Dec. 3, 1968 S. S. DE MARCO 3,413,816

LIQUEFACTION OF NATURAL GAS

Filed Sept. 7, 1966 2 Sheets-Sheet 1

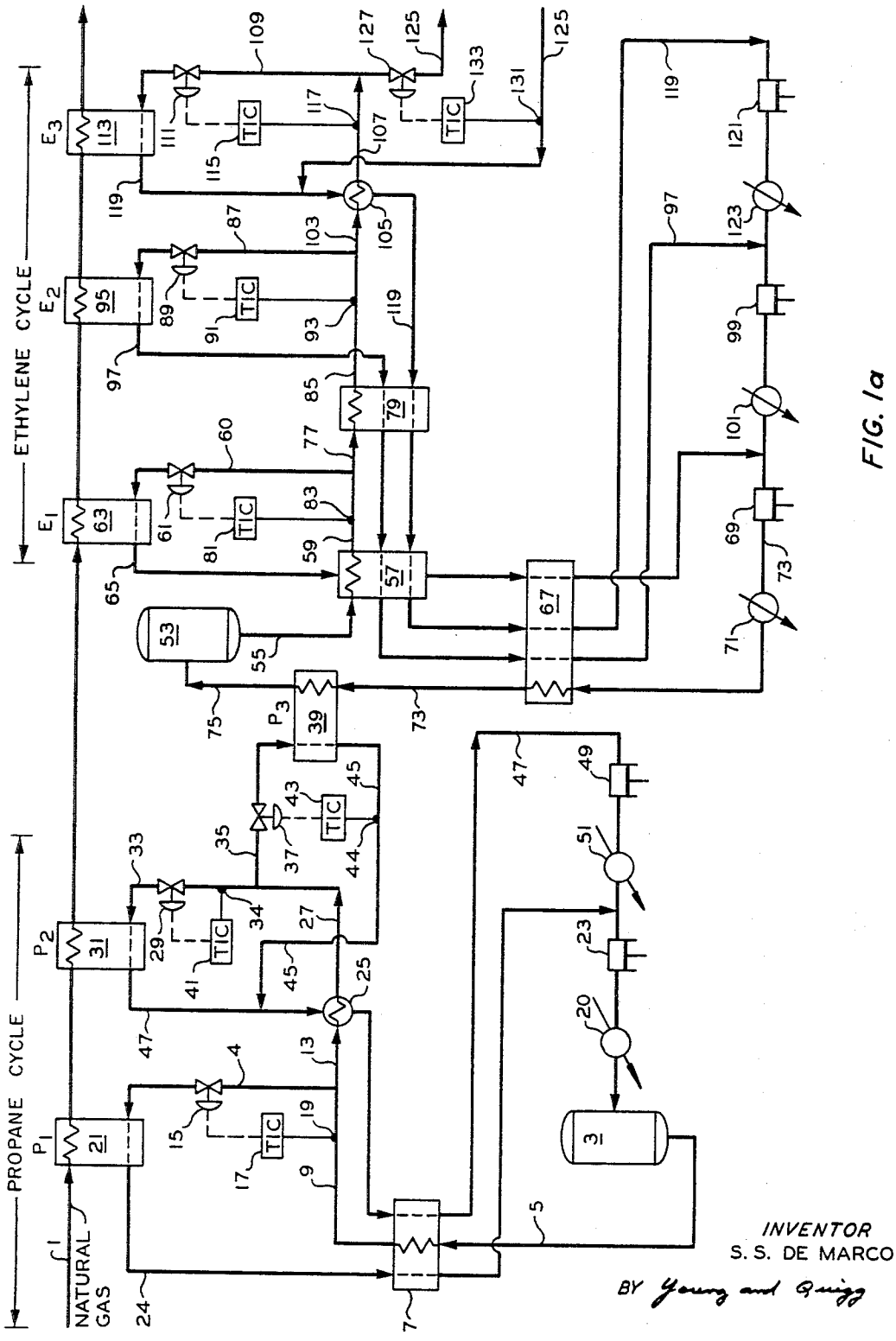

FIG. 1a

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Dec. 3, 1968 S. S. DE MARCO 3,413,816

