

COLD ENERGY RECOVERY SYSTEM AND METHOD

FIELD OF THE INVENTION

The present invention relates to a cold energy recovery system and method. In particular, the invention relates (but is not limited) to a system and method
5 for recovering cold energy from vaporizing Liquefied Natural Gas (LNG) for further usage and will be described in this context.

BACKGROUND ART

The following discussion of the background to the invention is intended to facilitate an understanding of the present invention only. It should be
10 appreciated that the discussion is not an acknowledgement or admission that any of the material referred to was published, known or part of the common general knowledge of the person skilled in the art in any jurisdiction as at the priority date of the invention.

Liquefied Natural Gas (LNG), predominantly methane, is natural gas from oil
15 field and gas field that has been refined.

Cold energy recovery and utilization techniques have been applied to gas feeding pipe line in LNG receiving terminals, where stored LNG are re-gassed and supplied to end users as city gas. In the process of re-gassing from the liquid natural gas, the evaporation/boiling process is an endothermic reaction
20 that takes in heat energy and gives out 'cold' energy. The 'cold' energy may be recovered and be used for a variety of applications including for example, manufacturing of high-purity methane, low-temperature grinding, supply to neighbouring factories, air-conditioning equipment, open rack vaporizer (ORV), and generation of electric power by expansion turbine etc. as
25 illustrated in Fig. 1.

However, due to the complexity of the cold energy recovery system, cold energy recovery facility is currently only utilized for facilities within a limited area from the LNG receiving terminals.

For distributed electric power stations located away from the LNG receiving terminals, supply to the end-users is done via transportation of LNG by way of tank rolly, which installs a storage tank and a pump for transferring on a vehicle, to the stationary storage tanks at the electric power stations (on site),
5 and for the purpose of usage, the transported LNG storage tanks are vaporized on site via an example of LNG supply configuration as illustrated in Fig. 2.

Fig. 2 shows a conventional configuration of a LNG storage tank 20 depending on user's preference for supply to end-users located far from the LNG receiving terminals. The LNG is controlled and held under desired
10 pressure in a pressure tank 22 via a pressure build-up unit (PBU) 24. There also comprises a main gas heater 26 connected to the LNG storage tank 22 for vaporizing the LNG in the storage tank 22 for use. However, any cold energy generated from the vaporization process is inadvertently wasted (i.e.
15 dissipated to the environment), as it is not harnessed for the uses as described in Fig. 1. The need for a main gas heater to vaporize the LNG requires additional heat source that consumes energy.

In light of the above, there exists a need to harness and utilize the cold energy effectively as well as to reduce such "cold" energy loss during LNG supply to
20 end-users located far from the LNG receiving terminals. The harnessing and utilizing of cold energy is understood as 'cold energy recovery'.

The present invention seeks to provide a system and method that address the need at least in part.

SUMMARY OF THE INVENTION

25 In accordance with an aspect of the present invention, there is provided a cold energy recovery system comprising means for receiving a LNG storage tank; a LNG vaporizer; the LNG vaporizer comprising a heat source operable to vaporize the LNG within the LNG storage tank; and a cold energy recovery mechanism, the cold energy recovery mechanism comprising a plurality of
30 heat exchanges arranged to facilitate heat exchange between a heat source

and the LNG to achieve vaporization of the LNG and cooling of the heat source for further use.

5 Preferably, the LNG vaporizer is an ambient heat vaporizer using ambient air as the heat source.

Preferably, the means for receiving the LNG storage tank is an insulated vacuum for surrounding the LNG storage tank.

10 Preferably, the cold energy recovery mechanism comprises a turbocharger operable to compress the ambient air.

Preferably, the compressed ambient air from the turbocharger is fed to an after cooler for cooling.

15 Preferably, the ambient air vaporizer comprises a pressure build up heating coil installed on an outer surface wall of the LNG storage tank.

20 Preferably, the compressed air from the turbo charger is operable to drive a gas engine generator.

Preferably, the gas engine generator is further arranged to receive the vaporized LNG as input.

25 Preferably, the cold energy recovery system further comprises a heat exchanger for cooling the ambient air prior to compression by the turbocharger.

30 Preferably, the system comprises an evaporator coupled to the ambient air vaporizer.

Preferably, the heat source is a water source which had been utilized for cooling hot engine.

