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(54) **METHOD OF COOLING BOIL OFF GAS AND AN APPARATUS THEREFOR**

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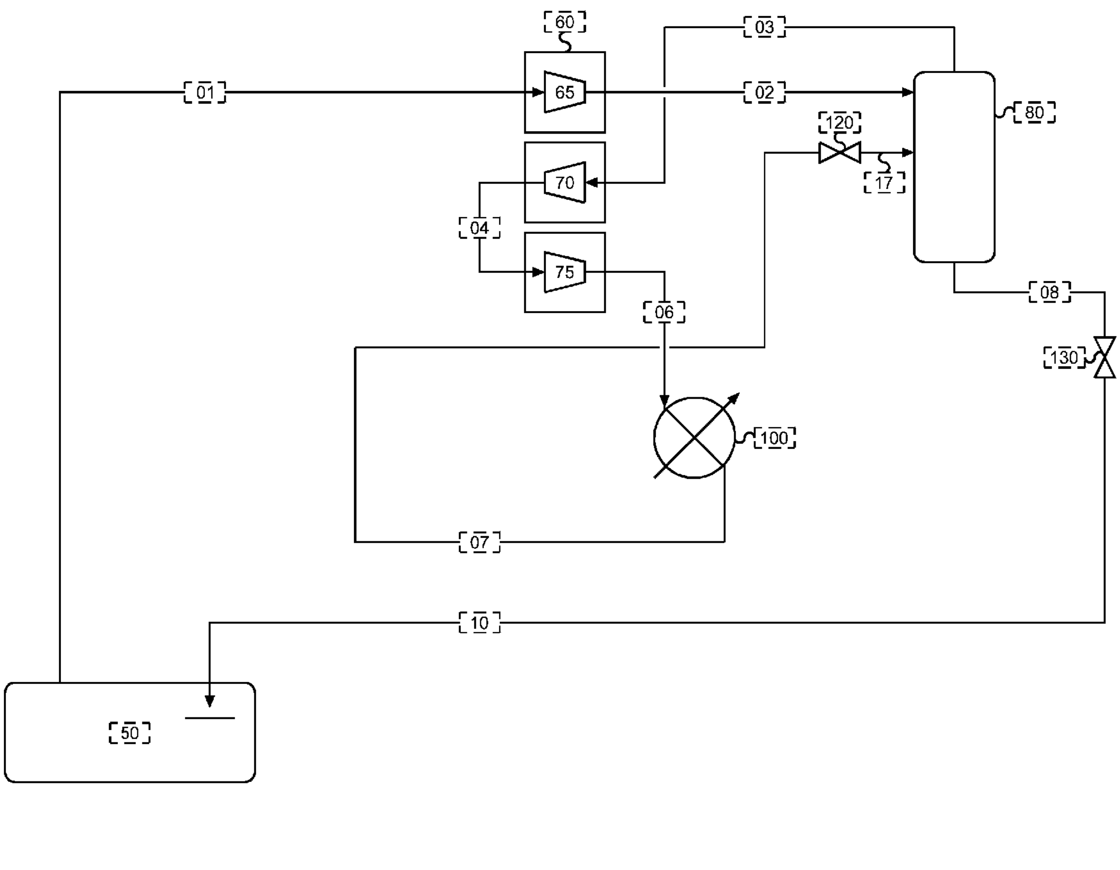
(57) **ABSTRACT**

The disclosure relates to a method and apparatus for cooling, preferably liquefying a boil off gas (BOG) stream from a liquefied cargo in a floating transportation vessel, said liquefied cargo having a boiling point of greater than −110° C. at 1 atmosphere, said method comprising at least the steps of: -compressing a boil off gas stream (**01**) from said liquefied cargo in three or more stages of compression comprising at least a first stage (**65**), a second stage (**70**) and final stage (**75**) to provide a compressed discharge stream (**06**), wherein intermediate compressed BOG streams (**02**, **04**) are provided between consecutive stages of compression; -cooling the compressed discharge stream (**06**) to provide a cooled compressed discharge stream (**07**); -heat exchanging an expanded, optionally further cooled, portion of the cooled compressed discharge stream (**07**), with (i) one or more intermediate compressed BOG streams (**04**) from consecutive stages selected from between the second and final stages (**75**) of compression to provide one or more cooled intermediate compressed BOG streams (**05**) and optionally (ii) one or more portions (**07***a,* **108***a*), optionally after further cooling, of the cooled compressed discharge stream (**07**); and -passing the one or more cooled intermediate compressed BOG streams (**05**) to the next stage of compression (**75**).