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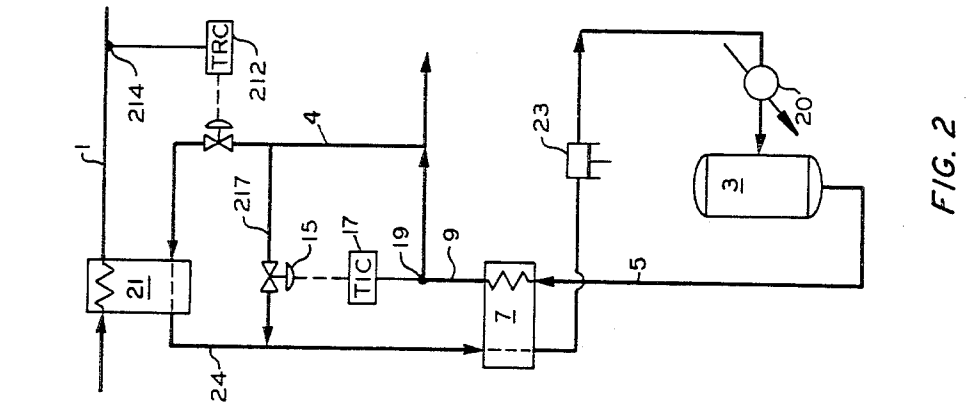

FIG. 2

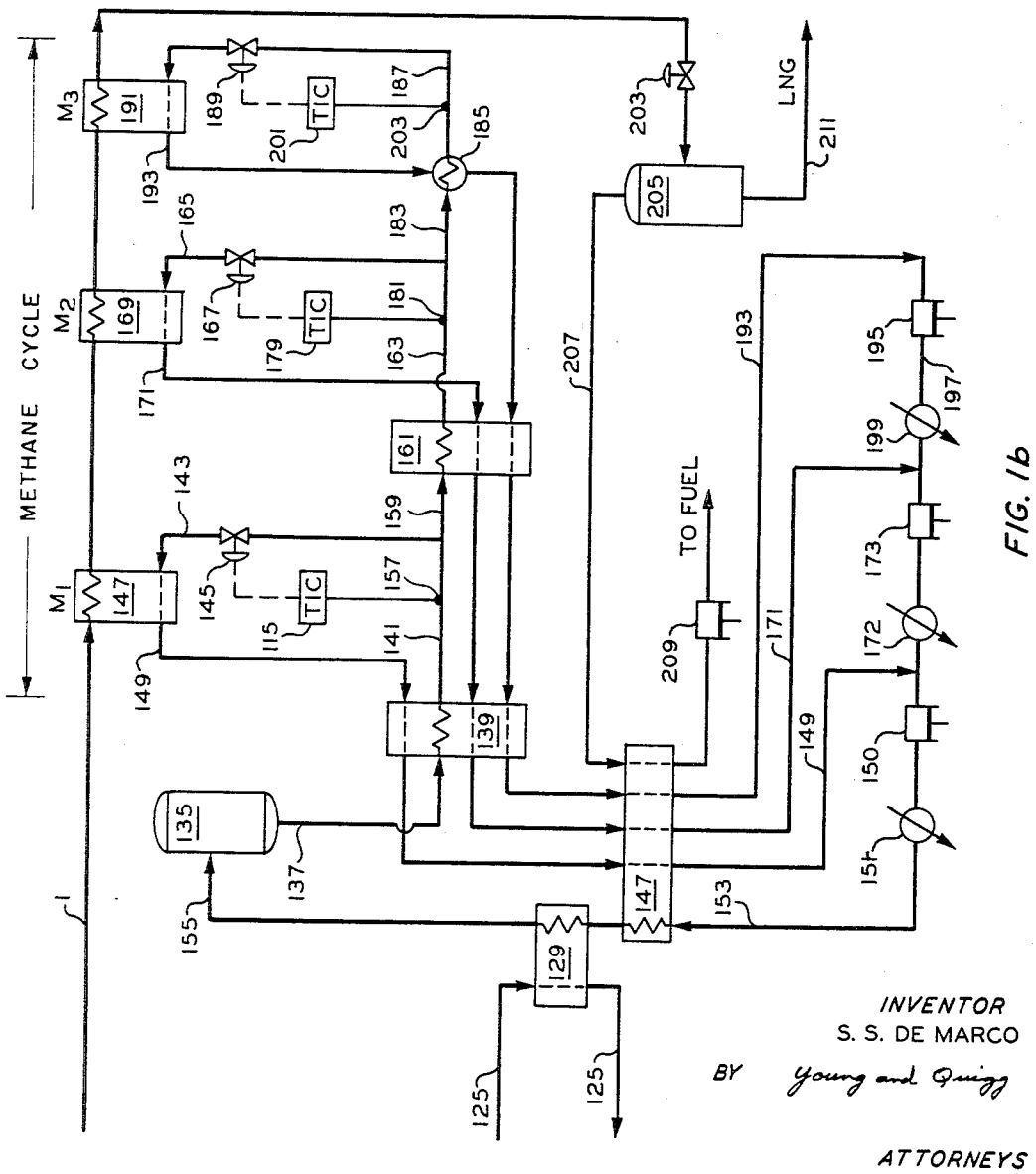

FIG. 1b

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3,413,816

LIQUEFACTION OF NATURAL GAS

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6 Claims. (Cl. 62—21)

