METHOD FOR ADJUSTING HEATING VALUE OF LNG

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ABSTRACT
Systems and methods for adjusting the heating value of liquefied natural gas ("LNG") are provided. LNG can be apportioned into at least two portions. A first portion can be warmed to provide a vapor-liquid mixture which can be separated in a first separator to provide a first vapor and a first liquid. The first liquid can be separated to provide ANGL and a second vapor. The first vapor can be compressed and mixed with the second vapor to provide a first effluent. At least a portion of the first effluent can be used to heat the first portion. At least a portion of the first effluent can be used as a first reflux in the first separator. At least a portion of the first effluent can be mixed with a second portion of the LNG to provide an adjusted LNG.
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CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of and priority to U.S. Provisional Application having Ser. No. 60/872,706, filed on Dec. 4, 2006, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field

The present embodiments generally relate to systems and methods for reducing or otherwise adjusting the heating value and Wobbe Index of a liquefied natural gas ("LNG"). More particularly, systems and methods for reducing the heating value of liquefied natural gas ("LNG") and recovery of natural gas liquids ("NGL") are provided.

2. Description of the Related Art

Liquefied natural gas is rapidly becoming the preferred means for transporting commercial quantities of natural gas, especially from stranded deposits to major world markets. However, depending upon the source of the raw natural gas, LNG can contain significant quantities of C3 to C5 hydrocarbons which increases the heating value of the natural gas above the maximum of 1,070 BTU/scf and/or maximum Wobbe Index of 1,390 Btu/SCF, which are typically required for importation and transportation within the United States and the United Kingdom, among others.

Several methods are currently employed for reducing the heating value of a to meet United States and United Kingdom requirements including: blending with a low heating value LNG; injecting inert gases into the LNG; and/or removing the heavier hydrocarbon components (collectively referred to asNatural Gas Liquids or "NGL") from the LNG. Blending with a low value LNG requires a substantial investment in both equipment and low heating value inventory for dilution at the destination port. Dilution with an inert gas requires a similar substantial investment in both equipment and inert gas inventory for handling the inert gas at the destination port. Removal of NGL components from the LNG can also be capital intensive; however, the cost to remove the NGL may be offset in markets where the NGL commands a premium over LNG, thereby providing a potential revenue stream based upon the volume of recovered NGL.

A need exists, therefore, for a cost effective system and method for adjusting a high-heating value LNG by selectively separating the C3 and higher NGL to meet pipeline requirements and provide a fungible NGL product.

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 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 depicts an illustrative system for adjusting the heating value of LNG according to one or more embodiments described.

FIG. 2 depicts another illustrative system for adjusting the heating value of LNG according to one or more embodiments described.

FIG. 3 depicts yet another illustrative system for adjusting the heating value of LNG according to one or more embodiments described.

DETAILED DESCRIPTION

A detailed description will now be provided. Each of the appended claims defines a separate invention, which for infringement purposes is recognized as including equivalents to the various elements or limitations specified in the claims. Depending on the context, all references below to the "invention" may in some cases refer to certain specific embodiments only. In other cases it will be recognized that references to the "invention" will refer to subject matter recited in one or more, but not necessarily all, of the claims. Each of the inventions will now be described in greater detail below, including specific embodiments, versions and examples, but the inventions are not limited to these embodiments, versions or examples, which are included to enable a person having ordinary skill in the art to make and use the inventions, when the information in this patent is combined with available information and technology.

Systems and methods for adjusting the heating value of liquefied natural gas ("LNG") are provided. LNG can be apportioned into at least two portions. A first portion can be warmed to provide a vapor-liquid mixture which can be separated in a first separator to provide a first vapor and a first liquid. The first liquid can be separated to provide NGL and a second vapor. The first vapor can be compressed and mixed with the second vapor to provide a first effluent. At least a portion of the first effluent can be used as a first reflux in the first separator. At least a portion of the first effluent can be mixed with a second portion of the LNG to provide an adjusted LNG.

As used herein, the terms "Natural Gas Liquids" and/or "NGL" can refer to those hydrocarbons in natural gas that are separated as liquids at natural gas processing plants, fractionating and cycling plants. Natural gas liquids can include, but are not limited to, ethane; liquefied petroleum gases (propane, butanes, propane-butane mixtures, ethane-propane mixtures); isopentane; C5 and heavier hydrocarbons; and other small quantities of finished products, such as motor gasoline, special naphthas, jet fuel, kerosene, and distillate fuel oil.

With reference to the figures, FIG. 1 depicts an illustrative system for adjusting the heating value of LNG according to one or more embodiments. The system 100 can include one or more heat exchangers 120, two or more separators 140, 190 and one or more compressors 150. In one or more embodiments, at least a portion of the adjusted LNG can be returned as a first reflux to the one or more separators 140 to enhance the separation of LNG and NGL within the separators 140 and 190. The one or more heat exchangers 120 can be an interchanger, using heat from one or more intermediate process streams and/or waste streams to preheat the incoming LNG.