5 Preferably, there comprises a plurality of evaporators for vaporizing and heating the LNG.

In accordance with another aspect of the present invention there is a cold energy recovery method comprising the following steps:- a. building pressure within a LNG storage tank to a predetermined pressure level; b. directing the
10 liquid LNG to a plurality of heat exchangers, the heat exchangers arranged to facilitate heat exchange between a heat source and the LNG to achieve vaporization of the LNG and cooling of the heat source for further use.

Preferably, the heat source is ambient air.
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Preferably, the method further comprises a step of compressing the ambient air before usage.

20 **BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 illustrates the possible use of cold energy recovered from a LNG terminal;

25 Fig. 2 shows an example of a prior art gas supply system;

Fig. 3 is a system diagram of the cold energy recovery system in accordance with an embodiment of the invention;

Fig. 4 shows another embodiment of the cold energy recovery system of the invention; and

30 Fig. 5 shows yet another embodiment of the cold energy recovery system of the invention.

Other arrangements of the invention are possible and, consequently, the accompanying drawings are not to be understood as superseding the generality of the preceding description of the invention.

5 **PREFERRED EMBODIMENTS OF THE INVENTION**

In accordance with an embodiment of the invention there is a cold energy recovery system 100. The cold energy recovery system 100 comprises a vacuum insulation 220 suited to receive a LNG storage tank 200. The system 100 further comprises an ambient air vaporizer 300 operable to receive liquid
10 LNG from the storage tank 200 for vaporization; and a cold recovery arrangement 400 operable to receive vaporized LNG from the air vaporizer 300 for further processing.

The vacuum insulation 220 prevents heat (in the ambient environment) from entering the LNG storage tank 200 and vice versa.

15 The ambient air vaporizer 300 treats ambient air as a heat source to vaporize the liquid LNG in the storage tank 200. With reference to Fig. 3, the ambient air vaporizer 300 comprises a pressure build-up coil 340 coupled to an inlet valve 350 and an outlet valve 360.

The input/output valve system and pipes for delivery to the end user are
20 based on individual users' requirement and are not within the scope of the invention.

The pressure build-up coil 340 contacts the surface of the outer wall of the vacuum insulation 220. The outer wall of the vacuum insulation is exposed to the ambient air, which is at an ambient temperature. By regulating the liquid
25 LNG flowing through the coil 340 via the inlet valve 350, the pressure build-up coil 340 controls or regulate the pressure of the LNG in the storage tank 200. As the evaporated LNG's volume is about eight hundred times the volume of the LNG in its liquid state, it is relatively easy to achieve the desired build-up pressure in the storage tank 200.

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The inlet valve 350 is a throttling valve operable to regulate the evaporation of the liquid LNG within the storage tank 200 by regulating the flow of the liquid

LNG through the build-up coil 340. As liquid LNG passes through the build-up coil 340, the liquid LNG starts evaporating as it gets heated by the ambient heat.

As liquid LNG evaporates, pressure within the storage tank 200 starts to build up when the outlet valve 360 is closed. In this way, the inner pressure of the storage tank 200 is built up to a desired level using the build-up coil 340.

The build-up pressure within the storage tank 200 may be controlled by varying the flow rate of the LNG passing through the build-up coil 340. The variation of flow rate is necessary to vaporize and build up pressure in the storage tank 200. This method is known as "cold evaporator" (hereinafter referred to as CE).

Such an arrangement using cold evaporator does not require a main gas heater or heat source 24 like hot water, steam or electric heater as in the prior art case as the heat energy necessary for vaporization of the LNG will be drawn from the ambient environment or ambient air. Up to seven (7) bar of pressure may be provided to the storage tank 200, depending on the capacity of the storage tank 200 and the heat exchange surfaces of the build-up coil 340 required for building up a necessary pressure to feed the LNG to the evaporator 420.

Upon reaching the desired pressure build up, the pressurized LNG liquid will be fed to a heat exchanger 420 by way of the outlet throttling valve 360 once the valve 360 is opened. Heat exchanger 420 is an evaporator which provides an interface between heat to exchange between the liquid LNG and the ambient air. At the heat exchanger 420, the liquid LNG gains heat to vaporize while the ambient air loses heat and is cooled.

From the heat exchanger 420:-

i. The vaporized LNG is delivered to be fed into an output engine, such as for example a gas engine generator 500.