ABSTRACT OF THE DISCLOSURE

Natural gas is liquified by heat exchange with a series of separate progressively decreasing temperature level refrigerants. Each of the cold liquid refrigerants is expanded to a vapor-liquid condition, then passed in heat exchange with the natural gas and then with the cold unexpanded liquid refrigerant causing the liquid portion of the refrigerant to vaporize. The vaporized refrigerant is recompressed and condensed to complete the refrigeration cycle. Expansion of cold refrigerant is controlled responsive to the temperature of the cold refrigerant upstream of the expansion means and downstream of the heat exchanger where liquid refrigerant is cooled prior to expansion.

This invention relates to the liquefaction of a gas. In one aspect, it relates to a method and apparatus for the liquefaction of natural gas which is composed mostly of methane but which may contain heavier hydrocarbons such as ethane, propane, butane and the like, small amounts of aromatic hydrocarbons and variable amounts of non-hydrocarbons such as nitrogen, helium, carbon dioxide, hydrogen sulfide and the like. Illustration of this invention is made with reference to the liquefaction of natural gas but it will be understood that the concepts employed are capable also of application to other low boiling liquefiable gases such as nitrogen, helium, air, oxygen, and the like.

For many practical and economical reasons, the oil and gas industry is interested in reducing natural gas to a liquefied state. It is more practical to store and transport natural gas in its liquefied state rather than its gaseous state because it occupies less space.

There are many patents and publications which deal with the problem of reducing natural gas to its liquefied state. For example, it is known to employ a refrigeration cycle for reducing the compressed natural gas to a liquefied state using a modified cascade system in combination with a modified expansion system. The refrigeration system can be divided into a propane cycle, an ethylene cycle and a methane cycle, each adapted to achieve a reduction in temperature of the compressed gas in the area where each of the cycle subdivisions can be operated with greatest efficiency from the standpoint of horsepower of refrigeration required to achieve the desired refrigeration.

The subject invention to be described in greater detail hereinbelow uses the vapors from the refrigerant employed to cool the natural gas stream and to cool the liquid refrigerant prior to its being passed in heat exchange with the natural gas stream. The applicant has surprisingly discovered that if the refrigerant is maintained simultaneously in its liquid and vaporous state, better control of the liquefaction of the gas is obtained without the necessity of maintaining specified liquid levels in the heat exchangers in order to effect the required vaporization.

One object of this invention is to provide an apparatus and method for the economical and efficient conversion of a gas, especially natural gas, from a gaseous state to a liquefied state for storage and transportation.

Another object of this invention is to provide a method for heat exchanging the gas with a uniform concentration

of liquid and vapor which are passed in heat exchange therewith.

Yet another object of this invention is to provide a process for the liquefaction of natural gas which makes use of a minimum amount of horsepower refrigeration, which makes use of a minimum amount of heat exchange surface or equipment, which is capable of being carried out in a continuous operation with a minimum amount of labor and materials which is relatively free of the necessity of shut-down for the repair and replacement of equipment, which supplies a relatively pure liquefied gas at about atmospheric pressure; which is safe in operation and which is flexible in operation to enable adjustments to meet existing conditions from the standpoint of gas composition or increase in capacity due to shut-downs in adjacent lines and the like.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description, which is considered in connection with the accompanying drawing wherein:

FIGURE 1A is a flow diagram of a process for the liquefaction of natural gas in accordance with the teachings of this invention;

FIGURE 1B is a continuation of FIGURE 1A describing the methane cycle; and

FIGURE 2 is a diagrammatic sketch of a modification of the flow diagram of FIGURE 1.

Briefly, the subject invention relates to a method and apparatus for liquefying a process gas, which is maintained at an elevated pressure, through heat exchanging it with suitable refrigerants in a closed cascade refrigeration system, the improvements comprising temperature control means for maintaining the refrigerant at a predetermined temperature sufficient to maintain the refrigerant in a vaporizing state as it is heat exchanged with the process stream at each of the various pressure levels.