In one or more embodiments, the incoming LNG via line 105 can be apportioned equally or unequally into a first portion via line 115 and a second portion via line 110. The apportionment of the LNG between lines 110 and 115 can be dependent on multiple factors including, but not limited to,
the concentration of C_{2+} components in the LNG, performance and/or efficiency of the adjustment process, and the desired heating value of the final product. Based on one or more of these factors, about 0% wt, about 20% wt, about 40% wt, about 60% wt, about 80% wt, about 90% wt, about 95% wt, or about 100% wt of the incoming LNG can flow through the bypass via line 110, while the balance can be introduced via line 115 to the adjustment system 100. In one or more embodiments, about 0% wt, about 5% wt, about 10% wt, about 20% wt, about 40% wt, about 60% wt, about 80% wt, or about 100% wt of the incoming LNG via line 105 can be introduced to the one or more heaters 120 via line 115, while the second portion, containing the balance of the LNG, can flow through the bypass via line 110 for later remixing with an adjusted LNG effluent.

[0017] In one or more embodiments, the LNG in line 105 can include, but is not limited to, methane, ethane, propane, butane, pentane, nitrogen, mixtures thereof, or any combination thereof. In one or more embodiments, the LNG can contain one or more sulfur containing compounds, for example hydrogen sulfide, H_{2}S. In one or more embodiments, the methane content of the LNG can range from about 75% wt to about 99% wt, about 80% wt to about 95% wt, or about 80% wt to about 90% wt. In one or more embodiments, the ethane content of the LNG can range from about 1% wt to about 15% wt, about 2% wt to about 15% wt, or about 3% wt to about 12% wt. In one or more embodiments, the propane content of the LNG can range from about 0.1% wt to about 10% wt, about 0.1% wt to about 7% wt, or about 0.1% wt to about 5% wt. In one or more embodiments, the butane content of the LNG can range from about 0.1% wt to about 10.0% wt, about 0.1% wt to about 6.0% wt, or about 0.1% wt to about 3.0% wt. In one or more embodiments, the pentane content of the LNG can range from about 0.01% wt to about 5.0% wt, about 0.01% wt to about 4.0% wt, or about 0.01% wt to about 3.0% wt. In one or more embodiments, the nitrogen content of the LNG can range from about 0.01% wt to about 10.0% wt, about 0.01% wt to about 8.0% wt, or about 0.01% wt to about 6.0% wt. In one or more embodiments, the sulfur content of the LNG can range from about 1 ppmv to about 100 ppmv; from about 1 ppmv to about 75 ppmv; or from about 1 ppmv to about 50 ppmv.

[0018] In one or more embodiments, the heating value of the LNG in line 105 can be a minimum of about 1,000 BTU/ scf, about 1,150 BTU/scf, about 1,200 BTU/scf, or about 1,250 BTU/scf. In one or more embodiments, the Wobbe Index of the LNG in line 105 can be a maximum of about 1,300 BTU/scf, about 1,400 BTU/scf, about 1,500 BTU/scf or about 1,600 BTU/scf. In one or more embodiments, from about 1% wt to about 90% wt, about 1% wt to about 50% wt, or from about 1% wt to about 10% wt of the LNG via line 105 can be vaporized. In one or more embodiments, the temperature (“first temperature”) of the LNG via line 105 can range from about -155° C. (-265° F.) to about -80° C. (-176° F.), about -60° C. (-137° F.) to about -125° C. (-185° F.), or about -150° C. (-238° F.) to about -100° C. (-140° F.). In one or more embodiments, the pressure of the LNG via line 105 can range from about 100 kPa (7 psig) to about 720 kPa (105 psig), about 500 kPa (71 psig), or about 1,000 kPa (15 psig) to about 2,500 kPa (36 psig).

[0019] The first portion via line 115 can be heated using a heat transfer medium in one or more heaters 120 to at least partially vaporize the LNG therein and provide a vapor-liquid mixture (“first mixture”) via line 125. In one or more embodiments, the first mixture in line 125 can contain about 75% wt, about 80% wt, about 85% wt, about 90% wt, about 95% wt, or about 99% wt vapor with the balance liquid. In one or more embodiments, the vapor in the first mixture in line 125 can contain about 80 mol % or more, about 90 mol % or more, about 95 mol % or more, or about 99 mol % or more methane. In one or more embodiments, the liquid in the first mixture in line 125 can contain about 20 mol % or less, about 10 mol % or less, about 5 mol % or less, or about 1 mol % or less C_{2} and heavier hydrocarbons.

[0020] Maintaining the exit temperature (“second temperature”) of the one or more heaters 120 at a temperature above the boiling point of methane, but below the boiling point of C_{2} and heavier hydrocarbons can promote the formation of a vapor-liquid mixture in line 125 having a vapor phase rich in methane and a liquid phase rich in NGLs. For example, the second temperature can range from about -160° C. (-255° F.) to about -50° C. (-58° F.), about -180° C. (-292° F.) to about -75° C. (-103° F.), or about -160° C. (-255° F.) to about -100° C. (-140° F.).

