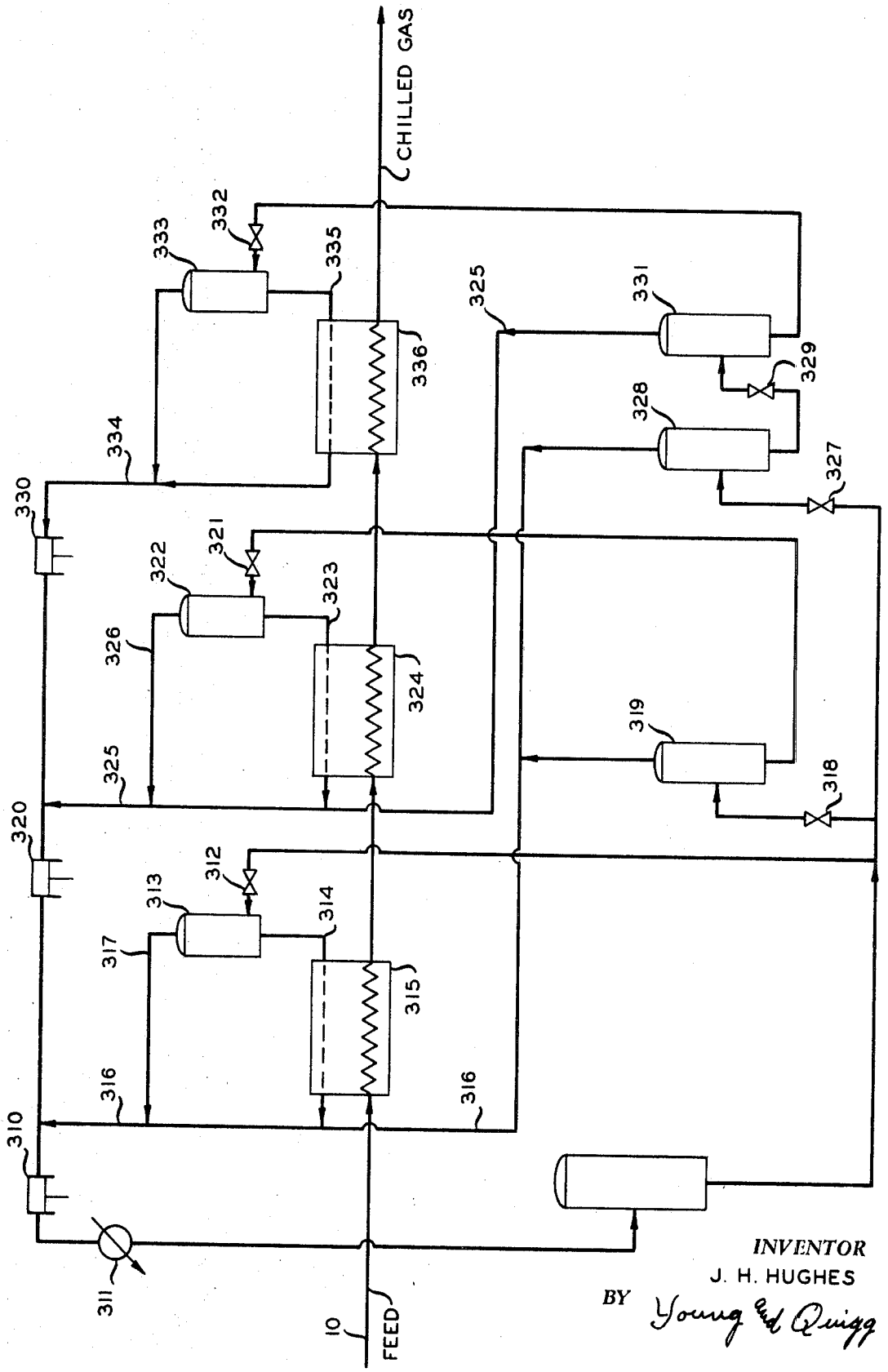


FIG. 2

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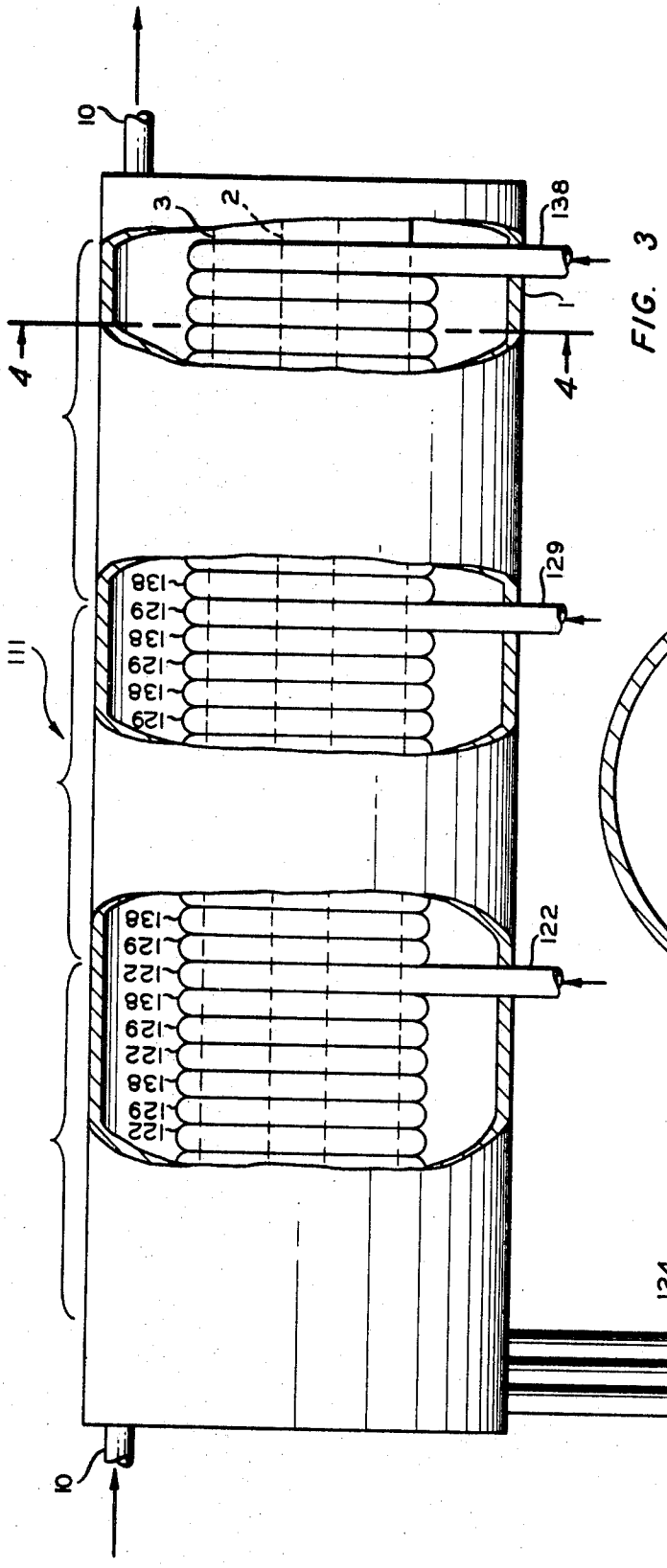
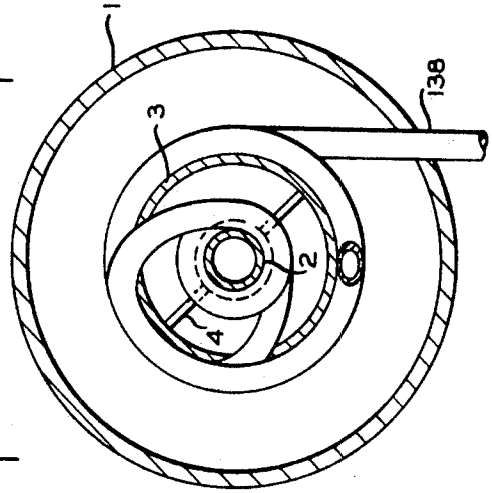


FIG. 3

FIG. 4



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GAS LIQUEFACTION BY REFRIGERATION WITH PARALLEL EXPANSION OF THE REFRIGERANT

This is a continuation of application, Ser. No. 510,299, filed Nov. 29, 1965 and now abandoned.