The process will hereinafter be described in detail with reference to the liquefaction of natural gas using a specific set of temperature and pressure conditions. It is to be understood, however, that the conditions set forth are merely illustrative and may easily and properly be varied in accordance with design and capacity of the system, the character of the gas from the standpoint of composition, temperature and pressure, and the conditions under which the liquefaction is carried out as influenced by the volume of material, types of refrigerants and the like. Such variations are within the skill of the art and are all considered within the scope of the invention.

The refrigeration cycle for reducing the compressed gas to a liquefied state by a modified cascade system and a modified expansion system will be divided into a sequence of refrigeration steps including a propane refrigeration cycle (P), an ethylene refrigeration cycle (E), and a methane refrigeration cycle (M), each of which is adapted to achieve a reduction of temperature of the compressed gas in the area where each of the cycle subdivisions can be operated with greatest efficiency from the standpoint of horsepower refrigeration required to achieve the desired refrigeration.

The propane refrigeration cycle (P) can in turn be subdivided into a high level propane refrigeration stage (P_1), and low level propane refrigeration stage (P_2) and an ethylene condensing stage (P_2).

Natural gas is passed from a suitable source not shown through conduit 1 to be cooled in the propane cycle of the liquefaction system at elevated pressure and temperature, such as 700 p.s.i. pressure and 90° F. temperature.

Propane refrigeration cycle

In the high level propane refrigeration stage (P_1) liquid propane refrigerant is maintained in a receiver 3 at about

175 p.s.i. pressure and 90° F. This liquid propane is fed via conduit **5** through heat exchanger **7** wherein the temperature is lowered to about 25° F. The propane is then passed via conduit **9** and is split into two streams one of which passes via conduit **4** and the other of which passes via conduit **13**. The flow of liquid propane in conduit **4** is controlled by an expansion valve **15** wherein the valve is operatively connected to a temperature indicator controller **17**. This controller **17** is operatively connected to a suitable thermocouple **19** located in conduit **9** which measures the temperature of the liquid propane flowing in conduit **9**. In this example, the temperature is maintained at 25° F. and valve **15** is operatively controlled by the temperature indicator controller **17** to permit sufficient flow of liquid propane in conduit **4** to maintain the temperature in conduit **9** at about 25° F. Upon passage through valve **15**, the pressure on the propane is reduced to about 55 p.s.i. whereupon part of the propane flashes resulting in a two-phase fluid being passed into heat exchanger **21**.

In order to insure maximum efficiency when the heat exchange medium is a two-phase fluid, heat exchanger **21** is of a special construction which has previously been described in a Patent, 3,212,277, issued on Oct. 19, 1965, to E. A. Harper et al. and assigned to Phillips Petroleum Company.

The refrigerant exits heat exchanger **21** via conduit **24**, passes through heat exchanger **7**, compressor **23**, cooler **20** wherein it is returned to receiver **3** at a pressure and temperature from which it is started to repeat the high level propane cycle.

When the process stream is continuously advanced via conduit **1** through heat exchanger **21**, heat will be extracted from the natural gas in amounts sufficient to reduce the temperature of the process stream from 90° F. to about 25° F. If the process stream were to be supplied at a temperature considerably below 90° F., the described high level propane refrigeration step can be omitted in favor of a single heat exchange step through the low level propane refrigeration cycle.

In the low level refrigeration stage (P_2), the liquid propane in conduit **13** passes through an economy heat exchanger **25**, wherein the temperature of the stream is reduced from 25° F. to approximately 7° F. The liquid propane leaving heat exchanger **25** via conduit **27** is again subdivided such that a portion passes via conduit **33** through an expansion valve **29** wherein the pressure is let down to slightly above atmospheric pressure, such as 21 pounds p.s.i. for introduction into the low level propane heat exchanger **31** and a portion passes via conduit **35**.

The construction of heat exchanger **31** is similar to that described hereinabove with relation to heat exchanger **21**. At this pressure, the propane will be maintained at a temperature of about —28° F. and will be in a mixed gas-liquid phase as it passes through exchanger **31**.

Again the flow of propane in conduit **33** is maintained by a temperature indicator controller **41** which measures the temperature in conduit **33** via thermocouple **34** and controls the flow through expansion valve **29** to maintain a predetermined temperature in conduit **33** which is about 7° F.

The remainder of the propane from line **27** is passed via conduit **35** through an expansion valve **37** wherein the pressure is let down to about the same pressure as that of the propane in conduit **33**. This propane is passed through the heat exchanger **39** wherein recompressed vapors of ethylene in the high level ethylene refrigeration stage are liquefied for use in the ethylene refrigeration cycle.