[0021] In one or more embodiments, the one or more heat exchangers 120 can include, but are not limited to shell and tube, U-tube, bayonet, regenerative, plate and frame, or any combination thereof in series or parallel. In one or more embodiments, the one or more heat exchangers 120 can include a directed fired heater. In one or more embodiments, the operating pressure of the heat exchanger 120 can range from 100 kPa (0 psig) to about 10,000 kPa (145 psig), about 500 kPa (70 psig) to about 5,000 kPa (710 psig), or about 500 kPa (70 psig) to about 2,500 kPa (350 psig).

[0022] The first mixture in line 125 can be introduced to the one or more separators (“first separator”) 140 to provide a vapor (“first vapor”) via line 145 and a liquid (“first liquid”) via line 160. In one or more embodiments, a reflux (discussed in greater detail below) can be circulated via line 175 through the first separator 140 to cool the vapor in the first separator 140, condensing any residual C_{2} and heavier hydrocarbons present, thereby minimizing the concentration of C_{2} and heavier hydrocarbons within the first vapor in line 145.

[0023] In one or more embodiments, the first vapor in line 145 can contain about 80 mol % or more; about 85 mol % or more; about 90 mol % or more; about 95 mol % or more; about 99 mol % or more; about 90 mol % or more; about 95 mol % or more; about 99 mol % or more; about 10 mol % or less; about 5 mol % or less; about 10 mol % or less; about 15 mol % or less; about 20 mol % or less; nitrogen and/or other non-condensables, for example hydrogen. The first vapor in line 145 can be compressed using one or more compressors 150 to provide a compressed first vapor via line 155. The compressor 150 can include any device suitable for compressing a gas, and/or multi-phase fluid, for example one or more reciprocating, rotary, axial flow, centrifugal, diagonal or mixed-flow, scroll, or diaphragm compressors or any series and/or parallel combination thereof. The compressor 150 can have one or more compressor stages with or without intercooling between successive stages. In one or more embodiments, the pressure of the compressed vapor in line 155 can range from about 200 kPa (15 psig) to about 20,000 kPa (2,880 psig), about 1,000 kPa (15 psig) to about 10,000 kPa (1,435 psig), or about 1,000 kPa (15 psig) to about 5,000 kPa (710 psig). In one or more embodiments, the temperature of the compressed vapor in line 155 can range from about -100°
C. (-150° F) to about 100° C. (210° F), about -100° C. (-150° F) to about 50° C. (120° F), or about -50° C. (-60° F) to about 50° C. (120° F).

[0024] In one or more embodiments, the first liquid in line 160 can contain about 60% wt or more; about 70% wt or more; about 80% wt or more; about 85% wt or more; about 90% wt or more; or about 95% wt or more C₂ and heavier hydrocarbons. In one or more embodiments, the temperature of the first liquid in line 160 can range from about -160° C. (-255° F) to about -90° C. (-130° F), about -160° C. (-255° F) to about -100° C. (-150° F), or about -160° C. (-255° F) to about -125° C. (-190° F). The pressure of the first liquid in line 160 can range from about 200 kPa (15 psig) to about 20,000 kPa (2,890 psig), about 1,000 kPa (15 psig) to about 10,000 kPa (1,430 psig), or about 1,000 kPa (15 psig) to about 5,000 kPa (710 psig).

[0025] The one or more first separators 140 can be a vessel having internal packing media, such as rings, saddles, balls, irregular sheets, tubes, spirals, trays, plates, and/or baffles, to facilitate the separation of liquids and vapors therein. In one or more embodiments, the operating temperature in the first separator 140 can range from -165° C. (-265° F) to about -100° C. (-150° F), about -160° C. (-255° F) to about -125° C. (-190° F), or about -150° C. (-240° F) to about -100° C. (-150° F). In one or more embodiments, the operating pressure in the first separator 140 can range from 100 kPa (0 psig) to about 10,000 kPa (1,435 psig), about 500 kPa (60 psig) to about 5,000 kPa (710 psig), or about 500 kPa (60 psig) to about 2,500 kPa (350 psig).

[0026] The first liquid, exiting the first separator 140 via line 160, can be transferred to the separator ("second separator") 190 via one or more transfer devices 143. In one or more embodiments, the transfer device 143 can be a pump or compressor. In one or more embodiments, the transfer device 143 can increase the pressure of the first liquid in line 160 about 690 kPa (100 psi); about 515 kPa (75 psi); or about 350 kPa (50 psi). Upon introduction to the one or more second separators 190, the first liquid can flash into a liquid ("second liquid") phase and a vapor ("second vapor") phase. The second vapor, containing essentially methane, can be withdrawn from the second separator 190 via line 170. The second liquid, containing one or more liquefied C₂ and heavier hydrocarbons (i.e. NGL), can be withdrawn via line 165. In one or more embodiments, the second vapor in line 170 can contain about 80 mol % or more; about 85 mol % or more; about 90 mol % or more; or about 95 mol % or more. In one or more embodiments, the second vapor in line 170 can contain about 20 mol % or less; about 15 mol % or less; about 10 mol % or less; about 5 mol % or less; or about 1 mol % or less; nitrogen and/or other non-condensables, for example hydrogen. In one or more embodiments, the temperature of the second vapor in line 170 can range from about -100° C. (-150° F) to about 100° C. (210° F), about -100° C. (-150° F) to about 50° C. (120° F), or about -50° C. (-60° F) to about 50° C. (120° F). In one or more embodiments, the pressure of the second vapor in line 170 can range from about 200 kPa (15 psig) to about 20,000 kPa (2,890 psig), about 1,000 kPa (15 psig) to about 10,000 kPa (1,435 psig), or about 1,000 kPa (15 psig) to about 5,000 kPa (710 psig).

