

CONFIGURATIONS AND METHODS FOR POWER GENERATION IN LNG REGASIFICATION TERMINALS

This application claims priority to our copending U.S. provisional patent application with the serial number 60/700649, which was filed July 18, 2005.

5 Field of The Invention

The field of the invention is power generation using LNG, and especially as it relates to power generation in LNG regasification facilities, and/or integration to a power plant.

Background of The Invention

10 Liquefied natural gas (LNG) import is expected to accelerate, mostly due to increased use and technological and economic advantages over crude oil. While some of the currently existing LNG regasification facilities are expanded, new regasification facilities must still be added to meet future demand for natural gas.

Conventional LNG regasification facilities typically require an external heat source such as an open rack seawater vaporizer, a submerged combustion vaporizer, an intermediate
15 fluid vaporizer (*e.g.*, using a glycol-water mixture), and/or ambient air vaporizers. However, LNG vaporization is an energy intensive process and typically requires a heat duty equivalent to about 3% of the energy content in LNG. More recently, attempts have been made to reduce the energy requirement for regasification by coupling heat producing processes with the LNG regasification.

20 For example, power plants may be coupled with LNG regasification, as described in U.S. Pat. Nos. 4,036,028 and 4,231,226 to Mandrin and Griepentrog, respectively. Similar configurations are reported in published U.S. Pat. App. No. 2003/0005698 to Keller, EP 0 683 847 to Johnson et al., and WO 02/097252 to Keller. In such known configurations, heat for regasification of LNG is provided by a heat exchange fluid, which is in thermal exchange
25 with turbine exhaust or a combined cycle power plant. While some of these configurations provide reduction in energy consumption, the gain in power generation efficiencies are often not significant, mainly due to the inability of these processes to effectively use the very low temperature of LNG (typically between -255°F to -150°F) as the heat sink. Still further, and among yet other difficulties, heat transfer in some of these configurations is limited by the
30 relatively high freezing point of the heat transfer medium. Due to these and other constraints, power generation efficiency is generally low.

In further known configurations, as described in EP 0 496 283, power is generated by a steam expansion turbine that is driven by a working fluid (here: water) that is heated by a gas turbine exhaust and cooled by a LNG regasification circuit. While such a configuration increases efficiency of a plant to at least some degree, several problems remain. For example, the utilization of the cryogenic refrigeration content of the LNG is often restricted due to the high freezing point of water. To overcome at least some of the difficulties associated with the high freezing temperatures, non-aqueous fluids may be employed as a working fluid in a typical Rankine cycle power generation. An exemplary configuration for such approach is disclosed in U.S. Pat. No. 4,388,092 to Matsumoto and Aoki, in which a multi-component hydrocarbon fluid from a distillation column is employed to improve the generation efficiency. However, operation of these systems and the monitoring and control of the multi-component working fluid is costly and complex.

Therefore, while numerous processes and configurations for LNG utilization and regasification are known in the art, all of almost all of them suffer from one or more disadvantages. Thus, there is still a need to provide improved configurations and methods for LNG utilization and regasification.

Summary of the Invention

The present invention is directed to configurations and methods for power generation in an LNG regasification operation in which LNG is used as a working fluid, wherein the LNG in liquefied state is used upstream of a vaporizer to condense expanded working fluid, while a portion of the LNG in vaporized state (vaporized natural gas) is used downstream of the vaporizer to drive an expansion turbine. Most advantageously, the LNG is vaporized at pipeline pressure, while the condensed expanded working fluid is pumped back to pipeline pressure and combined with the LNG in a position upstream of the vaporizer.

Therefore, in one aspect of the inventive subject matter, an LNG regasification plant is contemplated that includes a heat exchanger that is configured to condense expanded vaporized natural gas using refrigeration content from liquefied natural gas. A vaporizer in such plants is configured to produce vaporized natural gas from the liquefied natural gas, and an expander is fluidly coupled to the vaporizer and configured to expand at least a portion of the vaporized natural gas to thereby produce the expanded vaporized natural gas.

Preferably, contemplated plants will further include a pump that is configured to receive the condensed natural gas from the heat exchanger and a conduit fluidly coupled to the pump and configured to combine the condensed natural gas with the liquefied natural gas, and/or a second heat exchanger that is configured to heat the at least portion of the vaporized natural gas from the vaporizer using heat from the expanded vaporized natural gas. In further preferred aspects, the plant includes a third heat exchanger that is configured to heat the at least portion of the vaporized natural gas from the vaporizer to a temperature of at least 300 °F (*e.g.*, using flue gas from a gas turbine, a waste heat recovery unit, and/or a fired heater as a heat source). Additionally, or alternatively, a heat transfer fluid circuit may be included that is thermally coupled to the vaporizer and a fourth heat exchanger (that is typically configured to heat the portion of the vaporized natural gas from the vaporizer at a position upstream of the expander).

