

BOIL-OFF GAS RECYCLE SUBSYSTEM IN NATURAL GAS LIQUEFACTION PLANTS

CROSS REFERENCE TO RELATED APPLICATION

- 5 [0001] This application claims the priority benefit of United States Provisional Patent Application No. 62/718742 filed August 14, 2018, entitled BOIL-OFF GAS RECYCLE SUBSYSTEM IN NATURAL GAS LIQUEFACTION PLANTS.

FIELD

- 10 [0002] This disclosure relates generally to the subsystem for and methods related to recycling liquefied natural gas (LNG) boil-off gas (BOG) in natural gas liquefaction plants.

BACKGROUND

- 15 [0003] Because of its clean burning qualities and convenience, natural gas has become widely used in recent years. However, large volumes of natural gas (i.e., primarily methane) are located in remote areas of the world. This gas has significant value if it can be economically transported to market. Where gas reserves are located in reasonable proximity to a market and the terrain between the two locations permits, the gas is typically produced and then transported to market through submerged and/or land-based pipelines. However, when gas is produced in locations where laying a pipeline is infeasible or economically prohibitive, other techniques must be used for getting this gas to market.

- 20 [0004] A commonly used technique for non-pipeline transport of gas involves liquefying the gas at or near the production site and then transporting the liquefied natural gas to market in specially-designed storage tanks aboard transport vessels. The natural gas is cooled and condensed to a liquid state to produce liquefied natural gas ("LNG") at substantially atmospheric pressure and at temperatures of about -162 °C (-260 °F), thereby significantly increasing the amount of gas that can be stored in a storage tank, which can be on-site or aboard a transport vessel.

- 25 [0005] During storage, heat from the surrounding environment, which inherently leaks into the LNG storage tanks, causes some of the stored LNG to vaporize resulting in LNG "boil-off gas" (BOG) within the tanks. Additional storage tank LNG BOG is created by: (i) energy input to the LNG by the rundown pumps that provide sufficient pressure to effect LNG transfer from
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- the flash tank to the storage tank; (ii) heat leak through the insulation on the LNG rundown line; (iii) heat leak through the insulation on the LNG loading and recirculation line; and (iv) energy input to the stored LNG by the recirculation pump(s). This LNG BOG is typically recovered and compressed for use as fuel gas within the plant area. However, natural gas liquefaction plants that use natural gas with a moderate to high concentration of nitrogen also generate end-flash gas (EFG), which can be used as fuel gas. Depending on the plant fuel demand, there may not be the capacity to consume the LNG BOG as fuel, and so an alternative means of use or disposal will be required. While the LNG BOG could be flared, this is generally not permitted as a normal operating mode.
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- 10 **[0006]** U. S. Pat. No. 3,857,245 (Jones) discloses a process of condensing a nitrogen-containing boil-off in which LNG is injected into the nitrogen-containing boil-off vapor and the combined mixture is then condensed. The injection of the LNG into the nitrogen-containing boil-off increases the volume of vapor that must be reliquefied.
- [0007]** U. S. Pat. No. 6,192,705 (Kimble) discloses a process of passing boil-off through a heat exchanger followed by compressing and cooling stages, and then recycling the boil-off back through the heat exchanger. The compressed, cooled, and then heated boil-off is subsequently expanded and passed to a gas-liquid separator for removal of liquefied boil-off. The liquefied boil-off is then combined with a second liquefied gas stream to produce a desired product stream.
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- 20 **[0008]** Other less complicated methods of using LNG BOG are desired.

SUMMARY

- [0009]** This disclosure relates generally to the subsystem for and methods related to recycling LNG BOG in natural gas liquefaction plants. More specifically, the present disclosure utilized a bi-directional line to allow LNG BOG to be directed for liquefaction in a recycle mode or be directed for fuel gas in a fuel mode. Such methods and subsystems may advantageously provide a simple solution to using LNG BOG that brings value to the operator with a simple, straightforward implementation design.
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- [0010]** In a first embodiment, a natural gas liquefaction plant can comprise: a feed gas line fluidly connected to a liquefaction subsystem to supply feed gas to the liquefaction subsystem; a LNG line fluidly connecting the liquefaction subsystem to one or more LNG tanks to supply LNG from the liquefaction subsystem to the one or more LNG tanks; a EFG line fluidly connecting the liquefaction subsystem to a fuel gas subsystem to supply EFG from the
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liquefaction subsystem to a fuel gas subsystem; a LNG BOG header fluidly connecting the one or more LNG tanks to a compressor to supply LNG BOG from the one or more LNG tanks to the compressor; a compressed LNG BOG line fluidly connecting compressor to a fuel gas line and a bidirectional line; the fuel gas line fluidly connecting the compressed LNG BOG line and a bidirectional line to the fuel gas subsystem; the bidirectional line fluidly connecting the feed gas line to the fuel gas line and fluidly connecting the compressed LNG BOG line to the feed gas line; wherein when in recycle mode the compressed LNG BOG line supplies compressed LNG BOG from the compressor to the bidirectional line and the bidirectional line supplies the compressed LNG BOG from the compressed LNG BOG line to the feed gas line, and wherein when in fuel mode the compressed LNG BOG line supplies compressed LNG BOG from the compressor to the fuel gas line and the bidirectional line supplies the natural gas from the feed gas line to the fuel gas line.