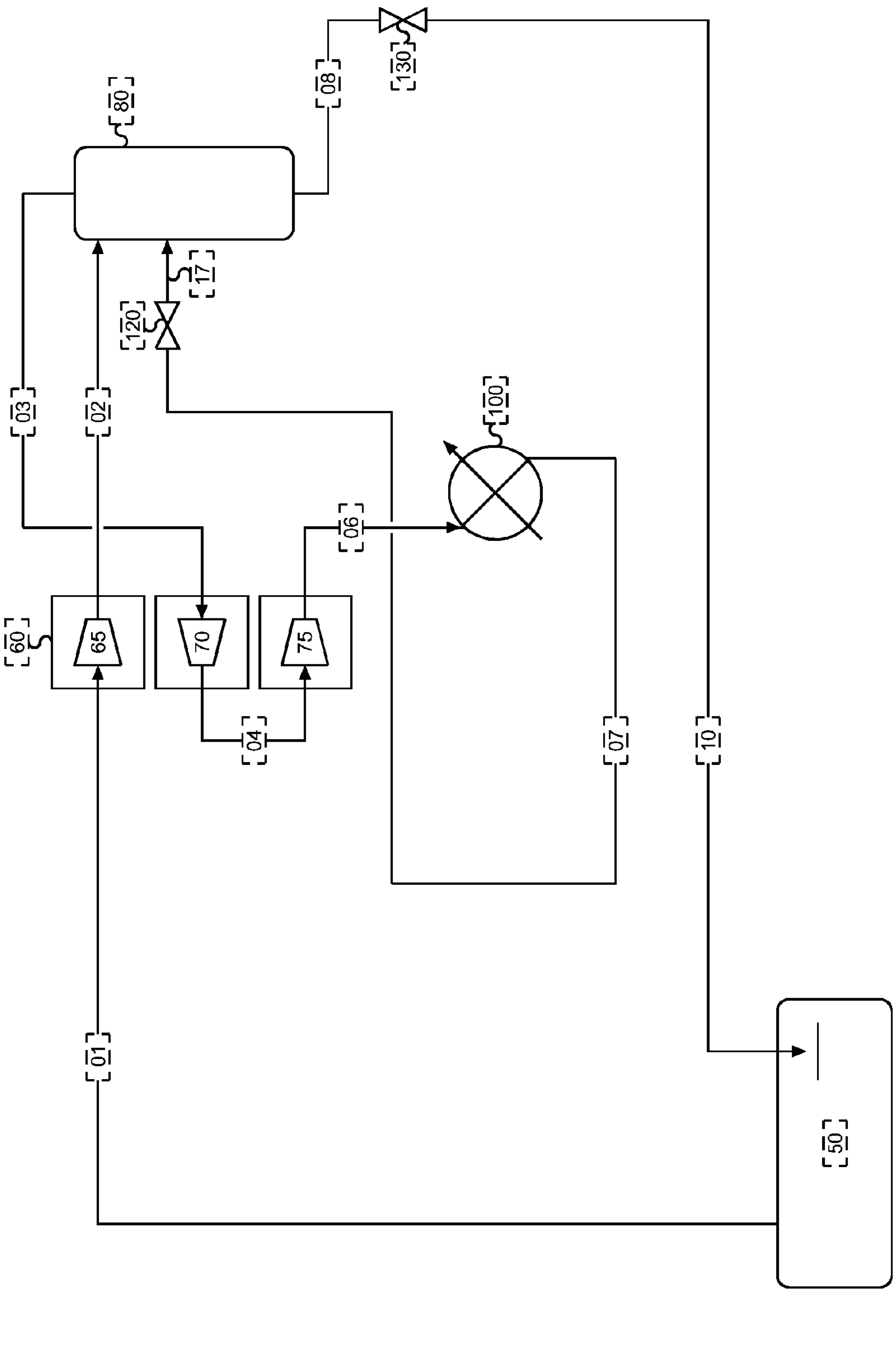


Figure 1

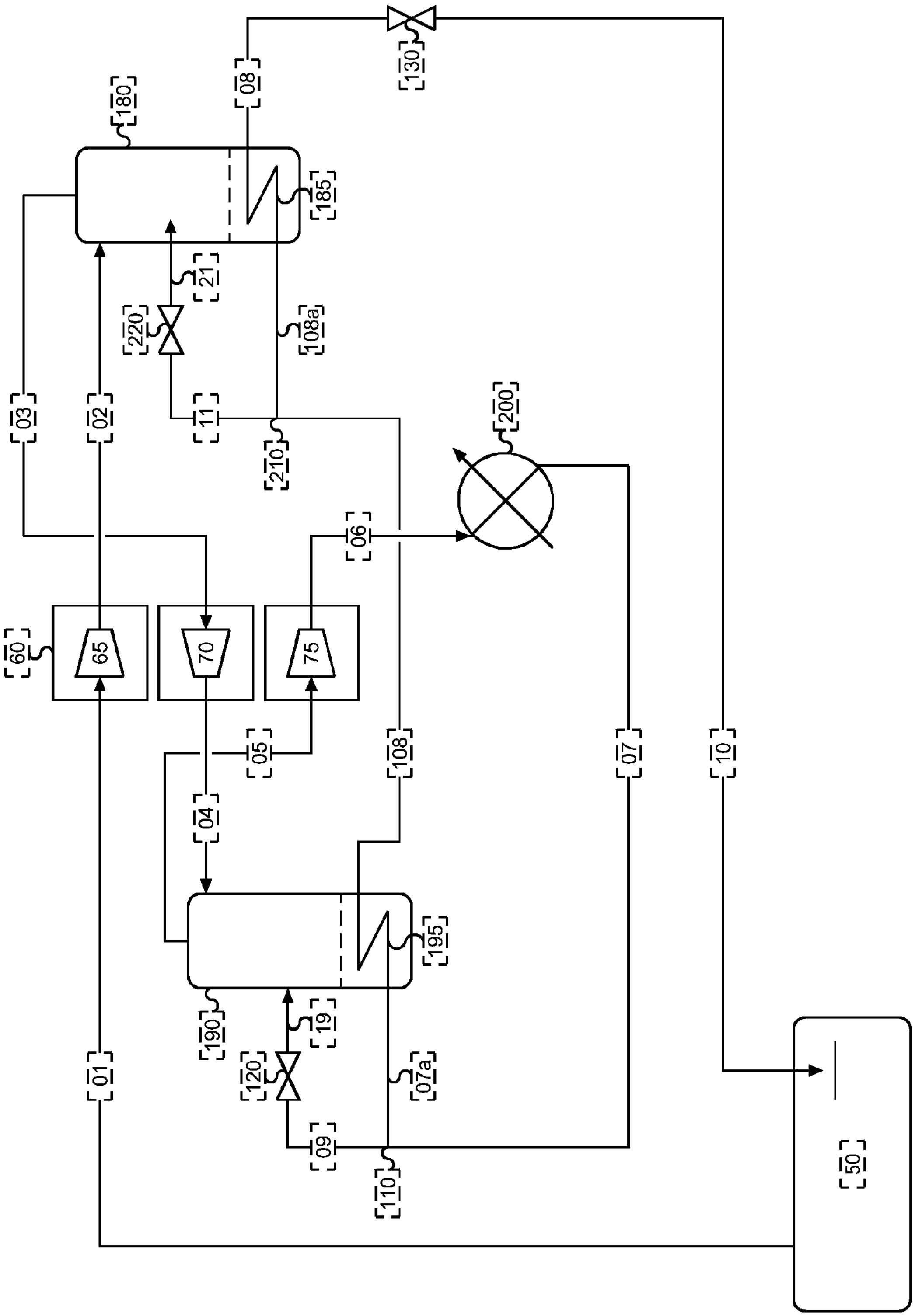


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Figure 2

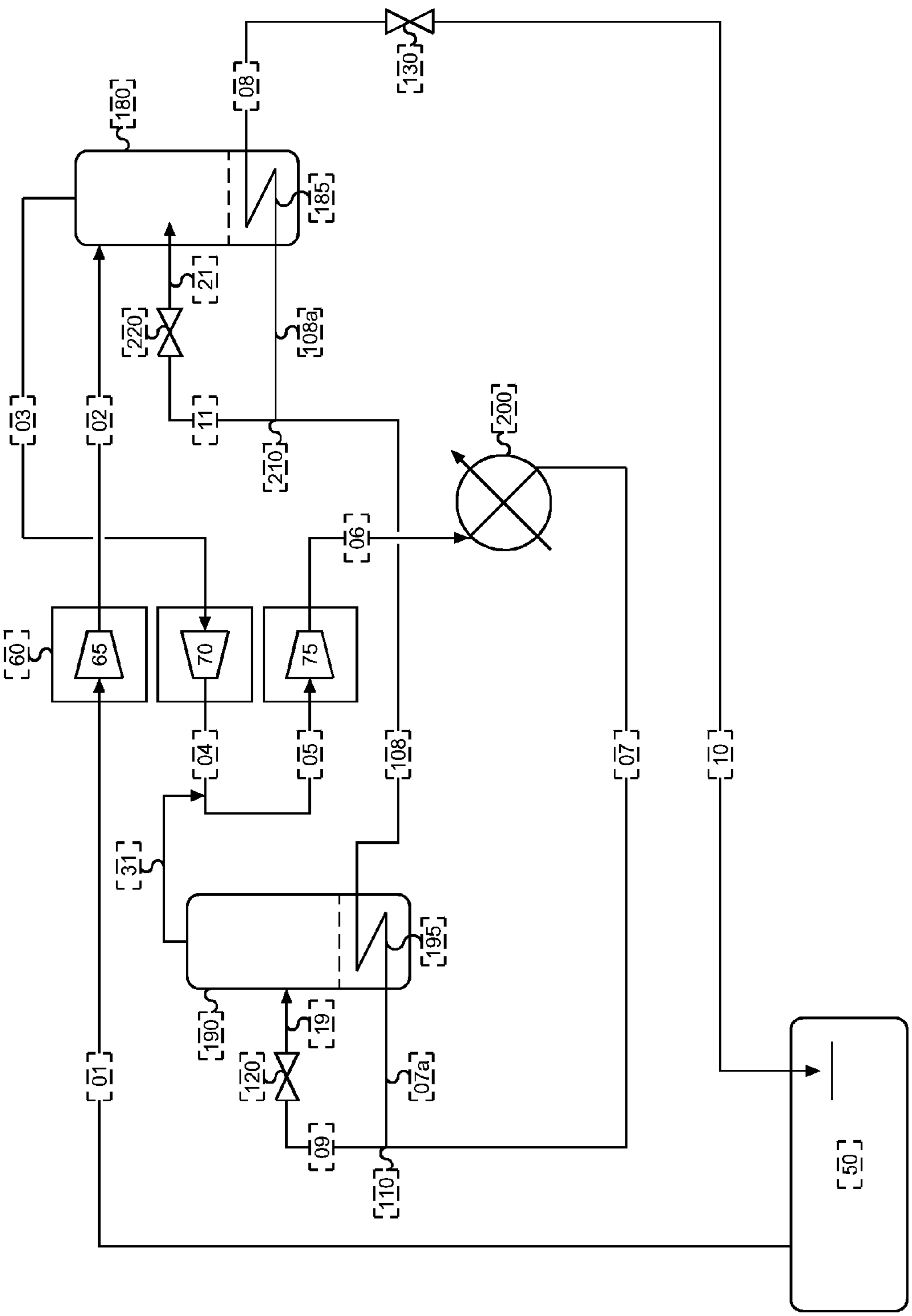
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Figure 3

METHOD OF COOLING BOIL OFF GAS AND AN APPARATUS THEREFOR

TECHNICAL FIELD

[0001] This disclosure relates to a method for the cooling, particularly the reliquefaction, of a boil off gas (BOG) from a liquefied cargo, such as liquefied petroleum gas (LPG), on a floating transportation carrier, and an apparatus therefor.

BACKGROUND OF THE DISCLOSURE

[0002] Floating transportation carriers, such as liquefied gas carrier vessels and barges, are capable of transporting a variety of cargoes in the liquefied state. In the present context, these liquefied cargoes have boiling points of greater than −110° C. when measured at 1 atmosphere and include liquefied petroleum gas, liquefied petrochemical gases such as propylene and ethylene, and liquefied ammonia. For instance, liquefied petroleum gas is a useful fuel source, such as for heating appliances and vehicles, as well as being a source of hydrocarbon compounds. LPG comprises one or more of propane, n-butane and i-butane, and optionally one or more other hydrocarbons such as propylene, butylenes and ethane.