[0027] In one or more embodiments, at least a portion of the second liquid in line 165 can be removed via line 167, heated using one or more heat exchangers 195, and returned to the second separator 190 as a second reflux. In one or more embodiments, the temperature of the second liquid in line 167 exiting the one or more heat exchangers 195 can range from about -160° C. (-255° F) to about -90° C. (-130° F), about -160° C. (-255° F) to about -100° C. (-150° F), or about -160° C. (-255° F) to about -125° C. (-190° F). In one or more specific embodiments, the second separator 190 can be operated in the two phase region, at a temperature less than the critical temperature of the second liquid. As the operating pressure of the second separator 190 is reduced, the required heat input to the reboiler 195 can be commensurately reduced as well.

[0028] In one or more embodiments, the second liquid in line 165 can contain about 60% wt or more; about 70% wt or more; about 80% wt or more; about 90% wt or more; about 95% wt or more; or about 99% wt or more C₂ and heavier hydrocarbons. In one or more embodiments, the ethane concentration in the second liquid in line 165 can range from about 40% wt to about 99% wt, about 60% wt to about 99% wt, or about 80% wt to about 99% wt. In one or more embodiments, the propane concentration in the second liquid in line 165 can range from about 1% wt to about 60% wt, about 1% wt to about 40% wt, or about 1% wt to about 20% wt. In one or more embodiments, the butane concentration in the second liquid in line 165 can range from about 1% wt to about 60% wt, about 1% wt to about 40% wt, or about 1% wt to about 20% wt. In one or more embodiments, the pentane concentration in the second liquid in line 165 can range from about 1% wt to about 60% wt, about 1% wt to about 40% wt, or about 1% wt to about 20% wt.

[0029] Any sulfur compounds present in the LNG in line 105 can concentrate in the second liquid in line 165. Sulfur compounds present in LNG can include, but are not limited to, hydrogen sulfide, carbonyl sulfide, methyl mercaptan, ethyl mercaptan, and n-propyl mercaptan. In one or more embodiments, the sulfur content of the second liquid in line 165 can range from about 1 ppmw to about 500 ppmw; from about 1 ppmw to about 400 ppmw; or from about 1 ppmw to about 300 ppmw. Where the second liquid in line 165 is used as a fuel supply, sulfur dioxide (SO₂) emissions should be included in the air emissions and suitable SO₂ corrosion resistance measures can be incorporated into the process design.

[0030] Sulfur compounds present in the second liquid can be removed prior to marketing the second liquid as an NGL. While several options exist to remove sulfur containing compounds, the ultimate selection of a sulfur removal process can be influenced by the imported LNG specifications and the NGL market specifications. The selection of a sulfur removal process can be influenced by the effectiveness of the process in removing various sulfur containing compounds, since some processes are effective at reducing mercaptan levels, but not hydrogen sulfide and carbonyl sulfide levels. The overall cost of desulfurization, including waste removal, disposal and associated costs can be evaluated and considered in the selection process.

[0031] The one or more second separators 190 can be any system, device or combination of systems and/or devices capable of separating a multiphase mixture into a relatively liquid-free second vapor via line 170 and a relatively vapor-free second liquid via line 165. The second separator 190 can include internal packing media, such as rings, saddles, balls, irregular sheets, tubes, spirals, trays, plates, and/or baffles, to facilitate the liquid/vapor separation. In one or more embodiments, the operating temperature of the second separator 190 can range from about -100° C. (-150° F) to about 100° C.
In one or more embodiments, the operating pressure of the second separator 190 can range from 200 kPa (15 psig) to about 20,000 kPa (2,890 psig), about 1,000 kPa (130 psig) to about 10,000 kPa (1,430 psig), or about 1,000 kPa (130 psig) to about 5,000 kPa (710 psig).

[0032] The one or more heat exchangers 195 can include, but are not limited to a shell and tube, U-tube, bayonet, regenerative, plate and frame, or any combination thereof in series or parallel. In one or more embodiments, a non-freezing heat transfer fluid can be used to supply heat to the heat exchangers 195 due to the potential for low operating temperatures within the reboiler. In one or more embodiments, the one or more heat exchangers 195 can be an interchanger or regenerative heat exchanger using process or waste heat, for example heat provided by the exhaust from a combustion process, to increase the temperature of the second liquid in line 167. In one or more embodiments, the one or more heat exchangers 195 can include a directed fired heater. In one or more embodiments, the operating temperature of the one or more heat exchangers 195 can range from about 165°C (330°F) to about 100°C (212°F), about 165°C (330°F) to about 50°C (122°F), or about 160°C (320°F) to about 50°C (122°F). In one or more embodiments, the pressure of the one or more heat exchangers 195 can range from about 1,000 kPa (130 psig) to about 10,000 kPa (1,435 psig), about 500 kPa (69 psig) to about 5,000 kPa (710 psig), or about 500 kPa (69 psig) to about 2,500 kPa (360 psig).