The ambient air may be processed to remove impurities/moisture before it is fed to the evaporator 420. In particular, it is important to remove moisture from the ambient air before the ambient air comes into contact with the

surface of the heat exchanger 420; otherwise the moisture (essentially water) freezes and blocks the passage within the heat exchanger 420.

ii. The cooled ambient air utilized for the vaporization of the LNG is directed to a turbocharger 450. Turbocharger 450 is operable to compress the cooled ambient air.

Upon compression, the compressed air at the output of the turbocharger 450 will be at a higher temperature than the uncompressed air at the input of the turbocharger 450. If required, the compressed air is further cooled using an after-cooler 480 so as to match the specification of the gas engine 500.

10 The gas engine generator 500 is arranged to receive one or both of the following as inputs:-

i. the compressed cooled ambient air which had passed through the after cooler 480; and

ii. the LNG which has been vaporized (as fuel LNG gas).

15 The compressed cooled ambient air after output of the turbo charger 450 should suitably be at a temperature as low as possible for the cooling load of the after-cooler 480 as well as for driving the gas engine generator 500, as such optimized configuration would result in an optimal range of electric power output.

20 A specific example of utilizing the cold energy recovery system 100 based the example and calculation as follows:-

The specific enthalpy of LNG (predominantly methane) at its boiling temperature of 111.55 K and atmospheric pressure at 1.013 Bar is 911.35kJ/kg.

25 The latent heat of methane is 510.25 kilo-Joules per kg (kJ/kg).

Pressurization in the storage tank 200 is achieved by pressure build up coil 340 and kept at a pressure of about five (5) bars. A compression ratio at the turbo charger 450 is assumed to be 3 to 4 (3:4), so delivery pressure is at around four (4) bars. In case of a certain type of gas engine, the engine input

30 pressure is 12psi which is 2.3 bar ($12 \div 5.17 = 2.3 \text{ bar}$).

Subtracted liquid (LNG) of 1964.5kg/hour is vaporized by exchanging heat with outdoor (ambient) air at 40°C. Cooled ambient air is fed to the turbocharger 450 at a rate of 39200kg/hour which corresponds to 1.7903×10^6 kJ per hour.

5 Accordingly, at the turbocharger 450,

The change in temperature ΔT for ambient air is calculated as $1.7903 \times 10^6 / 39200 / 1.1102$ (1.1102 = specific heat capacity of air) = 41.1376°C

10 Assuming that the ambient uncompressed air entering the turbocharger 450 may be brought down to 0°C .

In case of a boost pressure of turbocharger 450 at 18psi, then the compression ratio is 2.26 ($= (18+14.7)/14.7$).

Outlet temperature of turbocharger 450 at a higher temperature of = $273 \times 2.26^{(1.4-1)/1.4} = 344.6\text{K}$ ($=71.6^\circ\text{C}$)

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Comparing with a scenario without using cold energy, input temperature at the turbocharger 450 will be at 313K ($=40.0^\circ\text{C}$)

Outlet temperature of turbocharger 450 = $313 \times 2.26^{(1.4-1.0)/1.4} = 395.1\text{K}$ ($=122.1^\circ\text{C}$)

20 Where $C_p/C_v=1.4$ for air.

Based on the calculations, the saving energy of cooling water in the after-cooler 480 under a nominal operation temperature of gas engine generator of 25°C is 553.2kW. That is corresponding to 52% saving of cooling capacity as calculated below in the following steps:-

$$(122.1 - 25) \times 39200 \times 1.006 / 3600 = 1063.7\text{kW}$$

$$(71.6 - 25) \times 39200 \times 1.006 / 3600 = 510.5\text{kW}$$

$$1063.7 - 510.5 = 553.2\text{kW}$$

$$553.2 / 1063.7 = 52\%$$

Where the specific heat capacity of air is 1.006 kJ/kg/K.

In an example of a practical application of the turbocharger 450, by which the incoming air is boosted to 2 to 3 atmospheric pressure, outlet air temperature

of the turbocharger 450 is raised by compression heat. The after cooler 480 then cools the air temperature down to 25°C. As illustrated using the calculations, by using cold recovery from LNG, a cooling capacity after-cooler 480 may be saved by about 52%.