Especially contemplated plants will include a second pump that pumps the liquefied natural gas from a storage pressure to a pipeline pressure, wherein the storage pressure is between 1 psig and 100 psig, and wherein the pipeline pressure is between 700 psig and 2000 psig. Therefore, the expander is typically configured to expand the portion of the vaporized natural gas from between about 1000-2000 psig to a pressure of between about 1 psig and 100 psig. It is also contemplated that the plant includes a flow control unit that controls the flow volume of the portion of the vaporized natural gas from the vaporizer to the expander.

In another aspect of the inventive subject matter, a method of producing power using natural gas as a working fluid will include a step of expanding at least a portion of vaporized natural gas in a turbine to produce power (typically to a pressure of between 1-100 psig) and expanded vaporized natural gas. In yet another step, the expanded vaporized natural gas is condensed using refrigeration cold of liquefied natural gas, and combining the condensed natural gas with liquefied natural gas, and in yet another step, the combined liquefied and condensed natural gas are vaporized to produce the vaporized natural gas.

Especially preferred methods include a step of heating the portion of the vaporized natural gas in one or more heat exchangers using heat from flue gas from a gas turbine, a waste heat recovery unit, a fired heater, and/or the expanded vaporized natural gas. Further preferred methods include a step of pumping the liquefied natural gas to at least pipeline pressure at a location upstream of a vaporizer that produces the vaporized natural gas. Most typically, the vaporizer uses seawater, a heat exchange medium, and/or a submerged burner

as a heat source. In preferred aspects of the inventive subject matter, the portion of vaporized natural gas is between about 1% and 50% of the total vaporized natural gas.

Thus, and viewed from a different perspective, the inventors contemplate use of LNG drawn from a location upstream of a vaporizer to condense expanded vaporized natural gas working fluid from an open power cycle wherein the vaporized natural gas working fluid is drawn from a location downstream of the vaporizer. Typically, contemplated open power cycles comprise an expansion turbine and a heater that heats the vaporized natural gas working fluid, while both, the condensed natural gas working fluid and the LNG drawn from the location upstream of the vaporizer are combined and fed to the vaporizer. As in plants and methods contemplated above, it is typically preferred that the LNG at the location upstream of the vaporizer is at about pipeline pressure and the expanded vaporized natural gas working fluid is at a pressure of between 1-100 psig.

Various objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the invention, along with the accompanying drawing.

Brief Description of the Drawing

Figure 1 is one exemplary configuration of a power production scheme coupled to an LNG regasification operation according to the inventive subject matter.

Figure 2 is another exemplary configuration of a power production scheme coupled to an LNG regasification operation according to the inventive subject matter.

Detailed Description

The inventor has discovered that refrigeration content in LNG can be advantageously employed in the production of power in a regasification facility by using at least a portion of the regasified LNG as a working fluid in an open cycle, wherein the LNG is condensed after expansion using the cryogenic refrigeration content of the LNG fed to the facility. Depending on the vaporizer configuration, an intermediate heat transfer medium may be employed in contemplated configurations.

It should be particularly appreciated that the LNG is pumped to a desired pressure to supply refrigeration in an open power cycle that uses LNG as the working fluid. In such

plants, the LNG working fluid is condensed using the cryogenic temperatures of the LNG that is delivered to the plant. Therefore, it should be recognized that LNG regasification and/or power generation may be accomplished with the use of ambient air vaporizers, seawater vaporizers, and/or waste heat from gas turbine exhaust or fired heaters, which significantly reduces fuel consumption in power generation. Moreover, as LNG is used as a working fluid, no external working fluid is required. Viewed from a different perspective, a substantially increased amount of refrigeration content is recoverable as the working fluid will not freeze at cryogenic temperatures.

An exemplary open LNG power cycle is schematically depicted in **Figure 1**, in which power generation is operationally coupled to an LNG regasification plant having a send out rate of about 350 MMscfd. However, it should be noted that the inventive subject matter is not limited to a particular send out rate, and suitable plants may have higher or lower rates. **Table 1** below shows a typical LNG composition LNG in Figure 1.