This invention relates to the liquefaction of a gas. In another aspect it relates to a refrigeration cycle for natural gas liquefaction. In one aspect this invention relates to a method and means for the expansion of a refrigerant in a refrigeration system. In another aspect this invention relates to a method and means for obtaining optimum efficiency of the refrigerant in a refrigeration system.

In the liquefaction of a gas such as natural gas, methane, nitrogen, oxygen, and the like, by low-temperature refrigeration to produce liquefied natural gas for storage or transport or for the recovery of gaseous helium therefrom, it is of utmost importance to obtain maximum efficiency of the refrigeration cycle in order to keep power and equipment costs at a minimum.

According to the present invention, the refrigerant in a refrigeration system is divided into at least two and preferably three segments, i.e., high-pressure, intermediate pressure, and low-pressure segments. The refrigerant is expanded from the compressed and condensed state in parallel to provide the separate segments. For example, the condensed refrigerant is supplied to separate heat exchangers or to separate entry points in a multiple stream exchanger through separate expansion valves and flash chambers. The expanded refrigerant of each segment is passed in heat exchange with the process gas. The portion of the refrigerant which is expanded to the higher pressure level is passed in heat exchange with the warm gas stream, and the portion of the refrigerant which is expanded to a lower pressure level is passed in heat exchange with the gas effluent from the first heat exchange step in a second heat exchange step. Thus the refrigerant vapors leave the heat exchange steps at different pressure levels.

Further according to the invention the expanded refrigerant of each segment then passes in parallel heat exchange relationship with the process gas, i.e., the gas stream to be cooled or liquefied. Parallel heat exchange relationship means that the refrigerant expanded to the highest pressure is passed in counter flow exchange relationship with the warm gas stream; the refrigerant expanded to the intermediate pressure level is heat exchanged with the gas effluent from the first heat exchange step in a second heat exchange step and is then passed in heat exchange relationship with the warm gas in the first heat exchange step; and the refrigerant expanded to the lowest pressure level is heat exchanged with the gas effluent from the second heat exchange step in a third heat exchange step and is then passed in heat exchange relationship with the gas in the second and first heat exchange steps. Thus, the refrigerant vapors exit the final heat exchange steps at substantially the same temperature but at different pressure levels so that the sensible heat of the refrigerant vapors as well as the latent heat of vaporization of the refrigerant is utilized in cooling the gas stream. Thus, according to the invention, each refrigerant is expanded to a plurality of pressure levels in parallel and the expanded refrigerants are heat exchanged with the process gas in parallel.

It is an object of this invention to provide a method and means for conserving energy in the liquefaction of a gas such as methane or natural gas by refrigeration. Another object of this invention is to provide a method and means for the parallel expansion of a refrigerant to a plurality of pressure levels and heat exchange of the separately expanded portion with a stream to be cooled. It is also an object of this invention to provide a method and means for the parallel expansion of a refrigerant to a plurality of pressure levels coupled with parallel flow of the various segments of the expanded refrigerant with the gas to be cooled. Still another object of the invention is to provide a method and means for optimum utilization of each refrigerant in a cascade refrigeration cycle.

Other objects, aspects and advantages of the invention will be apparent to one skilled in the art upon studying the disclosure, including the detailed description of the invention and the appended drawing wherein

FIG. 1 is a schematic flow diagram of a preferred embodiment of the invention;

FIG. 2 illustrates a modification of the invention as applied to the propane cycle of FIG. 1;

FIG. 3 is a detailed view, partly in section, of a heat exchanger applicable for use in the invention; and

FIG. 4 is a section of FIG. 3 along lines 4–4.