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It is to be appreciated that as the density of the inlet air at 0°C to the turbocharger 450 is 14% higher than the density of the inlet air at 40°C; i.e. the density of inlet air is 1.251kg/m³ at 0°C, and 1.091kg/m³ at 40°C. The embodiment as described allows for more air to be fed into the cylinders of the gas engine generator at each firing cycle. This utilization of cold and denser air thus provides more power and better combustion efficiency for a given engine size.

In accordance with another embodiment of the invention and with reference to Fig. 4, wherein like numerals reference like parts, ambient air (without being cooled) is fed directly into a turbocharger 450 for compression. The compressed air (at a higher temperature than the uncompressed air) is then cooled by an after cooler 480. The cooled air output from the after cooler 480 is thereafter passed through another heat exchanger 630. Heat exchanger 630 is an evaporator to facilitate heat exchange between liquid LNG and the compressed ambient air at the output of the after cooler 480. The compressed and cooled ambient air is then further cooled during the vaporization process of the LNG (vaporization process similar to that described in the earlier embodiment) before being fed the gas engine generator 500 for consumption. The arrangement may be exemplified using a CATERPILLAR G3520E gas engine generator 500 having the following example specification:-

GENSET POWER (power rating) =1995 kW
Turbocharger (compressor) 450 outlet air pressure=422kPa (abs)
Turbocharger (compressor) 450 outlet air temperature=218°C
Compressed air temperature after passing through the after cooler 480 (Air cooling) is about 59°C
Fuel Pressure range=10 to 35kPag (=111.3 to 136.3kPa abs)

Assuming a flow rate of LNG gas fuel at 392.9 kg/hour and that of air is 7840kg/hour, respectively.

Recovered cold energy of LNG is at 3.5808×10^5 kJ/hour ($=392.9 \times 911.35$), which allows to decrease the air temperature by 45°C.

5 $3.5808 \times 10^5 / (7840 \times 1.006) = 45^\circ\text{C}$

Accordingly the temperature of the ambient air at the evaporator 630 may be reduced from 59°C to 14°C ($=59-45$) after the ambient air is used for vaporization of the LNG.

The above arrangement is designed to meet an ISO-rated power output of
10 15°C corresponding to 26% increase of output power in principle ($=0.57\% / 1^\circ\text{C} \times 45$). This is achievable due to more amount of ambient air being fed into the cylinders of the gas engine generator at each firing cycle.

In accordance with another embodiment of the invention and with reference to
15 Fig. 5, wherein like numerals reference like parts, there is a cold energy recovery system 1000 operable to utilize hot water which had been used for cooling a gas engine 500 (i.e. hot water from gas engine jacket). The hot water utilized for the vaporization of LNG gas.

The system 1000 comprises a LNG tank 200, a first heat exchanger 1200, an
20 expander 1400, and a second heat exchanger 1600.

The LNG storage tank 200 may include the vacuum insulation 220, pressure build-up coil 340, and valves 350, 360 as described in the earlier embodiments to achieve build up pressure of the Liquid LNG.

Liquid LNG is delivered via a pump 1800 to the first heat exchanger 1200
25 where it is vaporized. The vaporized LNG from the first heat exchanger 1200 is then fed as input to the expander 1400 to drive the expander 1400.

The expander 1400 is typically a turbine expansion generator for producing electrical power. As the vaporized LNG is utilized for the generator, the pressure of the vaporized LNG reduces. Concurrently, the temperature of the
30 vaporized LNG gas is reduced as well. In order for the LNG gas to be suitable for driving the gas engine 500, further heating of the LNG needs to take place.

This is achieved by passing the LNG gas through a second heat exchanger 1600.

The first heat exchanger 1200 is an evaporator. At the first and second heat exchanger 1200, 1600, the heat source is hot water from the gas engine jacket which had been utilized for the cooling of gas engine 500.

As the hot water is utilized for the vaporization/heating of LNG; the hot water is cooled and recycled back to the engine jacket to be used for cooling for the gas engine 500 again. It is to be appreciated that the heating and cooling process for the gas engine jacket hot water may be repeated.

A pump 1800 may be used for compressing and directing the LNG liquid to the first heat exchanger 1200.

As an example, the LNG system 1000 may comprise LNG gas at a pressure of 1.03 Bar (i.e. atmospheric pressure) at a temperature of 110 K (-163.2°C) near boiling point of the LNG.

