METHOD AND APPARATUS FOR PRODUCING LIQUEFIED NATURAL GAS

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ABSTRACT
Systems and methods for producing liquid natural gas from heat exchange with liquid nitrogen or air is provided. The produced liquid natural gas may be used as vehicle fuel. After heat exchange, the vaporized liquid nitrogen or air may be routed in the system to regenerate a heat exchange unit and/or a natural gas pretreatment unit. After assisting with the regeneration, the vaporized nitrogen or air may be safely vented to atmosphere. In one embodiment, a system for liquefying natural gas using a refrigerant includes a first treating unit configured to remove a contaminant from the natural gas; a first exchanger unit for liquefying the natural gas using the refrigerant; a second exchanger unit configured to receive the refrigerant from the first exchanger unit, wherein the first exchanger unit and the second exchanger unit operate on alternating cycles; a second treating unit configured to receive the refrigerant from the second exchanger unit; and a storage unit for the receiving the liquid natural gas.
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BACKGROUND OF THE INVENTION

1. Field of the Invention

Embodyments of the present invention generally relate to systems and methods for producing liquid natural gas. Particularly, embodyments of the present invention relate to liquefying natural gas using liquid nitrogen or air and thereafter, using the vaporized nitrogen or air to regenerate a heat exchange unit and/or natural gas pretreatment unit.

2. Description of the Related Art

Natural gas is a known alternative to combustion fuels such as gasoline and diesel. One benefit of natural gas as a fuel over gasoline or diesel is that it is a cleaner burning fuel. Additionally, natural gas is considered to be safer than gasoline or diesel because natural gas will rise in the air and dissipate, rather than settling. However, the production of natural gas has various drawbacks such as higher production costs and the subsequent emissions created by the use thereof. Therefore, much effort has gone into the development of natural gas as an alternative combustion fuel.

In addition, due to its clean burning qualities and convenience, natural gas has become widely used in a variety of applications, such as heating homes. Many sources of natural gas are located in remote areas, great distances from any commercial markets for the gas. Normally a pipeline is available for transporting the natural gas to commercial markets. When pipeline transportation of natural gas is not feasible, however, it is desirable to convert the natural gas into LNG for transport and storage purposes. The primary reason for this is that the liquefaction enables the volume of natural gas to be reduced by a factor of about 600. While the capital and running costs of the systems required to liquefy the natural gas are very high, they are still much less than the costs of transporting and storing liquefied natural gas. In addition, it is much less hazardous to transport and store LNG than liquefied natural gas.

Conventionally, two of the known basic cycles for the liquefaction of natural gases are referred to as the “cascade cycle” and the “expansion cycle.” The cascade cycle typically consists of a series of heat exchanges with the feed gas, with each exchange being at successively lower temperatures until the desired liquefaction is accomplished. The levels of refrigeration are obtained with different refrigerants or with the same refrigerant at different evaporating pressures. Although the cascade cycle may have a relatively low operating cost, the cascade cycle generally requires relatively high investment costs for the purchase of heat exchange and compression equipment. Additionally, a liquefaction system using a cascade cycle requires a large footprint for its equipment.

In an expansion cycle, gas is conventionally compressed to a selected pressure, cooled, and then allowed to expand through an expansion turbine, thereby producing work as well as reducing the temperature of the feed gas. The low temperature feed gas is then heat exchanged to effect liquefaction of the feed gas. Conventionally, such a cycle has been seen as being impracticable in the liquefaction of natural gas since there is no provision for handling some of the components present in natural gas which freeze at the temperatures encountered in the heat exchangers, for example, water and carbon dioxide.

Additionally, to make the operation of conventional systems cost effective, such systems are conventionally built on a large scale to handle large volumes of natural gas. As a result, fewer facilities are built making it more difficult to provide the raw gas to the liquefaction plant or facility as well as making distribution of the liquefied product an issue. An additional problem with large facilities is the cost associated with storing large amounts of fuel in anticipation of future use and/or transportation. Not only is there a cost associated with building large storage facilities, but there is also an efficiency issue related therewith as stored LNG will tend to warm and vaporize over time creating a loss of the LNG fuel product. Further, safety may become an issue when larger amounts of LNG fuel product are stored.

There is a need, therefore, for a system and method for efficiently producing liquid natural gas. There is also a need for a system and method for producing liquid natural gas using indirect heat exchange with liquid nitrogen without the use of compressors. Further, there is a need for a system and method of producing liquid natural gas on a continuous basis. Further still, there is a need for a system and method of producing liquid natural gas using liquid nitrogen and thereafter, using the vaporized nitrogen to regenerate the heat exchange unit and/or natural gas pretreatment unit.