A temperature controller **43** controls the operation of valve **37** in accordance with the temperature in conduit **45** as measured by thermocouple **44**. This propane passes via conduit **45** and is combined with the propane refrigerant which exits from heat exchanger **31** via conduit **47**.

The two phase propane fluid in line **47** is completely vaporized in heat exchangers **25** and **7** and is compressed in the low stage propane compressor **49** to raise the pressure to a level which corresponds to the pressure of the propane released from heat exchanger **21** (about 55 p.s.i.) so that the two streams of propane vapor can be joined for subsequent processing through high stage compressor **23**. The high stage compressor raises the pressure of the propane vapors to a pressure level at which they can be readily condensed. The propane vapor is raised to about 175 pounds p.s.i. for subsequent liquefaction and storage in receiver **3**. Heat of compression in compressor **49** raises the temperature of the propane fluid in line **47** and it is passed through cooler **51** in order to bring its temperature down to about 90° F. wherein it can be joined with the propane fluid in line **24**.

When the process stream is continuously advanced via conduit **1** through heat exchanger **31** heat will be extracted from the gas in amounts sufficient to reduce its temperature from 25° F. to about —23° F.

Ethylene refrigeration cycle

The ethylene refrigeration cycle (E) is, in a manner similar to the propane cycle except that it is subdivided into a high level ethylene refrigeration stage (E_1), an intermediate level ethylene, refrigeration stage (E_2) and a low level ethylene refrigeration stage (E_3).

In the high level ethylene stage (E_1), liquid ethylene maintained in a receiver **53**, at 280 p.s.i.g. and —22° F. is passed via conduit **55** through a heat exchanger **57** wherein the temperature is further reduced to —48° F. The ethylene at this temperature exits from heat exchanger **57** via conduit **59** wherein it is subdivided into conduits **60** and **77**.

The portion in conduit **60** passes through expansion valve **61** wherein the pressure is let down to about 107 pounds for introduction into the low level ethylene heat exchanger **63** which is similar in construction to heat exchangers **21** and **31**. At this pressure, the ethylene is a dual phase fluid as it enters heat exchanger **63**.

Just as in the propane cycle, the flow rate of ethylene via conduit **60**, is regulated by valve **61** whose operation is controlled by temperature controller **81**. Temperature controller **81** receives a signal from thermocouple **83** indicative of the temperature in conduit **59**. The flow rate via conduit **60** is kept at a rate sufficient to maintain the temperature in conduit **59** at —48° F. for this illustrative example.

The ethylene two phase fluid refrigerant exits from heat exchanger **63** via conduit **65** and passes through heat exchanger **57** wherein its temperature is increased to —27° F. At this point it is in the vapor phase. The ethylene refrigerant passes via conduit **65** through heat exchanger **67** wherein its temperature is further increased to 80° F.

This ethylene vapor is compressed in compressor **69**, passed via conduit **73** through a cooler **71** wherein the temperature is reduced to 90° F., through heat exchanger **67** wherein the temperature is reduced to 2° F., through the propane heat exchanger **39** wherein the ethylene is liquefied by heat exchanging it with the propane in heat exchanger **39** from which it exits via conduit **75** to the ethylene receiver **53**.

The process stream enters, via conduit **1**, the low level ethylene heat exchanger **63** at about —23° F. and will leave at about —70° F. while still at about 700 p.s.i. pressure.

The other portion of ethylene refrigerant in conduit **77** is passed through heat exchanger **79** wherein its temperature is dropped to —66° F.

The ethylene refrigerant exits heat exchanger **79** via conduit **85** for subdivision wherein a portion is fed into conduit **87** for passage to the intermediate ethylene refrigeration heat exchanger **95** and the remaining portion is fed into conduit **103** from whence a portion is passed into the low level ethylene heat exchanger **113**.

Temperature controller **91** in cooperation with thermocouple **93** controls expansion valve **89** in the same manner

as described hereinabove with relation to the other cycles so as to maintain a temperature in conduit **85** at —66° F. This temperature will permit the ethylene to enter heat exchanger **95** as a two phase fluid at a pressure of 46 p.s.i.

The construction of this heat exchanger is also similar to the heat exchangers previously described hereinabove in order to insure maximum efficiency which can be obtained from the two phase fluid.

The ethylene refrigerant exits from heat exchanger **95** via conduit **97** at a pressure of approximately 46 p.s.i. The ethylene refrigerant is passed via conduit **97** through heat exchanger **79** wherein its temperature is raised to —79° F., through heat exchanger **57** wherein its temperature is raised to —27° F. through heat exchanger **67** wherein its temperature is raised to 80° F. It is then passed to an intermediate level compressor **99** to raise the pressure to a level which corresponds to the pressure of the ethylene vapor released from the heat exchanger **63**.