With the above arrangement, the enthalpy is 130 BTU/lb or 302.38 kJ/kg. The liquid LNG is fed to the first exchanger 1200 at a rate of 1960 kg/hour, the rate may be varied by means the pump 1800. Assuming the heat input at the first exchanger 1200 is 442.8 thermal kW, the compressed liquid LNG is vaporized and has a pressure of 45.96 bar; temperature of 300K (26.85 °C) and specific enthalpy of 480BTU/lb. The expander 1400 has an electrical power output of 71.3 kW.

Once the vaporized LNG is utilized for the driving of expander 1400, the inlet gas is expanded and its pressure is decreased from 45.95 bar to 5 bar. The work done by the gas in this expansion results in an output of 71.3 kW as mentioned above, in addition to a lowering of temperature to 170K (-103.15 °C) due to adiabatic expansion of the gas; and enthalpy $H = 480$ BTU/lb.

Upon passing through the second heat exchanger 1600, the heat input provided is 126.5 kW that raises the gas to a temperature of 15°C at a pressure of 5.0 bars.

It should be appreciated by the person skilled in the art that the above invention is not limited to the embodiments described. In particular, the following modifications and improvements may be made without departing from the scope of the present invention:

- 5 • The cold energy recovery system may be used for other gas driven appliances instead of driving a gas engine generator 500.
 - The heat exchangers may include evaporators, condensers, after-coolers or other functional equivalents for realising the functions as described in the embodiments.
- 10 It should be further appreciated by the person skilled in the art that variations and combinations of features described above, not being alternatives or substitutes, may be combined to form yet further embodiments falling within the intended scope of the invention.

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Claims

1. A cold energy recovery system comprising
means for receiving a LNG storage tank;
5 a LNG vaporizer; the LNG vaporizer comprising a first heat source operable to vaporize the LNG within the LNG storage tank; and
a cold energy recovery mechanism, the cold energy recovery mechanism comprising a plurality of heat exchangers arranged to facilitate heat exchange between a second heat source and liquid LNG to achieve
10 vaporization of the LNG and cooling of the heat source for further use.
2. The cold energy recovery system according to claim 1, wherein the LNG vaporizer is an ambient heat vaporizer using ambient air as the first heat source.
- 15 3. The cold energy recovery system according to claim 1 or 2, wherein the means for receiving the LNG storage tank is an insulated vacuum for surrounding the LNG storage tank.
- 20 4. The cold energy recovery system according to claim 2, wherein the cold energy recovery mechanism comprises a turbocharger operable to compress the ambient air.
- 25 5. The cold energy recovery system according to claim 4, wherein the compressed ambient air from the turbocharger is fed to an after cooler for cooling.
6. The cold energy recovery system according to any one of the preceding claims, wherein the ambient air vaporizer comprises a pressure build up
30 heating coil installed on an outer surface wall of the LNG storage tank.
7. The cold energy recovery system according to claims 4, 5 or 6, wherein the compressed air from the turbo charger is operable to drive a gas engine generator.

8. The cold energy recovery system according to claim 7, wherein the gas engine generator is further arranged to receive the vaporized LNG as input.
- 5 9. The cold energy recovery system according to any one of the preceding claims, the system further comprises a heat exchanger for cooling the ambient air prior to compression by the turbocharger.
- 10 10. The cold energy recovery system according to any one of the preceding claims, wherein the system comprises an evaporator coupled to the ambient air vaporizer.
- 15 11. The cold energy recovery system according to claim 1, wherein the second heat source is a water source which had been utilized for cooling hot engine.
12. The cold energy recovery system according to claim 11, wherein there comprises a plurality of evaporators for vaporizing and heating the LNG.
- 20 13. The cold energy recovery system according to claim 1, wherein the first heat source and the second heat source are ambient air.
14. A cold energy recovery method comprising the following steps:-
- 25 a. building pressure within a LNG storage tank to a predetermined pressure level;
- b. using a LNG vaporizer comprising a first heat source operable to vaporize LNG within the LNG storage tank;
- 30 c. directing the liquid LNG to a plurality of heat exchangers, the heat exchangers arranged to facilitate heat exchange between a second heat source and the LNG to achieve vaporization of the LNG and cooling of the second heat source for further use.

15. The cold energy recovery method according to claim 14 wherein the first heat source is ambient air.

16. The cold energy recovery method according to claim 15, the method
5 further comprises a step of compressing the ambient air before usage.