In the embodiment shown in FIG. 1 of the drawing, natural gas from which water, gasoline components and CO_2 have been removed is passed through conduit **10** at about 600 pounds per square inch absolute (p.s.i.a.) to a first heat exchanger **11** which can be a multistream heat exchanger of the type shown in greater detail in FIGS. **2**, **3** and **4**. Propane is compressed to about 150 p.s.i.a. in compressor **14** and passed via conduit **15** to a water cooler **16** where the propane is condensed with 90° F. water and then passed to a surge tank **17**. Liquid propane is removed from surge tank **17** and passed via conduit **18** and flashed through valve **19** into flash chamber **21** maintained at about 40° F. and about 80 p.s.i.a. Liquid propane at about 40° F. is passed from flash tank **21** via conduit **22** into heat exchanger **11** at the locus of heat exchanger **11** where the temperature is about 40° F. and the 80 p.s.i.a. vapors removed from heat exchanger **11** are passed to the high compression stage **23** of propane compressor **14** via conduit **24**. Vapors from flash tank **21** are removed via conduit **25** and also passed to high stage compression via conduit **24**.

Liquid propane is removed from surge tank **17** and passed via conduit **26** and flash valve **27** to flash tank **28** where the temperature is maintained at about 10° F. and a pressure of about 45 p.s.i.a. Liquid is removed from flash tank **28** via conduit **29** and passed into heat exchanger **11** at the point where the temperature in the heat exchanger is about 10° F. The 45 p.s.i.a. vapor is removed from heat exchanger **11** and then passed via conduit **33** to the intermediate stage of compression **34** of propane compressor **14**. Vapor from flash tank **28** is passed via conduit **31** to conduit **33**.

Liquid propane from surge tank **17** is passed via conduit **35** and flash valve **36** to a flash tank **37** where the temperature is maintained at about −30° F. at a pressure of about 20 p.s.i.a. Liquid from flash tank **37** is passed via conduit **38** into the cold end of heat exchanger **11** and the 20 p.s.i.a. vapors removed from the heat exchanger **11** are passed to the low compression stage **45** of compressor **14** via conduit **44**. Vapors from flash tank **37** are passed via conduit **39** to conduit **44**. A portion of the liquid from flash tank **37** is passed via conduit **47** through heat exchanger **48** in indirect heat exchange with ethylene in conduit **49** and thence via conduits **50** and **39** to conduit **44**.

Ethylene is compressed to about 300 p.s.i.a. in ethylene compressor **114** and passed via conduit **49** to heat exchanger **48** where it is condensed by heat exchange with liquid propane and then passed to surge tank **117** at about −20° F. and about 300 p.s.i.a. Liquid ethylene is removed from surge tank **117** via conduit **118** and flashed through valve **119** into flash tank **121** at about −90° F. and about 80 p.s.i.a. Liquid from flash tank **121** is passed via conduit **122** into heat exchanger **111** at the locus in heat exchanger **111** where the temperature is about −90° F. The 80 p.s.i.a. vapors removed from heat exchanger **111** are passed via conduit **124** to high stage of compression **123** of ethylene compressor **114**. Vapor from flash tank **121** is passed via conduit **125** to conduit **124**. Liquid ethylene from flash tank **117** is also passed via conduit **126** and flash valve **127** to flash tank **128** at about −135° F. and about 30 p.s.i.a. Liquid ethylene is removed from flash tank **128** and passed via conduit **129** to heat exchanger **111** at the locus of the heat exchanger where the temperature in the heat exchanger is about −135° F. The 30 p.s.i.a. vapors from heat exchanger **111** are passed via conduit **132** to the intermediate stage of ethylene compression **133** of ethylene compressor **114**. Vapors removed from flash tank **128** are passed via conduit **131** to conduit **132**.

Liquid ethylene from surge tank **117** is also passed via conduit **135** and flash valve **136** to flash tank **137** at about −140° F. and about 25 p.s.i.a. Liquid is passed from flash tank **137**

via conduit 138 into the cold end of heat exchanger 111. The 25 p.s.i.a. vapors from heat exchanger 111 are passed via conduit 144 to the low stage of compression 145 of ethylene compressor 114. Liquid ethylene from flash tank 137 is also passed via conduit 147 through heat exchanger 148 in indirect heat exchange with methane in conduit 149. Ethylene vapors from heat exchanger 148 are passed via conduit 150 along with vapors from flash tank 137 and conduit 139 to conduit 144.