[0003] Petroleum gases can be extracted from natural gas or produced in the refining of crude oil. As a consequence, petroleum gases normally comprise a plurality of components. It is often desirable to liquefy petroleum gases in a liquefaction facility at or near the source. As an example, petroleum gases can be stored and transported over long distances more readily as a liquid than in gaseous form because they occupy a smaller volume and may not need to be stored at high pressures. Such LPG can be stored at atmospheric pressure if maintained at or below its boiling temperature, such as at −42° C. or below, being the boiling point of the propane component. Alternatively, LPG may be stored at higher temperatures if it is pressurized above atmospheric pressure.

[0004] The long distance transportation of LPG or other liquefied cargo having boiling point of greater than −110° C. when measured at 1 atmosphere may be carried out in a suitable LPG carrier, particularly a carrier vessel, such as an ocean-going tanker having one or more storage tanks to hold the liquefied cargo. These storage tanks may be insulated and/or pressurized tanks. During the loading of the tanks and the storage of liquefied cargo such as LPG in the tanks, petroleum gas may be produced due to the evaporation of the cargo. This evaporated cargo gas such as petroleum gas is known as boil off gas (BOG). In order to prevent the build up of BOG in the tank, a system may be provided on the carrier to re-liquefy the BOG so that it can be returned to the storage tank in a condensed state. This can be achieved by the compression and cooling of the BOG. In many systems, the compressed BOG is cooled and condensed against seawater.

[0005] Liquefied cargoes such as those comprising primarily propane, particularly commercial grade propane, may further comprise relatively high concentrations of lighter components, such as ethane. Such liquefied cargoes, particularly those comprising ethane at or above 3.5 mol %, may require the presence of three stages of compression to provide sufficient compression to facilitate the condensation of the lighter components of the boil off gas. In some circumstances, the compressed BOG stream between the discharge of the first stage of compression and the suction of the second stage of compression may be cooled. The cooling duty may be provided by the compressed and condensed BOG.

[0006] There are many considerations associated with providing systems to reliquefy boil off gas from such liquefied cargoes in floating transportation carriers. The size of the carrier imposes limitations on the space available for the reliquefaction system. This can restrict the number and size of the compressor trains. Furthermore, size restrictions may also preclude the use of a closed refrigeration system to cool the condenser for the compressed BOG stream, such that the cooling duty may be supplied by seawater. When seawater is used, the reliquefaction system is generally designed to operate with seawater temperatures at up to 32° C.

[0007] It would be advantageous to provide an improved method of cooling, particularly re-liquefying, boil off gas from a liquefied cargo having a boiling point of greater than −110° C. when measured at 1 atmosphere in a floating transportation carrier. In particular, a more efficient method in terms of one or more of reduced power requirements, increased capacity and increased coefficient of performance is desirable.

SUMMARY

[0008] The present disclosure utilises a method of heat exchanging one or more intermediate BOG streams between the second and further stages of multiple stages of compression with part of the cooled compressed discharge from the final compressor stage. This can provide an improvement in the co-efficient of performance for the reliquefaction of the boil off gas.

[0009] In a first aspect, there is provided a method of cooling a boil off gas stream from a liquefied cargo in a floating transportation vessel, said liquefied cargo having a boiling point of greater than −110° C. at 1 atmosphere, said method comprising at least the steps of:

[0010] compressing a boil off gas stream from said liquefied cargo in three or more stages of compression comprising at least a first stage, a second stage and final stage to provide a compressed discharge stream, wherein intermediate compressed BOG streams are provided between consecutive stages of compression;

[0011] cooling the compressed discharge stream to provide a cooled compressed discharge stream;

[0012] heat exchanging an expanded, optionally further cooled, portion of the cooled compressed discharge stream, with (i) one or more intermediate compressed BOG streams from consecutive stages selected from between the second and final stages of compression to provide one or more cooled intermediate compressed BOG streams and optionally (ii) one or more portions, optionally after further cooling, of the cooled compressed discharge stream; and

[0013] passing the one or more cooled intermediate compressed BOG streams to the next stage of compression.

[0014] In one embodiment, the method comprises the steps of:

[0015] compressing the boil off gas stream in a first stage of compression to provide a first intermediate compressed BOG stream as an intermediate compressed BOG stream;

[0016] compressing the first intermediate compressed BOG stream, optionally after heat exchange to provide a cooled first intermediate compressed BOG stream, in a second stage of compression to provide a second intermediate compressed BOG stream as an intermediate compressed BOG stream.