COMPONENT	MOL%
C ₁	86 to 95%
C ₂	4 to 14%
C ₃ -C ₅	3 to 7%
C ₆ +	0.5 to 1%
N ₂ +CO ₂	0.1 to 1%

Table 1

LNG stream 1 from LNG storage tank or other sources is typically at a pressure between 70 psig to 100 psig and at a temperature of about -260°F to -250°F. Stream 1 is pumped by LNG pump 51 to a suitable pressure, typically about 1200 to 1600 psig to form pressurized LNG stream 2, as needed to meet pipeline requirement. As used herein, the term "about" in conjunction with a numeral refers to a range of that numeral starting from 20% below the numeral to 20% above the numeral, inclusive. For example, the term "about -150°F" refers to a range of -180°F to -120°F, and the term "about 1400 psig" refers to a range of 1372 psig to 1680 psig.

A portion of the LNG stream 2 is split off as stream 3 and sent to exchanger 54 using bypass valve 52. Stream 3 is heated in the exchanger from about -250°F to about -170°F to form stream 4, while the expanded vaporized natural gas working fluid 8 is cooled and condensed from about 40°F to about -215°F. The so condensed LNG working fluid 9 is at a pressure of about 80 psig and a temperature of about -215°F and pumped by pump 55 to a

pressure of about 1400 psig, forming stream 10 that is combined with the remaining portion of the LNG stream 2 to form combined stream 5. Stream 5 is then heated in vaporizer 53 to about 40°F with heat supplied by ambient heat sources (*e.g.*, ambient air or seawater). The vaporized natural gas stream 6 is then split into a first portion (about 85%, stream 7) and a second portion (about 15%, stream 30) using a flow control device (not shown). It should be noted that, among other factors, the split ratio of the vaporized natural gas stream generally depends on the LNG composition and the desirable power generation output. Stream 7 is sent to the consumer pipeline, while stream 30 is utilized in the power cycle as described below.

Stream 30 is first heated in exchanger 56 to about 155°F forming stream 11 using the heat content from the expander discharge stream 13. The so heated vaporized natural gas is further heated in heater 57 with an external source to about 450°F (or higher) forming stream 12. It should be appreciated that numerous external heat sources are suitable (*e.g.*, flue gas from a gas turbine, waste heat recovery unit, and/or a fired heater). The resultant high pressure high temperature working fluid stream 12 is then expanded in expander 58 to about 75 psig forming stream 13, generating power that can be used to drive an electric generator. Heat content in the expander discharge is recovered in exchanger 56 forming stream 8 that is subsequently condensed in exchanger 54 forming stream 9 to repeat the power cycle.

In the exemplary configuration of Figure 1, the open power cycle circulates about 550 GPM LNG working fluid, generating about 5,000 kW. The power generation efficiency, as calculated by the heat equivalent of net power output from the cycle divided by heat input to exchanger 57, is about 68%. The efficiency can be further increased with higher operating temperature and pressure, which should be balanced with higher equipment costs and heating requirement. With respect to the quantities of streams 3 and 30 that are drawn from LNG streams 2 and 6, respectively, it should be recognized that the particular amounts will be at least in part determined by the amount of power that is to be generated. For example, where relatively large quantities of power are desired, stream 30 may be more than 15% (*e.g.*, 16-20%, 20-25%, or even higher) of stream 6. Consequently, and depending on the temperature of cooled expander discharge 8, amounts of stream 3 may vary considerably. Most typically, stream 3 will be at least in an amount effective to condense expanded natural gas stream 8. Thus, it should be recognized that a first portion of the cryogenic refrigeration content of the LNG stream 2 is used as a heat sink for the LNG working fluid, and that at least a portion of

the LNG in at least partially vaporized form is heated and expanded to produce work in an open power cycle.

Another exemplary open LNG power cycle is schematically depicted in **Figure 2**, in which power generation is operationally coupled to an LNG regasification plant that uses an intermediary heat transfer fluid (*e.g.*, glycol-water, alcohol, or Dowtherm, etc.) to provide heat to the LNG vaporizer. Here, the intermediate fluid stream 14 is pumped by pump 59 to about 120 psig forming stream 15 which is preferably heated with ambient air in vaporizer 60 forming stream 16. A first portion of stream 16 is further heated via stream 17 with waste heat 22 in exchanger 61 to about 480 °F or higher, forming a heated stream 19 that heats the preheated LNG stream 11. Stream 19 exits heat exchanger 57 as stream 20 and is combined with the second portion of stream 16 (stream 18) to form stream 21 that is used in vaporizer 53. With respect to remaining components of Figure 2, the same considerations apply for like components with like numerals as depicted in Figure 1.