Methane is compressed in compressor 214 to about 540 p.s.i.a., passed via conduit 149 and methane condenser 148 to surge tank 217 at about −130° F. and about 530 p.s.i.a. Liquid methane from surge tank 217 is passed via conduit 218 and flash valve 219 to flash tank 221 at about −175° F. and about 215 p.s.i.a. Liquid from flash tank 221 is passed via conduit 222 into heat exchanger 211 at the locus of heat exchanger 211 where the temperature is about −175° F. The 215 p.s.i.a. vapors from heat exchanger 211 are passed via conduit 224 to the low stage of compression 223 of methane compressor 214. Vapors from flash tank 221 are passed via conduit 225 to conduit 224. The liquid is also passed from surge tank 217 via conduit 226 and flash valve 227 to flash tank 228 at about −210° F. and about 85 p.s.i.a. Liquid from flash tank 228 is passed via conduit 229 into heat exchanger 211 at the locus where the temperature in heat exchanger 211 is about −210° F. The 85 p.s.i.a. vapor removed from heat exchanger 211 is passed via conduit 232 to the intermediate stage of compression 233 of methane compressor 214. Vapor from flash tank 228 is passed via conduit 231 to conduit 232.

Liquid methane from surge tank 217 is also passed via conduit 235 and flash valve 236 to flash tank 237 at about −240° F. and a pressure of about 30 p.s.i.a. Liquid from flash tank 237 is passed via conduit 238 into the cold end of heat exchanger 211. The 30 p.s.i.a. Vapors from heat-exchanger 211 are passed via conduit 244 into the low stage of compression 245 of methane heat-exchanger compressor 214. Vapors from flash tank 237 are passed via conduit 239 into conduit 244.

The natural gas stream removed from the cold end of heat exchanger conduit 10 is flashed in valve 300 and passed into flash tank 301 at about 15 p.s.i.a. (about atmospheric pressure) and a temperature of about −258° F. Vapors removed from product tank 301 via conduit 302 are passed in countercurrent flow relationship to the natural gas in conduit 10 through heat exchangers 211, 111 and 11 and removed from the warm end of heat exchanger 11 and passed to fuel gas supply or other disposition. Liquid natural gas product is removed as needed via conduit 303.

Referring now to FIG. 2, propane is compressed to 190 p.s.i.a. in propane compressor 310 and cooled to 100° F. in water cooled propane condenser 311. A first portion of the condensed propane is flashed through expansion valve 312 into flash tank 313 to a pressure of 90 p.s.i.a. and 50° F. Liquid propane is withdrawn from flash tank 313 and passed via conduit 314 into heat exchanger 315 in countercurrent flow relationship with natural gas, thus cooling the natural gas stream down to 55°. The propane effluent from heat exchanger 315 is passed via conduit 316 to the third stage of compression of propane 310. Vapors from flash tank 313 are passed via conduit 317 to conduit 316.

A second portion of condensed propane at 190 p.s.i.a. is flashed via expansion valve 318 into flash tank 319 at 90 p.s.i.a. and 50° F. Vapors from flash tank 319 are passed via conduit 316 to the high stage of compression of propane 310. Liquid from flash tank 319 is flashed through expansion valve 321 into flash tank 322 at 60 p.s.i.a. and 25° F. Liquid from flash tank 322 is passed via conduit 323 into heat exchanger 324 in heat exchange with the natural gas effluent from heat exchanger 315. Refrigerant vapors exiting heat exchanger 324 are passed via conduit 325 into an intermediate stage of compression of propane 320. Vapors from flash tank 322 are passed via conduit 326 to conduit 325.