[0017] In a further embodiment, the method further comprises the steps of:

[0018] splitting the cooled compressed discharge stream into a continuing cooled compressed discharge stream and a cooled compressed discharge side stream;

[0019] expanding the cooled compressed discharge side stream to provide an expanded cooled discharge stream.

[0020] In another embodiment, the method further comprises the step of:

[0021] heat exchanging the expanded cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the second and final stages of compression to provide a cooled intermediate compressed BOG stream.

[0022] In yet another embodiment, the method comprises the further step of:

[0023] flashing the expanded cooled discharge stream to provide an overhead expanded cooled discharge stream;

[0024] heat exchanging the overhead expanded cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the second and final stages of compression to provide a cooled intermediate compressed BOG stream.

[0025] In a further embodiment of the method, the intermediate compressed BOG stream may be a second intermediate compressed BOG stream and the cooled intermediate compressed BOG stream may be a cooled second intermediate compressed BOG stream.

[0026] In another embodiment, the method comprises the further step of:

[0027] heat exchanging the expanded cooled discharge stream with the continuing cooled compressed discharge stream to provide a further cooled compressed discharge stream.

[0028] In a further embodiment, the method comprises the further steps of:

[0029] splitting the further cooled compressed discharge stream into a continuing further cooled compressed discharge stream and a further cooled compressed discharge side stream;

[0030] expanding the further cooled compressed discharge side stream to provide an expanded further cooled discharge stream.

[0031] In a still further embodiment, the method comprises the further step of:

[0032] heat exchanging the expanded further cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the first and final stages of compression to provide a cooled intermediate compressed stream.

[0033] In another embodiment, the method comprises the further step of:

[0034] flashing the expanded further cooled discharge stream to provide an overhead expanded further cooled discharge stream;

[0035] heat exchanging the overhead expanded further cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the first and final stages of compression to provide a cooled intermediate compressed BOG stream.

[0036] In another embodiment of the method, the intermediate compressed BOG stream is a first intermediate compressed BOG stream and the cooled intermediate compressed BOG stream is a cooled first intermediate compressed BOG stream.

[0037] In a further embodiment, the method comprises the further step of:

[0038] heat exchanging the expanded further cooled discharge stream with the continuing further cooled compressed discharge stream to provide a cooled return stream.

[0039] In another embodiment, the method comprises the further step of:

[0040] expanding the cooled return stream to provide an expanded cooled return stream.

[0041] In yet another embodiment of the method, the liquefied cargo is LPG, such as LPG comprising at least 3.5 mol % ethane.

[0042] In another embodiment of the method, the compressed discharge stream can be cooled against a water stream, such as a seawater stream, to provide the cooled compressed discharge stream. Typically, the water stream has a temperature of +36° C. or below, more typically +32° C. or below.

[0043] In a further embodiment of the method, the first stage, second stage and final stage of compression are stages of a multi-stage compressor.

[0044] In a second aspect, there is provided an apparatus to cool a boil off gas stream from a liquefied cargo in a floating transportation vessel, said liquefied cargo having a boiling point of greater than −110° C. at 1 atmosphere, said apparatus comprising at least:

[0045] a multiple stage compression system to compress a boil off gas stream from a liquefied cargo, said compression system comprising three or more stages of compression comprising at least a first stage, a second stage and final stage to provide a compressed discharge stream, wherein intermediate compressed BOG streams are provided between consecutive stages of compression,

[0046] a first heat exchanger to cool the compressed discharge stream to provide a cooled compressed discharge stream; and

[0047] one or more further heat exchangers to heat exchange an expanded, optionally further cooled, portion of the cooled compressed discharge stream with (i) one or more intermediate compressed BOG streams from consecutive stages selected from between the second and final stages of compression to provide one or more cooled intermediate compressed BOG streams to the next stage of compression and optionally (ii) one or more portions, optionally after further cooling, of the cooled compressed discharge stream.

[0048] In a further embodiment said apparatus can be present on the floating transportation vessel.

[0049] In a further embodiment, the apparatus of the second aspect can be operated using the method of the first aspect.

[0050] The apparatus and method disclosed herein are applicable to any floating transportation vessel for a liquefied cargo having a boiling point of greater than −110° C. at 1 atmosphere, such as an LPG carrier. The apparatus and method disclosed herein may be utilized in floating transportation vessels where the liquefied cargo storage tanks are fully refrigerated to maintain the cargo in liquid phase at approximately atmospheric pressure by lowering the temperature, as well as in those vessels in which the cargo in the storage tanks is maintained in the liquid phase by a combination of reduced temperature and increased pressure.