Upon leaving the compressor **99** the ethylene refrigerant is cooled in water cooler **101** in order to lower its temperature to that of the ethylene coming from heat exchanger **63** with which it is combined in conduit **65** for passage through compressor **69**. When the natural gas is passed continuously through the intermediate ethylene heat exchanger **95**, its temperature will be reduced from —70° F. to —111° F. while still at about 700 p.s.i. pressure.

The other portion of the ethylene refrigerant in conduit **103** is passed to a heat exchanger **105** wherein its temperature is reduced to approximately —77° F.

The liquefied ethylene refrigerant leaves heat exchanger **105** via conduit **107** for subdivision wherein a portion is fed via conduit **109** to an expansion valve **111** wherein the pressure is let down to slightly above atmospheric pressure, such as 22 pounds p.s.i. whereby the ethylene is introduced into the low level ethylene heat exchanger **113** as a two phase fluid. This heat exchanger is of the same construction as described hereinabove.

Just as stated hereinabove, the flow in conduit **109** is controlled by a temperature controller **115** which is operatively connected to a thermocouple **117** positioned in conduit **107** for measuring the temperature therein. The temperature controller is regulated to maintain a predetermined temperature of the ethylene refrigerant in conduit **107** (—77° F.) so that when it passes through valve **111** it will only be partially vaporized.

The ethylene refrigerant exits from the low level ethylene heat exchanger **113** via conduit **119** and passes through heat exchanger **105** wherein its temperature is raised from —143° F. to —116° F., through heat exchanger **79** wherein its temperature is raised to —79° F., through heat exchanger **57** wherein its temperature is raised to —27° F. and finally through heat exchanger **67** wherein its temperature is raised to 80° F. The vaporized ethylene is then passed through low level compressor **121** to raise the pressure to a level which corresponds to the pressure of the ethylene refrigerant at the intermediate level.

The ethylene refrigerant exits from compressor **121** and passes through water cooler **123** in order to lower its temperature to approximately that of the ethylene which exited from intermediate heat exchanger **95** with which it is combined for passage into intermediate level compressor **99**.

The ethylene refrigerant in conduit **107** also passes via conduit **125** wherein it passes through an expansion valve **127** and then through a methaneliquefaction heat exchanger **129** (shown in FIGURE 1*b*).

Expansion valve **127** is operatively controlled by temperature regulator **133** and thermocouple **131** located in conduit **125**. The flow of ethylene through valve **127** is maintained at a rate sufficient to keep the temperature of the ethylene in conduit **125** the same as that entering heat exchange **113** via conduit **109**. This temperature is —143° F.

The ethylene is passed via conduit **125** and combined with the ethylene in conduit **119**.

The process stream advancing continuously via conduit **1** enters heat exchanger **113** at a temperature of —111° F. and leaves at a temperature of —138° F. for entry into the methane refrigeration cycles.

Methane refrigeration cycle

FIGURE 1B

In the methane refrigeration cycle, which is subdivided into a high level methane refrigeration stage (M_1); an intermediate level methane refrigeration stage (M_2) and a low level methane refrigeration stage (M_3), the methane is stored in its liquefied stage in receiver **135** at a temperature of —138° F. and a pressure of 485 p.s.i. The liquefied methane passes from receiver **135** via conduit **137** through the heat exchanger **139** and exits therefrom via conduit **141** at a temperature of —155° F. wherein a portion passes into conduit **143** for passage into the low level methane heat exchanger **147** and the remaining portion passes into conduit **159**.

Heat exchanger **147** is of the same construction as the heat exchanger used in the propane and ethylene cycles.

The flow rate of methane in conduit **143** is regulated by temperature controller **115** in accordance with a signal received from thermocouple **157** located in conduit **141**. This temperature is maintained at a level sufficient to produce a two phase fluid in conduit **143** after the pressure has been dropped in valve **145**. This temperature is —155° F. and the pressure is 200 p.s.i.

The methane refrigerant exits from the high level methane heat exchanger **147** via conduit **149** wherein it is passed through heat exchanger **139**, wherein its temperature is raised from —179° F. to —143° F. and heat exchanger **147**, wherein its temperature is raised to approximately 80° F. It then goes through compressor **150**, wherein the pressure is raised to 485 p.s.i., and exits via conduit **153**. The methane is passed through water cooler **151** to remove heat of compression from the methane.