A third portion of condensed propane at 190 p.s.i.a. is flashed via expansion valve 327 into flash tank 328 at 90 p.s.i.a. and 50° F. Vapors from flash tank 328 are passed via conduit 316 to the high stage of compression of propane 310. Liquid from flash tank 328 is flashed via expansion valve 329 into flash tank 331 at 60 p.s.i.s. and 25° F. Vapors from flash tank 331 are passed via conduit 325 to an intermediate stage of compression of propane 320. Liquid from flash tank 331 is flashed via expansion valve 332 into flash tank 333 at 20 p.s.i.a. and −30° F. Vapors from flash tank 333 are passed via conduit 334 to the low stage of compression of propane 330. Liquid from flash tank 333 is passed via conduit 335 into heat exchanger 336 in heat exchange with the natural gas effluent from heat exchanger 324.

The natural gas stream is cooled from about 80° F. to 55° F. in heat exchanger 315, exits heat exchanger 324 at 30° F. and exits heat exchanger 336 at −20° F.

It will be noted that in the modification of FIG. 2 a greater portion of the refrigerant vapors are returned to the high stage of compression than in the system of FIG. 1. The modification of FIG. 2 also makes it possible to accomplish a considerable amount of expansion of refrigerant outside the cold box where the low-temperature heat exchanger occurs and thus conserves space in the cold box.

Referring now to FIG. 3, one form of heat exchanger suitable for use in the invention is illustrated as applied to the ethylene cycle of the system of FIG. 1. Liquid ethylene at a temperature of about −90° F. and a pressure of about 80 p.s.i.a. is passed via conduit 122 into heat exchanger 111 at the locus in heat exchanger 111 where the temperature is about −90° F. The 80 p.s.i.a. vapors removed from heat exchanger 111 are passed via conduit 124 to the high stage of compression of the ethylene compressor. Liquid ethylene at about 30 p.s.i.a. and −135° F. is passed via conduit 129 to heat exchanger 111 at the locus of the heat exchanger where the temperature in the heat exchanger is about −135° F. The 30 p.s.i.a. vapors from heat exchanger 111 are passed via conduit 132 to the intermediate stage of the ethylene compressor. Liquid ethylene at about 25 p.s.i.a. and −140° F. is passed via conduit 138 into the cold end of heat exchanger 111. The 25 p.s.i.a. vapors from heat exchanger 111 are passed via conduit 144 to the low compression stage of the ethylene compressor.

The heat exchanger 111 can be fabricated as shown in FIGS. 3 and 4; for example, the heat exchanger 111 can be enclosed in a shell 1 having a primary core 2 and a secondary core 3 with tubing wrapped about the cores in alternate steps as shown in FIG. 4 with conduits 138 passing first about the secondary core 3 and then about the primary core 2, again about the secondary core 3, again about the primary core 2 and this sequence repeated to the point where conduit 129 enters the heat exchanger and then conduits 138 and 129 will alternate and this sequence will then be repeated until conduit 122 enters the heat exchanger and then these three conduits will alternate in the above-described sequence to the warm end of the heat exchanger.

The primary core 2 can be tubular and the secondary core 3 can be made up of wheellike segments supported on primary core 2 by spokes 4 with openings for entrance to and exits from the secondary core 3.

Any natural gas feed stream will contain compounds heavier than methane and as a result will condense at some temperature warmer than −124° F. at 600 p.s.i.a. (pure methane). This will move the refrigeration load to a warmer temperature and thus reduce the compression requirements for the refrigerants operating at the colder temperatures. The natural gas feed stream will often be obtained as the effluent from a natural gasoline plant and will, therefore, have the heavier hydrocarbons, water and CO_2 removed. In the example used in the description of FIG. 1, the natural gas stream had been dehydrated to a −100° F. dew point and contained less than 0.02 mol percent CO_2. If a wet gas stream is to be refrigerated for liquefaction of natural gas, provision should be made to withdraw as liquids compounds such as benzene and CO_2 which would solidify at the low temperatures contemplated. Such liquids can be tapped off from the heat exchangers at appropriate points of temperature and pressure.

Propane, ethylene and methane have been chosen as the refrigerant in the cascaded system in the specific embodiment of the invention described; however, other refrigerants such as ammonia, freons and the like, can be utilized if desired. Hydrocarbons will often be preferred as refrigerants because of their availability in connection with natural gas liquefaction and because of the range of hydrocarbons available for use as refrigerants.