[0033] Referring back to the one or more compressors 150, at least a portion of the compressed first effluent exiting the compressor 150 via line 155 can be combined with at least a portion of the second vapor exiting the separator 190 via line 170 to form a first effluent in line 180. In one or more embodiments, all or a portion of the first effluent via line 180 can be used as the heat transfer medium in the one or more heat exchangers 120, supplying the heat necessary to warm the first portion of the LNG in line 115. In one or more embodiments, the contact with the first portion of the LNG in line 115 can condense and sub-cool at least a portion of the first effluent. In one or more embodiments, about 2% wt, about 20% wt, about 40% wt, about 60% wt, about 80% wt, about 98% wt, or about 99% wt of the first effluent via line 180 can condense in the one or more heat exchangers 120.

[0034] In one or more embodiments, the partially condensed first effluent can exit the one or more heat exchangers 120 via line 182. In one or more embodiments, the first effluent in line 182 can contain a minimum of about 50 mol% or more; about 85 mol% or more; about 90 mol% or more; about 95 mol% or more; or about 99 mol% or more. In one or more embodiments, the first effluent in line 182 can contain about 20 mol% or less; about 15 mol% or less; about 10 mol% or less; about 5 mol% or less; or about 1 mol% or less; nitrogen and/or other non-condensables, for example hydrogen. In one or more embodiments, the temperature of the first effluent in line 182 can range from about -100°C (-150°F) to about 50°C (122°F), about -100°C (-150°F) to about 100°C (212°F), or about -100°C (-150°F) to about 150°C (302°F). In one or more embodiments, the pressure of the first effluent in line 182 can range from about 200 kPa (15 psig) to about 20,000 kPa (2,890 psig), about 1,000 kPa (130 psig) to about 10,000 kPa (1,435 psig), or about 1,000 kPa (130 psig) to about 5,000 kPa (710 psig).

[0035] In one or more embodiments, at least a portion of the first effluent in line 182 can be used to provide the first reflux via line 175 to the one or more first separators 140. In one or more embodiments, the first reflux via line 175 can enhance the separation of methane and NGL liquids within the first separator 140. The reflux ratio (first mixture-to-finished product reflux) of the first reflux can range from about 200:1 to about 5:1; about 150:1 to about 10:1; or, more preferably from about 100:1 to about 20:1. In one or more specific embodiments, sharp increases in NGL recovery rates can occur at first reflux rates up to approximately 100:1 (i.e. up to a 1% recycle) with lesser increases occurring at reflux rates greater than 100:1 (i.e. greater than 1% recycle).

[0036] In one or more embodiments, at least a portion of the first effluent via line 182 can be combined with the second portion of the LNG via line 110 to form a first product via line 185 containing natural gas having a heating value suitable for pipeline transfer. In one or more embodiments, the first product can contain about 80 mol% or more; about 85 mol% or more; about 90 mol% or more; about 95 mol% or more; or about 99 mol% or more methane. In one or more embodiments, the ethane content of the first product in line 185 can range from about 0.1% wt to about 5% wt, about 0.1% wt to about 4% wt, or about 0.1% wt to about 3% wt. In one or more embodiments, the propane content of the first product can range from about 0.05% wt to about 2% wt, about 0.10% wt to about 1% wt, or about 0.10% wt to about 0.75% wt. In one or more embodiments, the butane content of the first product can range from about 0.01% wt to about 0.3% wt, about 0.01% wt to about 0.2% wt, or about 0.01% wt to about 0.01% wt. In one or more embodiments, the pentane content of the first product can range from about 0.001% wt to about 0.01% wt, about 0.001% wt to about 0.008% wt, or about 0.001% wt to about 0.005% wt. In one or more embodiments, the nitrogen content of the first product can range from about 0.1% wt to about 5% wt, about 0.5% wt to about 3% wt, or about 0.5% wt to about 2% wt.

[0037] In one or more embodiments, the heating value of the first product in line 185 can be a maximum of about 1,100 BTU/scf, about 1,050 BTU/scf, or about 1,000 BTU/scf. In one or more embodiments, the Wobbe Index of the first product in line 185 can be a maximum of about 1,390 BTU/scf, about 1,350 BTU/scf, or about 1,310 BTU/scf. In one or more embodiments, the butane content of the first product can range from about 0% wt to about 90% wt, about 1% wt to about 90% wt, or from about 1% wt to about 10% wt of the first product via line 185 can be vaporized. In one or more embodiments, the temperature of the first product via line 185 can range from about -150°C (-240°F) to about 50°C (122°F), about -100°C (-150°F) to about 25°C (77°F), or about -50°C (-60°F) to about -25°C (-13°F). In one or more embodiments, the pressure of the first product via line 185 can range from 100 kPa (0 psig) to about 10,000 kPa (1,435 psig), about 500 kPa (69 psig) to about 5,000 kPa (710 psig), or about 500 kPa (69 psig) to about 2,500 kPa (360 psig).