The methane is passed via conduit **153**, through heat exchanger **147** wherein its temperature is lowered to —139° F. and is then passed in heat exchange with the ethylene in the ethylene cycle in heat exchanger **129** to liquify the methane for refrigeration at —130° F. and 485 p.s.i.

The natural gas in conduit **1** enters the high level methane heat exchanger **147** at a temperature of —138° F. and leaves at a temperature of —174° F.

The liquid methane in conduit **159** passes through heat exchanger **161** wherein its temperature is lowered to —175° F. The liquid methane exits from heat exchanger **161** via conduit **163**. A portion of the methane is passed via conduit **165** to the intermediate level methane heat exchanger **169**, and the remaining liquid methane is passed to conduit **183**.

The methane in conduit **165** passes through expansion valve **167**, wherein the pressure is dropped to 81 p.s.i. and a portion of the methane is flashed, to form a two phase fluid which enters the intermediate level methane heat exchanger **169** which is constructed like the previous heat exchanger.

Temperature controller **179** is operatively connected to valve **167** in order to regulate it in response to a signal received from thermocouple **181** located in conduit **163**. The flow rate is maintained sufficient in conduit **165** to keep a temperature of —175° F. in conduit **163**.

The methane refrigerant exits from heat exchanger **169** via conduit **171** for passage through heat exchanger **161**, wherein the temperature is raised from —213° F. to —179° F., heat exchanger **139**, wherein the temperature is raised from —179° F. to —143° F., and heat exchanger **147**, wherein the temperature is raised from —143° F. up to 80° F. The methane is then passed through compressor **173** from the heat exchanger **147**. The methane is then passed through water cooler **172**

wherein it is combined with the methane in conduit **149** for passage into compressor **150**.

The natural gas enters heat exchanger **169** at a temperature of —174° F. and exits at a temperature of —208° F.

The methane in conduit **183** passes through a heat exchanger **185** wherein its temperature is reduced to —187° F. The methane exits from heat exchanger **185** via conduit **187** and is fed through an expansion valve **189** wherein the pressure is let down to about 36 p.s.i. for entry into the low level methane heat exchanger **191**.

Expansion valve **189** is operatively connected to temperature controller **201** which regulates the flow of methane in conduit **187** in accordance with a signal received from thermocouple **203** located in conduit **187**. The predetermined temperature desired in the example is —187° F.

The methane enters heat exchanger **191** as a two phase fluid and the construction of this heat exchanger is identical to those described hereinabove.

The methane exists from the heat exchanger **191** via conduit **193**, passes through heat exchanger **185**, wherein its temperature is raised to —213° F., heat exchanger **161** wherein its temperature is raised to —179° F., heat exchanger **139**, wherein its temperature is raised to —143° F. and heat exchanger **147** wherein its temperature is raised to 80° F. This low level methane is then fed through compressor **195** wherein it is compressed to increase its pressure to that of the methane exiting the intermediate methane heat exchanger in conduit **171**. The methane exits from compressor **195** via conduit **197**, passes through water cooler **199**, and is reunited with the methane from the heat exchanger **169** in conduit **171**.

The process stream flowing in conduit **1** enters heat exchanger **191** at a temperature of 208° F. and exits at a temperature of —230° F. The natural gas passes through valve **203** into a flash tank **205** wherein any uncondensed light material flashes off via conduit **207** and passes through heat exchanger **147** wherein the temperature of this light material is raised to 80° F. for passage through compressor **209**. The compressed gas is then burned as fuel.

The liquefied natural gas is removed from flash tank **205** and sent to storage via conduit **211**.

FIGURE 2 describes another embodiment of the control system for operating the high level propane refrigeration portion of the cascade system. In the interest of brevity only this one cycle is shown; however, this aspect of the control system can be employed to each or all of the other refrigeration subdivisions. In this concept temperature controller **17** of FIGURE 1 is connected to expansion valve **15** where it is positioned in a bypass line **217**, which bypasses heat exchanger **21** and connects with exit conduit **24**. The flow rate through bypass line **217** is maintained at a rate sufficient to maintain a predetermined temperature in line **9** just as was described in regard to FIGURE 1. A second expansion valve, positioned upstream from the bypass line **217** is operatively connected to a second temperature regulator **212** which is responsive to a signal received from thermocouple **214** located in process line **1** downstream from heat exchanger **21**.

In this embodiment the flow of propane through the heat exchanger is controlled by the degree of cooling desired to be accomplished on the natural gas in the heat exchanger. Temperature recorder maintains a flow rate of propane through bypass line **217** sufficient to maintain a predetermined temperature in conduit **9**.

It will be understood that changes may be made in the details of construction, arrangement and operation without departing from the spirit of the invention, as defined in the appended claims.