[0011] In a second embodiment, a method of operating a natural gas liquefaction plant comprising: supplying a feed gas to a liquefaction subsystem; liquefying the natural gas to produce LNG and EFG; compressing the EFG to compressed EFG; using the compressed EFG as fuel gas; storing the LNG in one or more LNG tanks; compressing LNG BOG from the one or more LNG tanks to produce compressed LNG BOG; either (1) operating in recycle mode by supplying at least a portion of the compressed LNG BOG to the feed gas via a bidirectional line or (2) operating in fuel mode by (a) supplying a portion of the feed gas to the fuel gas via the bidirectional line and (b) supplying the compressed LNG BOG to the fuel gas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The following figures are included to illustrate certain aspects of the embodiments, and should not be viewed as exclusive embodiments. The subject matter disclosed is capable of considerable modifications, alterations, combinations, and equivalents in form and function, as will occur to those skilled in the art and having the benefit of this disclosure.

[0013] FIG. 1 is an illustrative diagram of a portion in a natural gas liquefaction plant.

[0014] FIG. 2 is an illustrative flow diagram of the subsystems of an example natural gas liquefaction plant.

DETAILED DESCRIPTION

[0015] This disclosure relates generally to the subsystem for and methods related to recycling liquefied natural gas (LNG) boil-off gas (BOG) in natural gas liquefaction plants.

More specifically, the present disclosure utilized a bi-directional line to allow LNG BOG to be directed for liquefaction in a recycle mode or be directed for fuel gas in a fuel mode.

[0016] FIG. 1 is an illustrative diagram of a portion **100** of a natural gas liquefaction plant. The portion **100** includes a feed gas line **102** fluidly connected to a liquefaction subsystem **104** to supply feed gas to the liquefaction subsystem **104**. The feed gas is natural gas having undergone the necessary treatments to be suitable for liquefaction. The treatments depend on the composition of the natural gas (e.g., sulfur, water, and mercury content) and can include, but are not limited to, condensate removal, acid gas removal, dehydration, mercury removal, heavy-hydrocarbon removal, and combinations thereof.

[0017] As used herein, when describing a line that fluidly connects two components, the line is used as a general term to encompass the line or lines that fluidly connect the two components and the other hardware like pumps, connectors, heat exchangers, and valves that may be installed along the line.

[0018] Referring again to FIG. 1, the liquefaction subsystem **104** liquefies the natural gas to produce LNG at substantially ambient pressure. As used herein, “substantially ambient pressure” refers to ambient pressure ± 5 bar gauge (barg). Liquefaction subsystems are known in the art and can have several different configurations. Typically, liquefaction subsystems include one or more heat exchangers, an expansion valve or hydraulic turbine, one or more pumps, and a separator. Examples of liquefaction subsystems include, but are not limited to, those described in U. S. Patent Nos. 5,916,260 and 6,658,892, U. S. Patent Application No. 2007/0193303 and PCT International Application No. WO2011/109117, each of which is incorporated herein by reference.

[0019] Generally, the feed gas can be at about 55 barg (about 798 psi gauge (psig)) to about 70 barg (about 1,015 psig) as introduced to the liquefaction subsystem **104**. To reduce the pressure of feed gas in the liquefaction subsystem **104**, the feed gas is typically passed from a cryogenic heat exchanger system across an expansion valve or hydraulic turbine (i.e. “flashed”) before it is passed into a separator (i.e., the flash tank). As the pressure of the cooled feed gas is reduced to produce LNG at substantially ambient pressure, some of the gas flashes and becomes vapor known as end-flash gas (EFG). LNG is removed from the flash tank and is pumped from the liquefaction subsystem **104** on to an LNG storage tank **108** via an LNG line **106** that fluidly couples the liquefaction subsystem **104** and the LNG storage tank **108**. The EFG is removed from the flash tank in the liquefaction subsystem **104** and pumped to an EFG

compressor **112** via an EFG line **110** that fluidly couples the liquefaction subsystem **104** and the EFG compressor **112**.