Reasonable variations and modifications are possible within the scope of this disclosure without departing from the spirit and scope of the invention.

What I claim is:

1. The method of cooling a first gas stream which comprises the steps of:

compressing and condensing a second gas as a refrigerant in a closed cycle separate from said first gas stream;

dividing the condensed refrigerant into a plurality of portions;

flashing a first portion of the refrigerant to a first pressure to obtain a first refrigerating fluid comprising the resulting flashed liquid;

passing the first refrigerating fluid into a first heat exchange zone wherein said first fluid cools said gas stream by boiling at a first temperature and vaporizing in heat exchange therewith;

flashing a second portion of said refrigerant to a second pressure lower than said first pressure to obtain a second refrigerating fluid comprising the resulting flashed liquid;

passing the second refrigerating fluid into a second heat exchange zone wherein said second fluid cools the gas stream which has been heat exchanged with said first fluid in said first heat exchange zone by boiling at a second temperature lower than said first temperature and vaporizing in heat exchange therewith, and then passing the second fluid in heat exchange with said gas stream in said first heat exchange zone, the expansion of said first and second portions being in parallel; and

returning said first and second fluids to compression.

2. The method of claim 1 which comprises compressing and condensing a plurality of different refrigerants consisting of a warmest refrigerant, an intermediate temperature refrigerant and a cold refrigerant;

dividing each condensed refrigerant into a plurality of portions;

expanding a first portion of the warmest refrigerant to a first pressure;

heat exchanging said first expanded warmest refrigerant with the gas stream in a first heat exchange zone;

expanding a second portion of said warmest refrigerant to a second pressure lower than that of said first portion;

heat exchanging said second portion of said warmest refrigerant with the gas stream which has been heat exchanged with said first expanded warmest refrigerant portion in said first heat exchange zone and then with said gas stream in said first heat exchange zone, the expansion of the first and second portions of warmest refrigerant being in parallel;

expanding a first portion of an intermediate temperature refrigerant to a first pressure;

heat exchanging said first expanded intermediate temperature refrigerant with said gas stream exiting heat exchange with said warmest refrigerant in a second heat exchange zone;

expanding a second portion of said intermediate refrigerant to a second pressure lower than that of the first portion;

heat exchanging said second portion of intermediate temperature refrigerant with the gas stream which has been heat exchanged with said first expanded portion of intermediate temperature refrigerant in said second heat exchange zone and then with said gas stream in said second heat exchange zone, the expansion of the first and second portions of intermediate refrigerant being in parallel;

expanding a first portion of the coldest refrigerant to a first pressure;

heat exchanging said first expanded coldest refrigerant with said gas stream exiting heat exchange with said intermediate temperature refrigerant in a third heat exchange zone;

expanding a second portion of said coldest refrigerant to a second pressure lower than that of the first portion; and

heat exchanging said second portion of coldest refrigerant with said gas stream which has been heat exchanged with said first expanded portion of coldest refrigerant in said third heat exchange zone and then with said gas stream in said third heat exchange zone, the expansion of the first and second portions of coldest refrigerant being in parallel.

3. The method of claim 1 which comprises:

1. expanding a first portion of liquid propane to a first pressure, passing said first expanded portion of liquid propane into heat exchange relationship with said gas stream in a first heat exchange zone, expanding a second portion of liquid propane to a second pressure lower than that of said first portion, the expansion of the first and second portions of liquid propane being in parallel, passing a first portion of said second expanded portion of liquid propane in heat exchange relationship with said gas stream which has been heat exchanged with the first expanded portion of liquid propane in said first heat exchange zone and then into heat exchange relationship with said gas stream in said first heat exchange zone, and passing a second portion of said second expanded portion of liquid propane into heat exchange relationship with liquid ethylene;