What is claimed is:

1. The method of cooling a gas by indirect heat exchange with a cold refrigerant which comprises expanding the cold refrigerant to provide a mixed vapor-liquid refrigerant stream, passing said mixed vapor-liquid refrigerant stream in indirect heat exchange relation with the gas to cool said gas, passing the heat exchanged refrigerant in further indirect heat exchange relation with compressed and condensed refrigerant to cool said compressed and condensed refrigerant and thereby provide said cold refrigerant and thereby vaporizing the liquid portion of said heat exchanged refrigerant, thereafter compressing and condensing said heat exchanged refrigerant to provide said compressed and condensed refrigerant, and regulating the expanding of said cold refrigerant in response to the temperature of said cold refrigerant prior to the expansion thereof and subsequent to the cooling of said compressed and condensed refrigerant in order that said expanding results in a mixed vapor-liquid state of said cold refrigerant.

2. A method according to claim **1** further including separating a portion of the cold refrigerant prior to the expansion thereof to provide a second cold refrigerant stream, expanding said second cold refrigerant stream to provide a second mixed vapor-liquid stream, passing said second mixed vapor-liquid stream in indirect heat exchange with the cooled gas to further cool said gas, passing the second heat exchanged refrigerant stream in further indirect heat exchange with said second cold refrigerant stream to further cool said second cold refrigerant stream prior to the expansion thereof, thereafter passing the second heat exchanged stream in indirect heat exchange with said compressed and condensed refrigerant to provide said cold refrigerant thereby vaporizing the liquid portion of said second heat exchanged stream, thereafter compressing and condensing said second heat exchanged stream to provide said compressed and condensed refrigerant; and regulating the expanding of said second cold refrigerant stream at a preselected value in response to the temperature of said second cold refrigerant stream prior to the expansions thereof and subsequent to the further heat exchange of said second heat exchanged refrigerant stream with said second cold refrigerant stream in order that said expanding results in a mixed vapor-liquid state of second cold refrigerant stream.

3. A method according to claim **2** further including the incremental reduction in the temperature of said gas utilizing a series of separate progressively decreasing temperature level refrigerants, each of which is utilized as said refrigerant according to claim **2**, and wherein said gas is cooled to a temperature sufficient to transport said gas in a liquid state at atmospheric pressure.

4. A method according to claim **3** wherein said refrigerants are propane, ethylene, and methane, and said gas is natural gas.

5. The method of cooling a gas by indirect heat exchange with a cold refrigerant which comprises expanding the cold refrigerant to provide a mixed vapor-liquid refrigerant stream, passing said mixed vapor-liquid refrigerant stream in indirect heat exchange relation with the gas to cool said gas, passing the heat exchanged refrigerant in further indirect heat exchange relation with compressed and condensed refrigerant to cool said compressed and condensed refrigerant and thereby provide said cold refrigerant and thereby vaporizing the liquid portion of said further heat exchanged refrigerant, thereafter compressing and condensing said further heat exchanged refrigerant to provide said compressed and condensed refrigerant, and regulating the temperature of said cold refrigerant by passing a portion of the cold refrigerant prior to expansion to the corresponding heat exchanged refrigerant thereby bypassing a portion of the said cold refrigerant around the indirect heat exchange relation with said gas, and regulating the flow in the bypass in response to the temperature of said cold refrigerant prior to the expansion thereof and subsequent to the cooling of said compressed and condensed refrig-

erant in order that the said expanding results in a mixed vapor-liquid state of the cold refrigerant.

6. The method of cooling a gas by indirect heat exchange wherein the incremental reduction in the temperature of said gas is accomplished by a series of separately progressively decreasing temperature level cold refrigerants, wherein each of said refrigerants is utilized to reduce the temperature of said gas by the steps of expanding the cold refrigerant to provide a mixed vapor-liquid refrigerant stream, passing said mixed vapor-liquid refrigerant stream in indirect heat exchange relation with the gas to cool said gas, passing the heat exchanged refrigerant in further indirect heat exchange relation with compressed and condensed refrigerant to cool said compressed and condensed refrigerant and thereby provide said cold refrigerant and thereby vaporizing a liquid portion of said heat exchanged refrigerant, thereafter compressing and condensing said heat exchanged refrigerant to provide said compressed and condensed refrigerant, and regulating the expanding of said cold refrigerant in response to the temperature of said cold refrigerant prior to the expansion thereof and subsequent to the cooling of said compressed and condensed refrigerant in order that said expanding results in a mixed vapor-liquid state of said cold refrigerant.

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