[0020] The EFG compressor **112** compresses the EFG to produce compressed EFG at a pressure of about 55 barg (about 798 psig) to about 70 barg (about 1,015 psig). The compressed EFG is supplied to a fuel gas subsystem **116** via compressed EFG line **114** that fluidly couples the EFG compressor **112** and the fuel gas subsystem **116**. The fuel gas subsystem **116** provides fuel gas to various components of the natural gas liquefaction plant.

[0021] As described above, LNG in the LNG storage tank **108** vaporizes to LNG BOG over time due at least in part to heat from the surrounding environment warming the LNG. The LNG BOG is captured in an LNG BOG header **118** that fluidly couples the LNG storage tank **108** to an LNG BOG compressor **120**. The LNG BOG compressor **120** compresses the LNG BOG to produce compressed LNG BOG at a pressure of about 55 barg (about 798 psig) to about 70 barg (about 1,015 psig). A compressed LNG BOG line **122** fluidly couples the LNG BOG compressor **120** to a fuel gas line **124** and a bidirectional line **126**.

[0022] Compressed LNG BOG is supplied to the fuel gas line **124** in an amount needed to supply or augment the supply of fuel gas needed to run the natural gas liquefaction plant. This can be all of the compressed LNG BOG, some of the compressed LNG BOG, or none of the compressed LNG BOG. When there is excess compressed LNG BOG not needed for fuel gas, the excess compressed LNG BOG is conveyed to the feed gas line **102** via the bidirectional line **126** in the flow direction of arrow **A**. The excess compressed LNG BOG is entrained with the feed gas for liquefaction. This configuration in flow direction **A** is referred to herein as being in “recycle mode.”

[0023] Alternatively, when all of the LNG BOG is insufficient to supply or augment the supply of fuel gas needed to run the natural gas liquefaction plant, at least a portion of the feed gas from feed gas line **102** can be conveyed to the fuel gas line **124** via the bidirectional line **126** in the flow direction of arrow **B**. This configuration in flow direction **A** is referred to herein as being in “fuel mode.”

[0024] Accordingly, methods of the present disclosure can include supplying a feed gas to a liquefaction subsystem; liquefying the feed gas, which may be natural gas, to produce LNG and EFG; compressing the EFG to compressed EFG; using the compressed EFG as fuel gas; storing the LNG in one or more LNG tanks; compressing LNG BOG from the one or more LNG tanks to produce compressed LNG BOG; and either (1) operating in a recycle mode by

supplying at least a portion of the compressed LNG BOG to the feed gas via a bidirectional line or (2) operating in a fuel mode by (a) supplying a portion of the feed gas to the fuel gas via the bidirectional line and (b) supplying the compressed LNG BOG to the fuel gas. In some instances, operating in recycle mode can further include supplying at least a portion of the compressed LNG BOG to the fuel gas.

[0025] Fuel demand at a natural gas liquefaction plant varies depending on the processes running. For example, typically several liquefaction subsystems **104** are operating in parallel. When some are off-line for maintenance or because supply or demand is low, the compressed EFG may be sufficient to supply the fuel gas needs of the plant. In such instances a portion of or none of the compressed LNG BOG may be needed to augment the supply of compressed EFG. In such instances, the portion **100** may operate in recycle mode.

[0026] In another example, the natural gas liquefaction plant may be operating several liquefaction subsystems **104** in parallel such that the combined amount of the compressed EFG and the compressed LNG BOG are insufficient to provide the amount fuel gas needed to operate the plant. In such instances, the portion **100** may operate in fuel mode.

[0027] In yet another example, the natural gas supply may have a low concentration of nitrogen, which results in lower amounts of EFG. Consequently, the portion **100** may operate in fuel mode more often than if the natural gas supply had a moderate to high concentration of nitrogen.

[0028] In the portion **100**, the feed gas, the compressed LNG BOG, and the compressed EFG can each individually be at a pressure of about 55 barg (about 798 psig) to about 75 barg (about 1,088 psig), or about 58 barg (about 841 psig) to about 72 barg (about 1,044 psig), or about 60 barg (about 870 psig) to about 70 barg (about 1,015 psig), or about 62 barg (about 899 psig) to about 68 barg (about 986 psig).