SUMMARY OF THE INVENTION

The present invention generally relates to systems and methods for producing liquid natural gas. The liquid natural gas may be produced from heat exchange with liquid nitrogen or air. The produced liquid natural gas may be used as vehicle fuel. The vaporized liquid nitrogen or air may be routed in the system to regenerate a heat exchange unit and/or a natural gas pretreatment unit. After assisting with the regeneration, the liquid nitrogen or air may be safely vented to atmosphere.

In one embodiment, a system for liquefying natural gas using a refrigerant includes a first treating unit configured to remove a contaminant from the natural gas; a first exchanger unit for liquefying the natural gas using the refrigerant; a second exchanger unit configured to receive the refrigerant from the first exchanger unit, wherein the first exchanger unit and the second exchanger unit operate on alternating cycles; a second treating unit configured to receive the refrigerant from the second exchanger unit, and a storage unit for the receiving the liquid natural gas. In another embodiment, the first and second treating units operate on alternating cycles. In yet another embodiment, the first exchanger unit is configured to remove an additional contaminant from the natural gas, wherein a temperature in the first exchanger unit is sufficient to freeze the additional contaminant. In yet another embodiment, a dispensing unit connected to the storage unit for transfer of the liquid natural gas to a vehicle.

In one embodiment, a method of liquefying natural gas includes supplying a natural gas to a first pretreatment unit to remove a contaminant; introducing the pretreated natural gas to a first heat exchange unit; introducing a refrigerant to the first heat exchange unit; liquefying the natural gas using heat from the refrigerant, thereby forming liquid natural gas; vaporizing the refrigerant; regenerating a second heat exchange unit using the vaporized refrigerant; heating the
vaporized refrigerant leaving the second heat exchange unit; regenerating a second pretreatment unit using the heated refrigerant; and collecting the liquid natural gas in a storage unit. In another embodiment, the method also includes dispensing the liquid natural gas in the storage unit to a vehicle. In yet another embodiment, the method further includes switching the second heat exchange unit to active operation after regeneration and regenerating the first heat exchange unit using refrigerant leaving the second heat exchange unit.

In another embodiment, a method of regenerating a pretreatment unit includes discharging a hydrocarbon to a fuel storage unit; heating the refrigerant; flowing the heated refrigerant through the pretreating unit; reducing a temperature of the heated refrigerant; and flowing the reduced temperature refrigerant through the pretreatment unit to cool the pretreatment unit to ambient temperature.

In another embodiment, a method of liquefying a natural gas includes introducing the natural gas to a first heat exchange unit; introducing a refrigerant to the first heat exchange unit; liquefying the natural gas by exchanging heat with the refrigerant, thereby forming liquid natural gas; freezing a contaminant from the natural gas; vaporizing the refrigerant; regenerating a second heat exchange unit using the vaporized refrigerant; venting the vaporized refrigerant; utilizing the mixed contaminants and natural gas to provide power from a gas turbine generator; and collecting the liquid natural gas in a storage unit.

In another embodiment, a system for liquefying a gas using a refrigerant includes a first exchanger unit for liquefying the gas and removing a contaminant using the refrigerant; a second exchanger unit configured to receive the refrigerant from the first exchanger unit, wherein the first exchanger unit and the second exchanger unit operate on alternating cycles; and a storage unit for receiving the liquid gas. In one embodiment, the gas contains at least 50 mole % of methane. In another embodiment, the gas contains at least 50 mole % of ethane.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to the embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

FIG. 1 is a process flow diagram of an exemplary embodiment of a gas liquefaction system for producing liquid natural gas.

FIG. 2 is a process flow diagram of another exemplary embodiment of a gas liquefaction system for producing liquid natural gas.

DETAILED DESCRIPTION

FIG. 1 illustrates an exemplary embodiment of a gas liquefaction system 10. The system includes a gas source 100 for supplying a feed gas such as natural gas for liquefaction. The gas source 100 may be connected to a pair of gas pretreatment units 500, 600 for pretreating the feed gas. The pretreatment units 500, 600 may be used to remove any undesired contaminants in the feed gas prior to liquefaction. As shown, the pair of pretreatment units 500, 600 are connected in parallel. In this respect, the pretreatment units 500, 600 may be operated in alternating cycles such that one unit 500 may be in treatment mode, while the other unit 600 is in the regeneration mode.