[0038] FIG. 2 depicts another illustrative system 200 for adjusting the heating value of LNG according to one or more embodiments. In addition to the one or more heat exchangers 120, and separators 140, 190, discussed above with reference to FIG. 1, the system 200 can include one or more turboexpanders/compressors 220. In one or more embodiments, the second vapor in line 170 can be introduced to an expander portion of the one or more turboexpanders/compressor 220 to provide a third vapor via line 215. The shaft power generated by the expander portion of the turboexpander/compressor can
be used to compress the first vapor in line 145 to provide the compressed first vapor in line 155. In one or more embodiments, at least a portion of the compressed first vapor in line 155 can be combined with at least a portion of the third vapor via line 215 to provide the first effluent via line 180. The system 200, as depicted in FIG. 2, can process LNG having a high concentration of C₂ and heavier hydrocarbons without experiencing a significant change in operating conditions. As depicted in FIG. 2, the first reflux to the first separator 140 can provide flexibility in increasing NGL production when compared to systems where no first reflux occurs.

The turboexpander/compressor 220 can control the process pressure in the first effluent in line 180, permitting a lower pressure in the feed and reduced condensing of the LNG product in the one or more heat exchangers 120. In one or more embodiments, the temperature of the third vapor in line 215 can range from -150° C. (-240° F.) to about 50° C. (120° F.), about -100° C. (-150° F.) to about 25° C. (80° F.), or about -50° C. (-60° F.) to about -25° C. (-10° F.). In one or more embodiments, the pressure of the third vapor in line 215 can range from 100 kPa (0 psig) atm to about 10,000 kPa (1,435 psig), about 500 kPa (60 psig) to about 5,000 kPa (710 psig), or about 500 kPa (60 psig) to about 2,500 kPa (350 psig).

In one or more embodiments, the turboexpander/compressor 220 can include a turbine and a centrifugal compressor, with the turbine and the compressor impeller sharing a common shaft. The compressor side of the turboexpander/compressor 220 can be used to compress the first vapor in line 145. The energy needed to drive the turboexpander/compressor 220 can be derived by passing the second vapor in line 170 through the turbine portion of the turboexpander/compressor 220. Since work can be extracted from the second vapor as it spins the turbine, the pressure and temperature of the third vapor via line 215 exiting the turbine can be lower than the pressure and temperature of the second vapor in line 170 entering the turbine. Although not shown in FIG. 2, the turboexpander/compressor 220 can be equipped with an electric driver to enable the compression of the first vapor in line 145 and should the expander section be taken offline.

In systems 100 and 200, as depicted in FIGS. 1 and 2, the first reflux via line 175 can return at least a portion of the first effluent in line 182 to the first separator 140. Increasing the first reflux rate via line 175 can proportionately increase the C₂ recovery rate in the first liquid in line 160, thereby decreasing the heating value of the first effluent in line 180. Due to the reduced heating value of the first effluent in line 180, the portion of LNG bypassing the adjustment process via line 110 can be increased, thereby reducing the size of the required LNG adjustment system.

FIG. 3 depicts yet another illustrative system 300 for adjusting the heating value of LNG according to one or more embodiments. In one or more embodiments, the LNG in line 105 can be proportioned into equal or unequal portions, with a first portion in line 115 and a second portion in line 110. The first portion in line 115 can be directed through a heat exchanger 320 wherein the first portion can be warmed using a heat transfer fluid. In one or more embodiments, the first vapor in line 145 can be used as the heat transfer fluid to provide a warmed feed via line 325 and a cooled first vapor, at least a portion of which can be condensed, via line 330. In one or more embodiments, the cooled first vapor in line 330 can be introduced to one or more third separators 340 where a liquid can be removed via line 335, and a vapor removed via line 345. The vapor in line 345 can be compressed using the one or more compressors 150 to provide the compressed first vapor via line 155. In one or more embodiments, at least a portion of the liquid in line 335 can be combined with the second portion of the feed via line 110 to form a mixture in line 375 which, when combined with the first effluent via line 180, can provide the first product via line 185.

In one or more embodiments, the vapor content in the warmed feed in line 325 can be about 50 wt % or more; about 60 wt % or more; about 70 wt % or more; about 80 wt % or more; about 90 wt % or more; about 95 wt % or more; or about 99 wt % or more, with the balance liquid. In one or more embodiments, the vapor present in the warmed feed of line 325 can contain a minimum of about 80 mol % or more; about 90 mol % or more; about 95 mol % or more; about 99 mol % or more; about 99.9 mol % or more methane. In one or more embodiments, the liquid present in the warmed feed of line 325 can contain about 60 wt % or more; about 70 wt % or more; about 80 wt % or more; about 90 wt % or more; about 95 wt % or more; or about 99 wt % or more, with the balance liquid. In one or more embodiments, the cooled first vapor in line 330 can contain about 80 mol % or more; about 90 mol % or more; about 95 mol % or more; or about 99 mol % or more methane. In one or more embodiments, the cooled first vapor in line 330 can contain a maximum of about 20 mol % or less; about 10 mol % or less; about 5 mol % or less; or about 1 mol % or less nitrogen and/or other non-condensables, for example hydrogen. In one or more embodiments, the temperature of the cooled first vapor in line 330 can range from about -160° C. (-255° F.) to about -90° C. (-130° F.), about -160° C. (-255° F.) to about -100° C. (-150° F.), or about -160° C. (-255° F.) to about -125° C. (-190° F.).