[0029] FIG. 2 is an illustrative flow diagram of the subsystems **230** of an example natural gas liquefaction plant. In alternate embodiments, some of the subsystems **230** can be eliminated or bypassed, the subsystems **230** can be reordered, and/or additional subsystems **230** can be included.

[0030] In the illustrated subsystems **230**, a natural gas supply **232** is provided to a gas receiving subsystem **234** and transported to a condensate removal subsystem **236**. The condensate removal subsystem **236** extracts unstabilized condensate **238**, which is transported to a condensate stabilization subsystem **240**. The product from the condensate removal

subsystem **236** is then treated through an acid gas removal subsystem **242**, a dehydration subsystem **244**, a mercury removal subsystem **246**, and a precooling subsystem **248** before removal of heavy hydrocarbons **252** in the heavy-hydrocarbon removal subsystem **250**. The heavy hydrocarbons **252** can be fractionated in a fractionation subsystem **254** into stabilized
5 condensate **256**, natural gas liquids **258** (NGL) (e.g., ethane, propane, butanes, and heavier hydrocarbons), and methane **260**. The stabilized condensate **256** can be transported to a condensate storage subsystem **262**, which is where the stabilized condensate **264** from the condensate stabilization subsystem **240** is also stored. The NGL **258** can be transported to a NGL storage subsystem **266**. The methane **260** can be transported to a refrigeration subsystem
10 **268** the cooled methane can be combined with the feed gas **270** product of the heavy-hydrocarbon removal subsystem **250**.

[0031] Then, as described in FIG. 1, the feed gas **270** is provided to the liquefaction subsystem **272**. The EFG **274** is compressed and transported to a fuel gas subsystem **276**. The LNG **278** produced in the liquefaction subsystem **272** can be stored in an LNG storage
15 subsystem **280**. The LNG BOG **282** from the LNG storage subsystem **280** can be compressed. Then, in recycle mode, at least a portion of the LNG BOG **282** can be transported via a bidirectional line **284** to be entrained with feed gas **270**. Alternatively, in fuel mode, the LNG BOG **282** can be transported to the fuel gas subsystem **276** along with a portion of the feed gas **270** via the bidirectional line **284** according to flow arrows **B**.

20 [0032] Finally, as needed, the LNG in the LNG storage subsystem **280** can be transferred to transportation vessels **286** (e.g., tanker trucks, tanker railcars, and ships).

[0033] Methods of the present disclosure can include treating a natural gas supply by one or more methods to produce the feed gas for liquefaction, the one or more methods being selected from the group consisting of: condensate removal, acid gas removal, dehydration,
25 mercury removal, precooling, heavy-hydrocarbon removal, and combinations thereof.

[0034] Unless otherwise indicated, all numbers expressing quantities of ingredients, properties such as molecular weight, reaction conditions, and so forth used in the present specification and associated claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set
30 forth in the following specification and attached claims are approximations that may vary depending upon the desired properties sought to be obtained by the embodiments of the present invention. At the very least, and not as an attempt to limit the application of the doctrine of

equivalents to the scope of the claim, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques.

[0035] One or more illustrative embodiments incorporating the invention embodiments disclosed herein are presented herein. Not all features of a physical implementation are described or shown in this application for the sake of clarity. It is understood that in the development of a physical embodiment incorporating the embodiments of the present invention, numerous implementation-specific decisions must be made to achieve the developer's goals, such as compliance with system-related, business-related, government-related and other constraints, which vary by implementation and from time to time. While a developer's efforts might be time-consuming, such efforts would be, nevertheless, a routine undertaking for those of ordinary skill in the art and having benefit of this disclosure.

[0036] While compositions and methods are described herein in terms of "comprising" various components or steps, the compositions and methods can also "consist essentially of" or "consist of" the various components and steps.

[0037] Therefore, the present invention is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the present invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered, combined, or modified and all such variations are considered within the scope and spirit of the present invention. The invention illustratively disclosed herein suitably may be practiced in the absence of any element that is not specifically disclosed herein and/or any optional element disclosed herein. While compositions and methods are described in terms of "comprising," "containing," or "including" various components or steps, the compositions and methods can also "consist essentially of" or "consist of" the various components and steps. All numbers and ranges disclosed above may vary by some amount. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range is specifically disclosed. In particular, every range of values (of the form, "from about a to about b," or, equivalently, "from approximately a to b," or, equivalently, "from approximately a-b") disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values. Also, the terms in the claims have their plain, ordinary meaning

unless otherwise explicitly and clearly defined by the patentee. Moreover, the indefinite articles “a” or “an,” as used in the claims, are defined herein to mean one or more than one of the element that it introduces.