As shown, the feed gas may be introduced into the system 10 via line 20. Valves 21, 22 may be used to control feed gas flow into the pretreatment units 500, 600. Line 20 may be equipped with a flow control 33 to control the flow of the feed gas in line 20. In one embodiment, natural gas may be introduced into line 20 at a pressure from about 20 psig to about 1200 psig; preferably, about 100 psig to about 350 psig, and at a temperature from about 0°F to about 120°F; preferably, from about 80°F to about 100°F. The natural gas feed may include a hydrocarbon mixture of gases having at least one carbon, such as methane, ethane, propane, butane, pentane, and heavier hydrocarbons. The natural gas feed may also include contaminants such as carbon dioxide, hydrogen sulfide, and water. In one embodiment, the natural gas feed includes at least 40 mole % of methane; preferably, at least 50 mole % of methane; and more preferably, at least 90 mole % of methane. It must be noted that the gas liquefaction system may be used to liquefy other gases such as ethane gas whereby liquid rich ethane is produced. In one embodiment, the ethane gas includes at least 40 mole % of ethane; preferably, at least 50 mole % of ethane; and more preferably, at least 60 mole % of ethane.

In one embodiment, each pretreatment unit 500, 600 may be configured to remove at least one contaminant from the natural gas. The pretreatment units 500, 600 may employ sorbent beds such as regenerable molecular sieves, activated alumina, other suitable adsorbents, and combinations thereof to remove the contaminants. The molecular sieves are effective to remove the contaminants from the natural gas to extremely low levels and to render the natural gas suitable for liquefaction. Suitable molecular sieves may include known molecular sieves that are suitable for dehydration and/or carbon dioxide and adsorb those molecules having a molecular diameter of less than three to five angstroms. The molecular sieves may be regenerated by passing a heated gas through the pretreatment unit to remove the water and carbon dioxide. In another embodiment, the pretreatment units 500, 600 may include an amine unit to assist with contaminant removal. The amine unit may use an aqueous amine-containing solution such as diglycolamine (DEA) or methyl diethanolamine (MDEA), as well as other types of known physical or chemical solvents to absorb water from the natural gas. In another embodiment, a glycol dehydration unit may be used to remove the contaminants instead of or in addition to the molecular sieve unit. In yet another embodiment, the glycol dehydration unit may be connected downstream from the amine unit.

In an exemplary operation of an alternating cycle, natural gas is introduced into the first pretreatment unit 500 via line 20 through valve 21. Valve 22 is closed to block entry into the second pretreatment unit 600. The first pretreatment unit 500 may be operated to treat the natural gas until the adsorbent beds are spent. When this occurs, the first pretreatment unit 500 is switched to regeneration mode to regenerate the adsorbent beds. In particular, valve 21 is closed and valve 22 is opened. As a result, the natural gas is directed to the second pretreatment unit 600. The second pretreatment 600, which had been in the regeneration mode, is switch to treatment mode to treat the incoming natural gas prior to lique-
faction. Operation of the pretreatment units 500, 600 in this alternating cycle allows the system to continuously produce liquefied natural gas. Although an alternating cycle is discussed, it is contemplated that the pretreatment units 500, 600 may be simultaneously active.

After pretreatment, the natural gas is directed to a heat exchange unit for liquefaction. As shown, the system includes two heat exchange units 700, 800 which may be operated simultaneously or in alternating cycles. The pretreated natural gas leaving each pretreatment unit 500, 600 may be directed to either or both heat exchange units 700, 800 via valves 23, 24, 25, 26. The heat exchange units 700, 800 may be selected from any suitable heat exchange unit for liquefying natural gas as is known to a person of ordinary skill. Exemplary heat exchange units include brazed aluminum heat exchangers, plate fin and tube exchangers, plate frame exchangers, welded plate exchangers, compact exchangers, brazed plate heat exchangers, shell and tube exchangers, and other suitable heat exchange units known to a person of ordinary skill.

In one embodiment, the natural gas leaving the first pretreatment unit 500 is directed to the first heat exchange unit 700 where it exchanges heat with a refrigerant such as liquid nitrogen or air. The pretreated natural gas may pass through valve 23 and enter the first heat exchange unit 700 via flow path 27. At this time, valve 24 is closed to block flow to the second heat exchange unit 800. The refrigerant enters the first heat exchange unit 700 via flow path 28. The refrigerant cools the natural gas sufficiently to cause liquefaction of the natural gas, thereby producing liquid natural gas. In turn, the indirect heat exchange causes vaporization of the liquid nitrogen or air.

In one embodiment, the heat exchange unit 700 may be utilized to remove contaminants from the natural gas through freezing to produce solid products of the contaminants, which may include carbon dioxide, hydrogen sulfide, water, and hydrocarbons having more than five carbons. The solid products may be removed by adherence to a surface of the heat exchanger or filtered out using a filter unit 710 as the liquefied natural gas leaves the heat exchange unit 700. In one embodiment, the filter unit 710 may include a screen to capture the solid contaminant products. Because the heat exchange units 700, 800 may be capable of removing contaminants from the natural gas, it is contemplated that the pretreatment units 500, 600 are optional equipment in the system.