In one or more embodiments, the liquid content in the condensed liquid in line 335 can be about 50 wt % or more; about 60 wt % or more; about 70 wt % or more; about 80 wt % or more; about 90 wt % or more; about 95 wt % or more; or about 99 wt % or more, with the balance vapor. In one or more embodiments, the condensed liquid in line 335 can contain about 20 mol % or less; about 10 mol % or less; about 5 mol % or less; or about 1 mol % or less methane. In one or more embodiments, the condensed liquid in line 335 can contain about 20 mol % or less; about 10 mol % or less; about 5 mol % or less; about 1 mol % or less nitrogen and/or other non-condensables such as hydrogen. In one or more embodiments, the temperature of the condensed liquid in line 335 exiting the one or more second separators 340 can range from about -160° C. (-255° F.) to about -90° C. (-130° F.), about -160° C. (-255° F.) to about -100° C. (-150° F.), or about -160° C. (-255° F.) to about -125° C. (-190° F.).

In one or more embodiments, the vapor content in the vapor in line 345 can be about 90 wt % or more; about 95 wt % or more; about 99 wt % or more; or about 99.9 wt % or more. In one or more embodiments, the vapor in line 345 can
contain about 80 mol % or more; about 90 mol % or more; about 95 mol % or more; or about 99 mol % or more methane. In one or more embodiments, the vapor in line 345 can contain about 20 mol % or less; about 10 mol % or less; about 5 mol % or less; about 1 mol % or less; nitrogen and/or other non-condensables such as hydrogen. In one or more embodiments, the temperature of vapor in line 345 can range from about −160° C. (−255° F.) to about −90° C. (−130° F.), about −160° C. (−255° F.) to about −100° C. (−150° F.), or about −160° C. (−255° F.) to about −125° C. (−195° F.).

[0047] In one or more embodiments, at least a portion of the condensate liquid in line 335 can be combined with the second portion of the LNG via line 110, forming a mixture in line 375. In one or more embodiments, the mixture in line 375 can contain about 80 mol % or more; about 90 mol % or more; about 95 mol % or more; or about 99 mol % or more methane. In one or more embodiments, the mixture in line 375 can contain about 20 mol % or less; about 10 mol % or less; about 5 mol % or less; about 1 mol % or less; nitrogen and/or other non-condensables such as hydrogen. In one or more embodiments, the temperature in line 375 can range from about −165° C. (−299° F.) to about 0° C. (32° F.), about −165° C. (−299° F.) to about −25° C. (−13° F.), about −125° C. (−195° F.) to about −125° C. (−195° F.), or about −165° C. (−299° F.) to about −140° C. (−250° F.). In one or more embodiments, the pressure in line 375 can range from about 200 kPa (15 psig) to about 20,000 kPa (2,885 psig), about 1,000 kPa (145 psig) to about 10,000 kPa (1,435 psig), or about 1,000 kPa (145 psig) to about 5,000 kPa (710 psig).

[0048] In one or more embodiments, the one or more heat exchangers 320 can be any system, device or combination of systems and/or devices capable of increasing the temperature of the incoming first portion of LNG via line 115. The one or more heat exchangers 320 can include, but are not limited to, one or more of the following: shell-and-tube, U-tube, bayonet, plate and frame heat exchangers or any combination thereof, arranged either in series, parallel, or any combination thereof. The heat exchanger 320 can include one or more direct fired heaters, combustion a liquid or gas fuel to increase the temperature of the first portion of the incoming LNG in line 115. The heat exchanger 320 can be any one or more interchangers or other regenerative type heat exchangers using process and/or waste heat to increase the temperature of the first portion of the LNG in line 115. In one or more embodiments, the operating temperature of the heat exchanger 320 can range from −165° C. (−299° F.) to about −100° C. (−150° F.), about −160° C. (−255° F.) to about −125° C. (−195° F.), or about −150° C. (−240° F.) to about −100° C. (−150° F.). In one or more embodiments, the operating pressure of the heat exchangers 320 can range from 100 kPa (0 psig) to about 10,000 kPa (1,435 psig), about 500 kPa (60 psig) to about 5,000 kPa (710 psig), or about 500 kPa (60 psig) to about 2,500 kPa (350 psig).

[0049] The one or more third separators 340 can be any system, device or combination of systems and/or devices capable of separating a mixture containing vapor and liquid into a vapor overhead and a liquid bottom. The third separator 340 can include internal packing media, such as rings, saddles, balls, irregular sheets, tubes, spirals, trays, plates, and/or baffles, to facilitate the liquid/vapor separation. In one or more embodiments, the operating temperature within the third separator 340 can range from −165° C. (−299° F.) to about −100° C. (−150° F.), about −160° C. (−255° F.) to about −125° C. (−195° F.), or about −150° C. (−240° F.) to about −100° C. (−150° F.). In one or more embodiments, the operating pressure within the third separator 340 can range from about 100 kPa (0 psig) to about 10,000 kPa (1,435 psig), about 500 kPa (60 psig) to about 5,000 kPa (710 psig), or about 500 kPa (60 psig) to about 2,500 kPa (350 psig).