Suitable heat sources for exchangers 22 and 57 include gas turbine combustion air, cooling water to surface condensers, flue gas from a gas turbine, and/or flue gas from a fuel fired heater. However, numerous alternative heat sources are also contemplated, including units found in plants other than a combined cycle plant. Similarly, suitable recipients for LNG cold may also include numerous cryogenic processes (*e.g.*, air separation plants) in which LNG cools the air or other gas, processes providing flue gas (*e.g.*, reformer flue gases, etc.), and other processes acting as a cold sink (*e.g.*, carbon dioxide liquids production plants, desalination plants, or food freezing facilities). Therefore, it should be appreciated that LNG drawn from a location upstream of a vaporizer can be used to condense expanded vaporized natural gas working fluid from a preferably open power cycle wherein the vaporized natural gas working fluid is drawn from a location downstream of the vaporizer.

In further contemplated aspect of the inventive subject matter, it is generally preferred that power production is operationally coupled with LNG regasification facilities and/or LNG receiving terminals, and particularly preferred configurations include those in which LNG is regasified in a process in which at least part of the LNG is used to generate electric power (most preferably with integration to a combined power cycle). For example, suitable plants and methods are described in our commonly owned and co-pending international patent application with the serial numbers PCT/US03/25372 and PCT/US03/26805, which are incorporated by reference herein.

Consequently, and depending on the particular heat source, it should be recognized that the energy needed for regasification of the LNG may be entirely, or only partially provided by contemplated heat sources. Where the heat source provides insufficient quantities of heat to completely gasify the LNG, it should be recognized that supplemental heat may be provided. Suitable supplemental heat sources include waste heat from the steam turbine discharge, condensation duty from the flue gas, ambient heating with air (*e.g.*, by providing air conditioning to buildings), with seawater, or fuel gas. Consequently, it should be appreciated that contemplated configuration and processes may be used to retrofit existing regasification plants to improve power generation efficiencies and flexibility, or may be used in new installations.

It should be especially appreciated that numerous advantages may be achieved using configurations according to the inventive subject matter. Among other things, contemplated configurations provide highly efficient LNG power generation cycles without external working fluid, such as steam, or hydrocarbons with a composition other than LNG.

Contemplated processes can be coupled with any type of power plant and still provide benefit or improved efficiency. Especially preferred configurations utilize the LNG cold in the cryogenic region and LNG as the working fluid to achieve high thermal efficiency, typically in the range of about 70% or higher. In most preferred plants, the LNG send out is pumped to supercritical pressure and regasified using conventional vaporizers while a portion of the regasified product is split off as the LNG working fluid (vaporized natural gas) to the open power cycle. The LNG working fluid is further superheated and expanded to a lower pressure to thereby generate power, wherein the expanded working fluid is condensed utilizing cryogenic temperatures of the LNG send out in the -250°F to -150°F range. Alternatively, the LNG working fluid is pumped to a supercritical pressure (here: above cricondenbar pressure), and heated with an external heat source, and then expanded to a lower pressure for power generation with a heat source integral with or thermally coupled to the power cycle. The expanded working fluid is condensed using the LNG send out, pumped and mixed with the send out LNG and heated in the vaporizers. Based on the conceptually simple configuration of contemplated plants, it should be recognized that the power generation according to the inventive subject matter may be implemented as a retrofit to an existing facility or in a facility built from scratch.

Thus, specific embodiments and applications for configurations and methods for power generation with integrated LNG regasification have been disclosed. It should be apparent, however, to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The
5 inventive subject matter, therefore, is not to be restricted except in the spirit of the present disclosure. Moreover, in interpreting the specification, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms "comprises" and "comprising" should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be
10 present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Furthermore, where a definition or use of a term in a reference, which is incorporated by reference herein is inconsistent or contrary to the definition of that term provided herein, the definition of that term provided herein applies and the definition of that term in the reference does not apply.