The newly formed liquid natural gas flows from the first heat exchange unit 700 to an insulated storage tank 300 via line 29. Valve 30 may be used to control fluid communication through line 29. Valve 72 is closed to block flow to the second heat exchange unit 800. Line 29 may further be equipped with a temperature/pressure control 31 to help maintain the liquid natural gas heading to the storage tank 300 at a temperature from about 200°F. to about 240°F. Additionally, line 29 may include a flow control 32. Flow control 32 may be linked to flow control 33 for monitoring and adjustment to optimize the liquefaction process. The storage tank 300 may be constructed as a stationary tank or a mobile tank. The pressure of the storage tank 300 may be controlled so that pumping to the liquid natural gas storage tank is not required. In one embodiment, the pressure in the storage tank 300 is from about 40 psiq to about 100 psiq; preferably, from about 65 psiq to about 80 psiq. A dispensing unit 400 may be connected to the storage tank 300 to facilitate the fueling of a vehicle or transfer of the liquefied natural gas to mobile storage unit. Alternatively, a pump may be provided to assist with the fueling of the vehicle or transfer of the liquid natural gas.

Refrigerant for cooling the feed gas is supplied from a refrigerant source unit 200 in the system 10. The refrigerant may be selected from liquid nitrogen or liquid air or other suitable material for liquefying the feed gas. The refrigerant may be stored in the refrigerant source unit 200 at a pressure from about 20 psig to about 150 psig and at a temperature from about −50°F. to about −270°F. In one embodiment, the refrigerant is obtained from a commercial vendor at approximately 100 psig. In another embodiment, a refrigerant liquefying unit may be connected to the system 10 to supply the refrigerant. The refrigerant, in this example liquid nitrogen, leaves the source unit 200 initially flows through a valve loop 120 having multiple valves 41, 42, 43, 44 for directing the liquid nitrogen to the appropriate heat exchange unit. In one embodiment, valve 41 is open and valves 42, 44 are closed to direct the liquid nitrogen to the first heat exchange unit 700. The liquid nitrogen may flow through the jacket of the filter unit 710 prior to entering the heat exchange unit 700 via flow path 28. The liquid nitrogen is vaporized to gas after indirectly exchanging heat with the natural gas. The nitrogen gas may leave the heat exchange unit 700 at a temperature from about 70°F. to 110°F.

The vaporized nitrogen may be used to regenerate (also referred to as derime) the second heat exchange unit 800. As discussed above, the second heat exchange unit 800 may be in regeneration mode while the first heat exchange unit 700 is in operation. The second heat exchange unit 800 may have collected sufficient frozen contaminants during operation to adversely affect its effectiveness. The warm nitrogen from the first heat exchange unit 700 is directed via line 45 to flow path 48 of the second heat exchange unit 800 to cause sublimation of the frozen contaminants. In this respect, solid contaminants accumulated on the heat exchange surfaces in flow path 47 may be removed, thereby restoring the effectiveness of the second heat exchange unit 800. The warm nitrogen may also flow through the jacket of the filter unit 810 connected to the second heat exchange unit 800. The warm nitrogen may similarly derime the filter unit 810. Thereafter, the warm nitrogen flows back to the valve loop 120, where it is directed to the second pretreatment unit 600 to facilitate regeneration thereof. As shown, the nitrogen gas flows through valve 43 of the valve loop 120 and is directed via line 51 to the second pretreatment unit 600. Valve 25 is open for communication to the unit 600 and valve 26 is closed to block communication to unit 800.

In one embodiment, a pulse regeneration process may be used to regenerate the second pretreatment unit 600. During operation, the adsorbents in the second pretreatment unit 600 may have retained a mixture of carbon dioxide, water, natural gas, and other contaminants. This mixture adversely affects the operation of the pretreatment unit 600 and is preferably removed to regenerate the unit 600. The regeneration process may include initially placing the second pretreatment unit 600 in fluid communication with a fuel storage unit 150. This step requires opening valve 61 and closing valves 62, 65, and 67. Gases such as methane are allowed to flow to the fuel storage unit 150 for a short period of time, for example, from about 5 seconds to about 5 minutes, preferably from about 10 seconds to 45 seconds. Directing the flow of these gases to the fuel storage unit 150 may
eliminate the discharge of hazardous material into the atmosphere while capturing these gases for use as fuel. Thereafter, the line between the second pretreatment unit 600 and the fuel storage unit 150 is closed, and the vent line to vent nitrogen to atmosphere is opened by opening valves 62 and 65 and closing valve 66.