[0050] The system 300, as depicted in FIG. 3, makes use of two heat exchangers, 120 and 320, to at least partially condense the overhead vapor from the separators, 140 and 190, and to further pressurize the LNG feeding into the separators 140 and 190. The use of two heat exchangers, 120 and 320 in the system depicted in FIG. 3 decreases the duty on the individual heat exchangers 120 and 320, thereby promoting stability in operation of the system 300. The use of two heat exchangers, 120 and 320 can reduce the power required to drive the one or more compressors 150 by decreasing the volume of vapor introduced to the compressor via line 345.

[0051] LNG extraction volume is strongly affected by C_2 recovery rate which, in systems 100 and 200, can be controlled via the first reflux of at least a portion of LNG product to the first separator 140, via line 175. Where the first reflux to the first separator 140 is not possible, for example in the system 300, depicted in FIG. 3, less flexibility exists for controlling the LNG recovery rate.

[0052] Certain embodiments and features have been described using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges from any lower limit to any upper limit are contemplated unless otherwise indicated. Certain lower limits, upper limits and ranges appear in one or more claims below. All numerical values are “about” or “approximately” the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0053] Various terms have been defined above. To the extent a term used in a claim is not defined above, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Furthermore, all patents, test procedures, and other documents cited in this application are fully incorporated by reference to the extent such disclosure is not inconsistent with this application and for all jurisdictions in which such incorporation is permitted.

[0054] 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.

What is claimed is:

1. A method for adjusting the heating value and Wobbe index of liquefied natural gas, comprising:
   a) apportioning liquefied natural gas at a first temperature into at least a first portion and a second portion;
   b) heating the first portion to provide a first vapor-liquid mixture having a second temperature;
   c) selectively separating, under a first reflux, the first vapor-liquid mixture to provide a first vapor and a first liquid;
   d) compressing at least a portion of the first vapor comprising methane to provide a compressed vapor;
   e) selectively separating the first liquid to provide a second vapor comprising methane and a second liquid comprising NGL; and
   f) combining the second vapor and the compressed vapor to form a first effluent.

2. The method of claim 1, further comprising combining the second portion of the liquefied natural gas with the first effluent to provide a first product.
3) The method of claim 2, further comprising vaporizing the first product.
4) The method of claim 1, wherein the second vapor is expanded and the first vapor is compressed using a turboexpander.
5) The method of claim 1, wherein at least a portion of the first effluent is used as a heat transfer fluid to warm the first portion of the liquefied natural gas.
6) The method of claim 1, wherein the first reflux comprises at least a portion of the first effluent.
7) The method of claim 1, wherein the first temperature is −160°C or lower.
8) The method of claim 1, wherein the second temperature is greater than −160°C and less than −88°C.
9) A method for adjusting the heating value of liquefied natural gas comprising:
   - apportioning the liquefied natural gas at a first temperature into a first portion and a second portion;
   - heating the first portion to provide a first intermediate at a second temperature;
   - heating the first intermediate to provide a first vapor-liquid mixture at a third temperature;
   - selectively separating the first vapor-liquid mixture to provide a first vapor and a first liquid;
   - selectively separating the first liquid to provide a second vapor and a second liquid product;
   - cooling and selectively separating the second vapor to provide a third vapor and a second liquid;
   - compressing the third vapor to provide a compressed vapor;
   - combining the second vapor and the compressed vapor to provide a first effluent; and
   - cooling the first effluent.
10) The method of claim 9, further comprising combining the second liquid and the second portion of the liquefied natural gas to provide a second effluent.
11) The method of claim 9, further comprising combining the second effluent with the first effluent to provide a first product.
12) The method of claim 11, further comprising vaporizing the first product.
13) The method of claim 9, wherein at least a portion of the first vapor is used as a heat transfer fluid to warm the first portion of the liquefied natural gas feed.
14) The method of claim 9, wherein at least a portion of the first effluent is used as a heat transfer fluid to warm the first intermediate.
15) The method of claim 9, wherein the first temperature is −160°C or lower.
16) The method of claim 9, wherein the second temperature is greater than −160°C and less than −88°C.
17) The method of claim 9, wherein the first temperature is greater than −160°C and less than −88°C.
18) A system for adjusting the heating value and Wobbe Index of liquefied natural gas, comprising:
   - a heating zone for increasing the temperature of at least a portion of a liquefied natural gas above the boiling point of methane and below the boiling point for C₂ and heavier hydrocarbons;
   - a first separation zone having an essentially liquid methane first reflux for separating the vaporized methane from liquid C₂ and heavier hydrocarbons;
   - a second separation zone for separating residual methane from the liquid C₂ and heavier hydrocarbons to provide an NGL liquid product and a methane rich effluent; and
   - a mixing zone for mixing a bypassed portion of the liquefied natural gas and the methane rich effluent to provide an adjusted liquefied natural gas product having a heating value suitable for pipeline transfer.
19) The system of claim 18, wherein the heating zone comprises an interchanger for exchanging heat between the methane rich first effluent and the liquefied natural gas.

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