CLAIMS

1. A natural gas liquefaction plant comprising:

a feed gas line fluidly connected to a liquefaction subsystem to supply feed gas to the liquefaction subsystem;

5 a liquefied natural gas (LNG) line fluidly connecting the liquefaction subsystem to one or more LNG tanks to supply LNG from the liquefaction subsystem to the one or more LNG tanks;

an end-flash gas (EFG) line fluidly connecting the liquefaction subsystem to a fuel gas subsystem to supply EFG from the liquefaction subsystem to a fuel gas subsystem;

10 a LNG boil off gas (BOG) header fluidly connecting the one or more LNG tanks to a compressor to supply LNG BOG from the one or more LNG tanks to the compressor;

a compressed LNG BOG line fluidly connecting the compressor to a fuel gas line and a bidirectional line in which fluid may flow in either of two directions;

15 the fuel gas line fluidly connecting the compressed LNG BOG line and the bidirectional line to the fuel gas subsystem;

the bidirectional line fluidly connecting the feed gas line to the fuel gas line and fluidly connecting the compressed LNG BOG line to the feed gas line;

20 wherein when in a recycle mode the compressed LNG BOG line supplies compressed LNG BOG from the compressor to the bidirectional line and the bidirectional line supplies the compressed LNG BOG from the compressed LNG BOG line to the feed gas line, and

wherein when in a fuel mode the compressed LNG BOG line supplies compressed LNG BOG from the compressor to the fuel gas line and the bidirectional line supplies the natural gas from the feed gas line to the fuel gas line.

25 2. The natural gas liquefaction plant of claim 1, wherein when the system is in the recycle mode the compressed LNG BOG line supplies compressed LNG BOG from the compressor to the fuel gas and bidirectional lines.

3. The natural gas liquefaction plant of claim 1 or claim 2, wherein the feed gas line, the compressed LNG BOG line, and the bidirectional line are pressurized at about 55 bar gauge to about 70 bar gauge.
- 5 4. The natural gas liquefaction plant of any of claims 1-3, wherein the feed gas line, the compressed LNG BOG line, and the bidirectional line are pressurized at about 60 bar gauge to about 65 bar gauge.
- 10 5. The natural gas liquefaction plant of any one of claims 1-4, further comprising one or more subsystems upstream of the liquefaction subsystem, the subsystems selected from the group consisting of a gas receiving subsystem, a condensate removal subsystem, an acid gas removal subsystem, a dehydration subsystem, a mercury removal subsystem, a precooling subsystem, a heavy-hydrocarbon removal subsystem, and any combination thereof.
- 15 6. A method of operating a natural gas liquefaction plant comprising:
supplying a feed gas to a liquefaction subsystem;
liquefying the feed gas to produce liquefied natural gas (LNG) and end-flash gas (EFG);
compressing the EFG to compressed EFG;
using the compressed EFG as fuel gas;
20 storing the LNG in one or more LNG tanks;
compressing LNG boil off gas (BOG) from the one or more LNG tanks to produce compressed LNG BOG; and
either
(1) operating in a recycle mode by supplying at least a portion of the compressed LNG
25 BOG to the feed gas via a bidirectional line in which fluid may flow in either of two directions,
or
(2) operating in a fuel mode by (a) supplying a portion of the feed gas to the fuel gas via the bidirectional line and (b) supplying the compressed LNG BOG to the fuel gas.

7. The method of claim 6, wherein operating in the recycle mode further includes supplying at least a portion of the compressed LNG BOG to the fuel gas.

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8. The method of claim 6 or claim 7, wherein the feed gas and the compressed LNG BOG are individually at a pressure of about 55 bar gauge to about 70 bar gauge.

9. The method of claim 6 or claim 7, wherein the feed gas and the compressed LNG BOG
10 are individually at a pressure of about 60 bar gauge to about 65 bar gauge.

10. The method of any one of claims 6-9, further comprising:

treating a natural gas supply by one or more methods to produce the feed gas for
liquefaction, the one or more methods being selected from the group consisting of: condensate
15 removal, acid gas removal, dehydration, mercury removal, precooling, heavy-hydrocarbon
removal, and any combination thereof.