[0030] After the vent line is opened, warm nitrogen from the second exchange unit 800 is supplied to flush contaminants such as carbon dioxide and water from the adsorbent beds. In one embodiment, the warm nitrogen may be heated by an optional heater 160 prior to entering the second pretreatment unit 600. The heater 160 may be configured to heat the nitrogen to a temperature from about 80°F to about 550°F; preferably, from about 80°F to about 450°F. Heated nitrogen is supplied to purge the contaminants from the second pretreatment unit 600 for a period of time from about 2 minutes to about 1,000 minutes; preferably, from about 100 minutes to about 180 minutes; and more preferably, from about 60 minutes to about 150 minutes.

[0031] After purging with heated nitrogen, the temperature of the nitrogen is decreased to cool the adsorbent beds. The heater 160 may be turned off or reduced to allow the nitrogen to cool. The cooler nitrogen is allowed to flow for a period from about from about 2 minutes to about 1,000 minutes; preferably, from about 45 minutes to about 100 minutes. At the end of the cooling period, the regeneration process is complete and the second pretreatment unit 600 may be returned to operation. In one embodiment, the pretreatment units 500, 600 are operated such that the timing for switching the active pretreatment unit to regeneration mode depends on whether the pretreatment unit already in regeneration mode is ready to become active. In another embodiment, the pretreatment unit in regeneration mode may become active before the first pretreatment unit is switched to regeneration mode so that both pretreatment units are active simultaneously.

[0032] Fuel for the heater 160 may be supplied from the fuel storage unit 150. As shown, valves 76 and 77 control communication between the storage unit 150 and the heater 160. Fuel in the storage unit 150 may be replenished by diverting a portion of the natural gas leaving the pretreatment units 500, 600. For example, natural gas may be diverted from the first pretreatment unit 500 via line 71 and directed through valve 73 and up flow path 47 of the second heat exchange unit 800. In this respect, water gas may be used to flush out heavier hydrocarbons accumulated in the heat exchange unit 800. From there, the natural gas may flow through valve 74 and toward the fuel storage unit 150. Alternatively, the natural gas may be diverted through valve 75 and flowed to the storage unit 150.

[0033] In operation, the gas liquefaction system 10 may be used to produce liquid natural gas. In one example, natural gas may be supplied to the system at a temperature of about 100°F and a pressure of about 100 psig. After processing in the first pretreatment unit 500, the natural gas is introduced into the first heat exchange unit 700. Liquid nitrogen, acting as the refrigerant, may be supplied at a temperature of about −283°F and a pressure of about 100 psia to the first heat exchange unit 700 to liquefy the natural gas. The natural gas leaves the first heat exchange unit 700 in liquid form at a temperature of about −208°F and a pressure of about 95 psig.

[0034] FIG. 2 illustrated another embodiment of a process flow diagram of a gas liquefaction system 210. In this embodiment, the heat exchange units 700, 800 are configured to facilitate heat exchange and remove contaminants from the natural gas. In this respect, this system does not require a pretreatment unit, but may nevertheless, include one. For clarity purposes, components in FIG. 2 that are similar to FIG. 1 have been labeled with the same reference number and may not be described in detail.

[0035] The system includes a gas source 100 for supplying a feed gas such as natural gas for liquefaction. The gas source 100 is connected to heat exchange units 700, 800. As shown, the pair of heat exchange units 700, 800 are connected in parallel. The heat exchange units 700, 800 may be operated in alternating cycles such that one unit 700 may be in liquefaction mode, while the other unit 800 is in the regeneration mode. In another embodiment, the heat exchange units 700, 800 may be operated on the same cycle such that both units 700, 800 are in the liquefaction mode. The heat exchange units 700, 800 may be selected from any suitable heat exchange unit for liqueifying natural gas as is known to a person of ordinary skill. Exemplary heat exchange units include brazed aluminum heat exchangers, plate fin and tube exchangers, plate frame exchangers, welded plate exchangers, compact exchangers, brazed plate heat exchangers, shell and tube exchangers, and other suitable heat exchange units known to a person of ordinary skill.

[0036] As shown, the feed gas may be introduced into the system 210 via line 20. Valves 221, 222 may be used to control feed gas flow into the heat exchange units 700, 800. The natural gas may be directed to either or both heat exchange units 700, 800 via valves 221, 222. Line 20 may be equipped with a flow control 33 to control the flow of the feed gas in line 20. In one embodiment, natural gas may be introduced into line 20 at a pressure from about 20 psig to about 1200 psig; preferably, about 100 psig to about 350 psig, and at a temperature from about 0°F to about 120°F; preferably, from about 80°F to about 100°F. The natural gas feed may include a hydrocarbon mixture of gases having at least one carbon, such as methane, ethane, propane, butane, pentane, and heavier hydrocarbons. The natural gas feed may also include contaminants such as carbon dioxide, hydrogen sulfide, and water.