2. expanding a first portion of liquid ethylene to a first pressure, passing said first expanded portion of liquid ethylene into heat exchange relationship in a second heat exchange zone with said gas stream exiting said first heat exchange zone, expanding a second portion of liquid ethylene to a second pressure lower than that of said first portion, the expansion of the first and second portions of liquid ethylene being in parallel, passing a first portion of said second expanded portion of liquid ethylene into heat exchange relationship with said gas stream which has been heat exchanged with first expanded portion of liquid ethylene in said second heat exchange zone and then into heat exchange relationship with said gas stream in said second heat exchange zone, and passing a second portion of said second expanded portion of liquid ethylene into heat exchange relationship with liquid methane;

3. expanding a first portion of liquid methane to a first pressure, passing said first expanded portion of liquid methane into heat exchange relationship in a third heat exchange zone with said gas stream exiting said second heat exchange zone, expanding a second portion of liquid methane to a second pressure lower than that of said first portion, the expansion of the first and second portions of liquid methane being in parallel, passing said second expanded portion of liquid methane into heat exchange relationship with said gas stream which has been heat exchanged with first expanded portion of liquid methane in said third heat exchange zone and then into heat exchange relationship with said gas stream in said third heat exchange zone; and recovering the cooled gas stream from said third heat exchange zone.

4. The method of claim 1 which comprises:

1. expanding a first portion of liquid propane to a first pressure, passing said first expanded portion of liquid propane into heat exchange relationship with said gas stream in a first heat exchange zone at about the locus of the heat exchange zone where the temperature is about the same as that of the propane, expanding a second portion of liquid propane to a second pressure lower than that of said first portion, the expansion of the first and second portions of liquid propane being in parallel, passing a first portion of said second expanded portion into heat exchange relationship with said gas stream which has been heat exchanged with first expanded portion of liquid

propane at the cold end of said first heat exchange zone and then into heat exchange relationship with said gas stream in said first heat exchange zone, and passing a second portion of said second expanded portion of liquid propane into heat exchange relationship with liquid ethylene;

2. expanding a first portion of liquid ethylene to a first pressure, passing said first expanded portion of liquid ethylene into heat exchange relationship in a second heat exchange zone with said gas stream exiting said first heat exchange zone at about the locus of the second heat exchange zone where the temperature is about the same as that of the first expanded portion of liquid ethylene, expanding a second portion of liquid ethylene to a second pressure lower than that of said first portion, the expansion of the first and second portions of liquid ethylene being in parallel, passing a first portion of said second expanded portion of liquid ethylene into heat exchange relationship with said gas stream which has been heat exchanged with first expanded portion of liquid ethylene at the cold end of said second heat exchange zone and then into heat exchange relationship with said gas stream in said second heat exchange zone, and passing the second portion of said second expanded portion of ethylene into heat exchange relationship with liquid methane;

3. expanding a first portion of liquid methane to a first pressure, passing said first expanded portion of liquid methane into heat exchange relationship in a third heat exchange zone with said gas stream exiting said second heat exchange zone at about the locus of the third heat exchange zone where the temperature is about the same as that of said first expanded portion of methane, expanding a second portion of liquid methane to a second pressure lower than that of said first portion, the expansion of the first and second portions of liquid methane being in parallel, passing said second expanded portion of liquid methane into heat exchange relationship with said gas stream which has been heat exchanged with first expanded portion of liquid methane at the cold end of said third heat exchange zone and then into heat exchange relationship with said gas stream in said third heat exchange zone.

5. The method of claim 2 wherein the refrigerants are propane, ethylene and methane.

6. The method of liquefying a gas stream which comprises the steps of:

compressing and condensing a refrigerant;

dividing condensed refrigerant into a plurality of portions;

expanding a first portion of said refrigerant to a first pressure;

heat exchanging said first portion with the gas stream;

expanding a second portion of said refrigerant to said first pressure;

removing from said second portion vapor formed by expanding said second portion to said first pressure;

expanding said previously expanded second portion from which vapor formed by expanding to said first pressure has been removed to a second pressure lower than that of said first portion;

heat exchanging that part of said second portion which is expanded to said second pressure with the gas stream effluent from the heat exchange zone of said first portion;

combining vapor of said first portion with said vapor formed by expansion of said second portion to said first pressure and returning said combined vapor to a first stage of compression; and

returning vapor from said second portion expanded to said second pressure to a lower stage of compression than said first stage.