CLAIMS

What is claimed is:

1. A LNG regasification plant, comprising:

a heat exchanger that is configured to condense expanded vaporized natural gas using refrigeration content from liquefied natural gas;
a vaporizer that is configured to produce vaporized natural gas from the liquefied natural gas; and
an expander fluidly coupled to the vaporizer and configured to expand at least a portion of the vaporized natural gas to thereby produce the expanded vaporized natural gas.
2. The regasification plant of claim 1 further comprising a pump configured receive the condensed natural gas from the heat exchanger and a conduit fluidly coupled to the pump and configured to combine the condensed natural gas with the liquefied natural gas.
3. The regasification plant of claim 1 further comprising a second heat exchanger that is configured to heat the at least portion of the vaporized natural gas from the vaporizer using heat from the expanded vaporized natural gas.
4. The regasification plant of claim 1 further comprising a third heat exchanger that is configured to heat the at least portion of the vaporized natural gas from the vaporizer to a temperature of at least 300 °F.
5. The regasification plant of claim 4 wherein the third heat exchanger is configured to use a heat source selected from the group consisting of a flue gas from a gas turbine, a waste heat recovery unit, and a fired heater.
6. The regasification plant of claim 1 further a second pump that is configured to pump the liquefied natural gas from a storage pressure to a pipeline pressure.
7. The regasification plant of claim 6 wherein the storage pressure is between 1 psig and 100 psig, and wherein the pipeline pressure is between 700 psig and 2000 psig.

8. The regasification plant of claim 1 wherein the expander is configured to expand the at least portion of the vaporized natural gas from between about 1000-2000 psig to a pressure of between about 1 psig and 100 psig.
9. The regasification plant of claim 1 further comprising a flow control unit that controls the flow volume of the at least portion of the vaporized natural gas from the vaporizer to the expander.
10. The regasification plant of claim 1 further comprising a heat transfer fluid circuit that is thermally coupled to the vaporizer and a fourth heat exchanger that is configured to heat the at least portion of the vaporized natural gas from the vaporizer at a position upstream of the expander.
11. A method of producing power using natural gas as a working fluid, comprising:

expanding at least a portion of vaporized natural gas in a turbine to produce power and expanded vaporized natural gas;
condensing the expanded vaporized natural gas using refrigeration cold of liquefied natural gas, and combining the condensed natural gas with liquefied natural gas;
and
vaporizing the combined liquefied and condensed natural gas to produce the vaporized natural gas.
12. The method of claim 11 further comprising a step of heating the portion of vaporized natural gas in at least one heat exchanger using heat from a source selected from the group consisting of a flue gas from a gas turbine, a waste heat recovery unit, a fired heater, and the expanded vaporized natural gas.
13. The method of claim 11 further comprising a step of pumping the liquefied natural gas to at least pipeline pressure at a location upstream of a vaporizer that produces the vaporized natural gas.
14. The method of claim 13 wherein the vaporizer uses at least one of sea water, a heat exchange medium, an a submerged burner as a heat source.
15. The method of claim 11 wherein step of expanding the portion of vaporized natural gas comprises expansion to a pressure of between 1-100 psig.

16. The method of claim 11 wherein the portion of vaporized natural gas is between 1% and 50% of the total vaporized natural gas.
17. Use of LNG drawn from a location upstream of a vaporizer to condense expanded vaporized natural gas working fluid from an open power cycle wherein the vaporized natural gas working fluid is drawn from a location downstream of the vaporizer.
18. The use of claim 17 wherein the open power cycle comprises an expansion turbine and a heater that heats the vaporized natural gas working fluid.
19. The use of claim 17 wherein the condensed natural gas working fluid and the LNG drawn from the location upstream of the vaporizer are fed to the vaporizer.
20. The use of claim 17 wherein the LNG at the location upstream of the vaporizer is at about pipeline pressure and wherein the expanded vaporized natural gas working fluid is at a pressure of between 1-100 psig.