[0037] In one embodiment, the natural gas entering first heat exchange unit 700 exchanges heat with a refrigerant such as liquid nitrogen or air. The natural gas may enter the first heat exchange unit 700 via flow path 27. At this time, valve 222 is closed to block flow to the second heat exchange unit 800. The refrigerant enters the first heat exchange unit 700 via flow path 28. The refrigerant cools the natural gas sufficiently to cause liquefaction of the natural gas, thereby producing liquid natural gas. In turn, the refrigerant absorbs heat from the natural gas, which causes vaporization of the liquid nitrogen or air.

[0038] In one embodiment, the heat exchange unit 700 may be utilized to remove contaminants from the natural gas by freezing the contaminants to produce solid products of the contaminants, which may include carbon dioxide, hydrogen sulfide, water, and hydrocarbons having more than five carbons. The solid products may be removed by adherence to a surface of the heat exchanger or filtered out using a filter unit 710 as the liquefied natural gas leaves the heat exchange unit 700. In one embodiment, the filter unit 710 may include a screen to capture the solid contaminant products. Even though the heat exchange units 700, 800 may be capable of purifying the natural gas, the system 210 may optionally include pretreatment unit to assist with removing contaminants in the natural gas.
The newly formed liquid natural gas in the first heat exchange unit 700 is directed to an insulated storage tank 300 via line 29, as discussed above with respect to FIG. 1. Valve 30 may be used to control fluid communication through line 29. Valve 72 is closed to block flow to the second heat exchange unit 800. Line 29 may further be equipped with a temperature/pressure control 31 to help maintain the liquid natural gas heading to the storage tank 300 at a temperature from about 200°F to about 240°F. Additionally, line 29 may include a flow control 32. Flow control 32 may be linked to flow control 33 for monitoring and adjustment to optimize the liquefaction process. The storage tank 300 may be constructed as a stationary tank or a mobile tank. The pressure of the storage tank 300 may be controlled so that pumping to the liquid natural gas storage tank is not required. In one embodiment, the pressure in the storage tank 300 is from about 40 psig to about 100 psig; preferably, from about 65 psig to about 80 psig. A dispensing unit 400 may be connected to the storage tank 300 to facilitate the fueling of a vehicle or transfer of the liquefied natural gas to mobile storage unit. Alternatively, a pump may be provided to assist with the fueling of the vehicle or transfer of the liquid natural gas.

Refrigerant for cooling the feed gas is supplied from a refrigerant source unit 200 in the system 210. The refrigerant may be selected from liquid nitrogen or liquid air or other suitable material for liquefying the feed gas. The refrigerant, in this example, liquid nitrogen, leaving the source unit 200 initially flows through a valve loop 120 having multiple valves 41, 42, 43, 44 for directing the liquid nitrogen to the appropriate heat exchange unit. In one embodiment, valve 41 is open and valves 42, 44 are closed to direct the liquid nitrogen to the first heat exchange unit 700. The liquid nitrogen may flow through the jacket of the filter unit 710 prior to entering the heat exchange unit 700 via flow path 28. The liquid nitrogen is vaporized to gas after absorbing heat from the natural gas. The nitrogen gas may leave the heat exchange unit 700 at a temperature from about 70°F to 110°F.

The vaporized nitrogen may be used to regenerate (also referred to as derime) the second heat exchange unit 800. As discussed above, the second heat exchange unit 800 may be in regeneration mode while the first heat exchange unit 700 is in operation. The second heat exchange unit 800 may have collected sufficient frozen contaminants during operation to adversely affect its effectiveness. The warm nitrogen from the first heat exchange unit 700 is directed via line 45 to flow path 48 of the second heat exchange unit 800 to cause sublimation of the frozen contaminants. In this respect, solid contaminants accumulated on the heat exchange surfaces in flow path 47 may be removed, thereby restoring the effectiveness of the second heat exchange unit 800. The warm nitrogen may also flow through the jacket of the filter unit 810 connected to the second heat exchange unit 800. The warm nitrogen may similarly derime the filter unit 810. Thereafter, the warm nitrogen flows back to the valve loop 120, where it is directed to the vent line 51. As shown, the nitrogen gas flows through valve 43 of the valve loop 120 and is directed to line 51 for venting.