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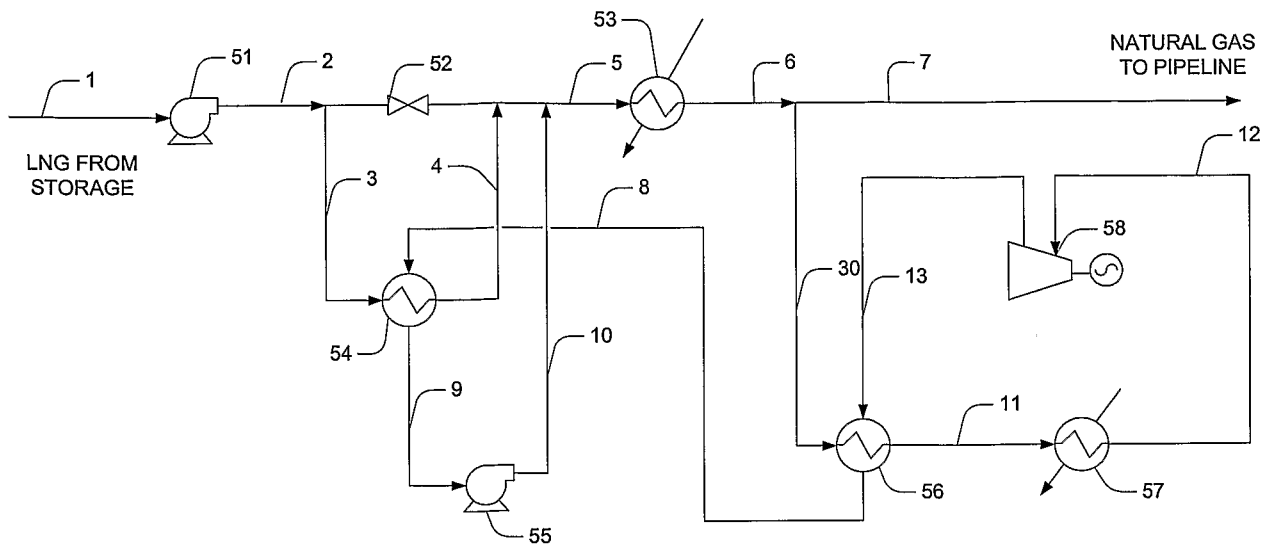


Figure 1

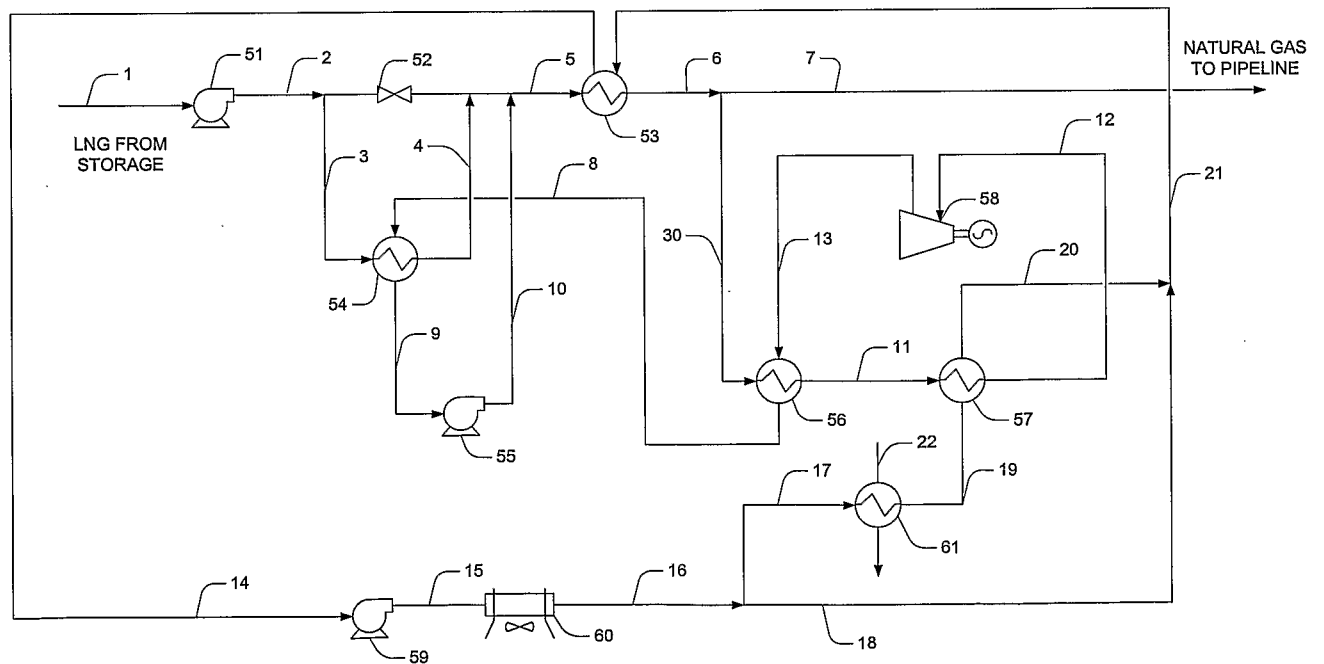


Figure 2