In one embodiment, natural gas may be diverted from the feed line 20 to assist with purging of natural gas flow path of exchange unit in regeneration mode. For example, natural gas from line 20 may be diverted to line 71 and directed through valve 73 and up flow path 47 of the second heat exchange unit 800. In this respect, the natural gas may be used to flush out heavier hydrocarbons and/or contaminants such as carbon dioxide and water accumulated in the heat exchange unit 800. After purging the heat exchange unit 800, the natural gas may flow through valve 74 and toward the fuel storage unit 150.

At the end of the regeneration process, the second heat exchange unit 800 may be returned to operation. In one embodiment, the heat exchangers units 700, 800 are operated such that the timing for switching the active heat exchange unit 700 to regeneration mode depends on whether the heat exchange unit 800 already in regeneration mode is ready to become active. In another embodiment, the heat exchange unit in regeneration mode may become active before the first heat exchange unit is switched to regeneration mode so that both heat exchange units are active simultaneously.

Natural gas in the fuel storage unit 150 may be used as fuel by a power generator 900 to generate energy for consumption. Fuel in the storage unit 150 may also be replenished by diverting a portion of the natural gas in line 20 via valve 265. Alternatively, the natural gas may be diverted through valve 75 and flowed to the storage unit 150.

In another embodiment, a method of liquefying a natural gas includes introducing the natural gas to a first heat exchange unit; introducing a refrigerant to the first heat exchange unit; liquefying the natural gas by absorbing heat from the refrigerant, thereby forming liquid natural gas; freezing a contaminant from the natural gas; vaporizing the refrigerant; regenerating a second heat exchange unit using the vaporized refrigerant; venting the vaporized refrigerant; utilizing the mixed contaminants and natural gas to provide power from a gas turbine generator; and collecting the liquid natural gas in a storage unit.

In one more of the embodiments described herein, the method further includes dispensing the liquid natural gas in the storage unit to a vehicle or to a liquid natural gas transporter.

In one more of the embodiments described herein, the method further includes switching the second heat exchange unit to active operation after regeneration.

In one more of the embodiments described herein, the method further includes regenerating the first heat exchange unit using refrigerant leaving the second heat exchange unit.

In one more of the embodiments described herein, the method further includes removing contaminants from the natural gas as it flows through the first heat exchange unit.

In one more of the embodiments described herein, the method the step of removing the contaminants comprises freezing the contaminants.

In one more of the embodiments described herein, the method further includes adhering the frozen contaminants to a surface of the first heat exchange unit.

In one more of the embodiments described herein, the method further includes filtering the frozen contaminants from the natural gas.

In one more of the embodiments described herein, the refrigerant is liquid nitrogen or liquid air.

In another embodiment, a system for liquefying natural gas using a refrigerant includes a first exchanger unit for liquefying the natural gas and removing a contaminant using the refrigerant; a second exchanger unit configured to
receive the refrigerant from the first exchanger unit, wherein the first exchanger unit and the second exchanger unit operate on alternating cycles; and a storage unit for the receiving the liquid natural gas.

[0056] In one more of the embodiments described herein, the contaminant includes one of water, carbon dioxide, and combinations thereof.

[0057] In one more of the embodiments described herein, the temperature in the first exchanger unit is sufficient to freeze the contaminant.

[0058] In one more of the embodiments described herein, the system further comprises a filter unit.

[0059] In one more of the embodiments described herein, the system further comprises a gas turbine generator to produce power.

[0060] In one more of the embodiments described herein, fuel for the gas turbine generator is supplied from a fuel storage unit that is in selectively fluid communication with the first and second heat exchange units for replenishing fuel in the fuel storage unit.

[0061] In one more of the embodiments described herein, the system further includes a dispensing unit connected to the storage unit for transfer of the liquid natural gas.

[0062] In one more of the embodiments described herein, the system includes a pump for transferring the liquid natural gas.

[0063] In one more of the embodiments described herein, the liquid natural gas is transferred to a vehicle or a mobile storage unit.

[0064] In one more of the embodiments described herein, the system further comprises an amine unit to remove carbon dioxide.

[0065] In one more of the embodiments described herein, the system further comprises a molecular sieve configured to dry the natural gas.

[0066] In one more of the embodiments described herein, the amine unit is followed by a glycol dehydration unit.

[0067] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

1. A method of liquefying natural gas, comprising:
   supplying a natural gas to a first pretreatment unit to remove a contaminant;
   introducing the pretreated natural gas to a first heat exchange unit;
   introducing a refrigerant to the first heat exchange unit;
   liquefying the natural gas by absorbing heat from the refrigerant, thereby forming liquid natural gas;
   vaporizing the refrigerant;
   regenerating a second heat exchange unit using the vaporized refrigerant;
   heating the vaporized refrigerant leaving the second heat exchange unit;
   regenerating a second pretreatment unit using the heated refrigerant; and
   collecting the liquid natural gas in a storage unit.

2. The method of claim 1, further comprising dispensing the liquid natural gas in the storage unit to a vehicle.

3. The method of claim 1, further comprising switching the second heat exchange unit to active operation after regeneration.

4. The method of claim 3, further comprising regenerating the first heat exchange unit using refrigerant leaving the second heat exchange unit.

5. The method of claim 1, wherein regenerating the second pretreatment unit includes discharging a hydrocarbon to a fuel storage unit.

6. The method of claim 5, further comprising reducing a temperature of the heated refrigerant and flowing the reduced temperature refrigerant through the second pretreatment unit.

7. The method of claim 1, further comprising removing contaminants from the natural gas as it flows through the first heat exchange unit.

8. The method of claim 7, wherein removing the contaminants comprises freezing the contaminants.

9. The method of claim 8, further comprising adhering the frozen contaminants to a surface of the first heat exchange unit.

10. The method of claim 9, further comprising filtering the frozen contaminants from the natural gas.

11. The method of claim 1, wherein the refrigerant is liquid nitrogen or air.

12. A system for liquefying natural gas using a refrigerant, comprising:
   a first treating unit configured to remove a contaminant from the natural gas;
   a first exchanger unit for liquefying the natural gas using the refrigerant;
   a second exchanger unit configured to receive the refrigerant from the first exchanger unit, wherein the first exchanger unit and the second exchanger unit operate on alternating cycles;
   a second treating unit configured to receive the refrigerant from the second exchanger unit; and
   a storage unit for the receiving the liquid natural gas.

13. The system of claim 12, wherein the first and second treating units operate on alternating cycles.

14. The method of claim 12, wherein the first exchanger unit is configured to remove additional contaminants from the natural gas.

15. The system of claim 14, wherein a temperature in the first exchanger unit is sufficient to freeze the additional contaminant.

16. The system of claim 12, wherein system further comprises a filter unit.

17. The system of claim 12, wherein the system further comprises a heating unit for heating the refrigerant.

18. The system of claim 17, wherein the fuel for the heating unit is supplied from a fuel storage unit that is in selectively fluid communication with the first and second treating units for replenishing fuel in the fuel storage unit.

19. The system of claim 12, further comprising a dispensing unit connected to the storage unit for transfer of the liquid natural gas.

20. The system of claim 19, further comprising a pump for transferring the liquid natural gas.

21. The system of claim 19, wherein the liquid natural gas is transferred to a vehicle or a mobile storage unit.

22. The system of claim 12, wherein the treating units include a molecular sieve to remove the contaminants.

23. The system of claim 12, wherein the treating units include an amine unit to remove carbon dioxide.

24. The system of claim 23, wherein the treating units further include a molecular sieve configured to dry the natural gas after treatment in the amine unit.
25. The system of claim 23, wherein the treating units include a glycol dehydration unit.

26. A method of liquefying a natural gas, comprising:
   introducing the natural gas to a first heat exchange unit;
   introducing a refrigerant to the first heat exchange unit;
   liquefying the natural gas by absorbing heat from the refrigerant, thereby forming liquid natural gas;
   freezing a contaminant from the natural gas;
   vaporizing the refrigerant;
   regenerating a second heat exchange unit using the vaporized refrigerant;
   venting the vaporized refrigerant;
   utilizing the mixed contaminants and natural gas to provide power from a gas turbine generator; and
   collecting the liquid natural gas in a storage unit.

27. The method of claim 26, further comprising dispensing the liquid natural gas in the storage unit to a vehicle or to a liquid natural gas transporter.

28. The method of claim 26, wherein regenerating the first heat exchange unit includes discharging a hydrocarbon and contaminants to a fuel storage unit.

29. The method of claim 26, further comprising removing contaminants from the natural gas as it flows through the first heat exchange unit.

30. The method of claim 29, wherein removing the contaminants comprises freezing the contaminants.

31. The method of claim 30, further comprising adhering the frozen contaminants to a surface of the first heat exchange unit.

32. A system for liquefying a gas using a refrigerant, comprising:
   a first exchanger unit for liquefying the gas and removing a contaminant using the refrigerant;
   a second exchanger unit configured to receive the refrigerant from the first exchanger unit, wherein the first exchanger unit and the second exchanger unit operate on alternating cycles; and
   a storage unit for the receiving the liquid gas.

33. The system of claim 32, wherein the contaminant includes one of water, carbon dioxide, and combinations thereof.

34. The system of claim 33, wherein a temperature in the first exchanger unit is sufficient to freeze the contaminant.

35. The system of claim 32, wherein the system further comprises a gas turbine generator to produce power.

36. The system of claim 32, wherein the gas contains at least 50 mole % of methane or ethane.