[0051] The liquefied cargo may be selected from the group comprising liquefied petroleum gas, liquefied petrochemical gas and liquefied ammonia. The apparatus and method disclosed herein are of particular benefit for a liquefied cargo, such as LPG, comprising light components, particularly ethane at or above 3.5 mol %. For compositions with higher concentrations of light components, additional compression stages may be required for cooling, particularly to effect condensation of the compressed discharge stream of BOG against seawater.

[0052] The method and apparatus disclosed herein utilizes three or more stages of compression. Heat exchangers such as economizers can be placed between consecutive stages of compression selected between the second and final stages. For instance, an economizer can be situated between at least the second and third stages, optionally in combination with an economizer between the first and second stages. In such an economizer, an expanded, optionally further cooled, portion of the cooled compressed discharge stream can be heat exchanged with (i) an intermediate compressed BOG stream and/or (ii) an optionally further cooled continuing portion of the cooled compressed discharge stream. This leads to further improvements in the coefficient of performance and increased cooling, particularly reliquefaction, capacity.

[0053] As used herein, the term "multiple stages of compression" defines two or more stages of compression in series in a compression system. Each stage of compression may be achieved by one or more compressors. The one or more compressors of each compression stage may be independent from those of the other stages of compression, such that they are driven separately. Alternatively, two or more of the stages of compression may utilize compressors which are linked, typically powered by a single driver and drive shaft, with optional gearing. Such linked compression stages may be part of a multi-stage compressor.

[0054] The method and apparatus disclosed herein requires at least three stages of compression. After the first stage of compression, each subsequent stage provides an increased pressure compared to the pressure at the discharge of a previous stage. The term "consecutive stages" refers to pairs of adjacent stages of compression i.e. a stage (n) and the next (n+1) stage where 'n' is a whole number greater than 0. Consequently, consecutive stages are, for instance, first and second stages or second and third stages or third and fourth stages. Intermediate compressed streams (and cooled intermediate compressed streams) refer to those streams connecting consecutive stages of compression. The term "next stage of compression" used in relation to the cooled intermediate compressed stream refers to the numerically higher number (and higher pressure stage) of the two consecutive stages defining the intermediate stream.

[0055] The heat exchange steps may be indirect, where the two or more streams involved in the heat exchange are not in direct contact. Alternatively, the heat exchange may be direct, in which case the two or more streams involved in the heat exchange can be mixed, thereby producing a combined stream.

[0056] Other aspects, features, and advantages will become apparent from the following detailed description when taken in conjunction with the accompanying drawings, which are a part of this disclosure and which illustrate, by way of example, principles of any inventions disclosed.

DESCRIPTION OF THE FIGURES

[0057] The accompanying drawings facilitate an understanding of the various embodiments.

[0058] FIG. **1** shows a schematic diagram of one possible known system of reliquefying boil off gas from a cargo tank in an LPG carrier;

[0059] FIG. **2** shows a schematic diagram of a system of cooling, particularly reliquefying, boil off gas from a liquefied cargo in a floating transportation vessel in accordance with this disclosure; and

[0060] FIG. **3** shows a schematic diagram of a system for cooling, particularly reliquefying, boil off gas from a liquefied cargo in a floating transportation vessel in accordance with this disclosure.

DETAILED DESCRIPTION

[0061] Shipboard LPG reliquefaction systems based on the open cycle refrigeration principle draw LPG vapor, also known as boil off gas, from one or more storage tanks, pass the boil off gas to a compressor in which it is compressed such that the compressed vapor can be cooled and condensed using sea water as the heat sink/refrigerant. Typically, the LPG is kept in the storage tank under one or both of reduced temperature (versus ambient) and increased pressure (versus atmospheric).

[0062] FIG. **1** shows a schematic diagram of a known system for reliquefying boil off gas in an LPG carrier vessel. Liquefied petroleum gas (LPG) is stored in a tank **50** which may be insulated and/or pressurized in order to maintain the petroleum gas in a liquefied state. Vaporization of the LPG in the tank, for instance due to imperfect thermal insulation, will result in the formation of petroleum gas in the overhead space of the tank **50**. In order to prevent the build-up of this gas, it is removed from the tank **50** as a boil off gas stream **01**. The removed boil off gas is normally compressed and cooled to condense it before it is returned to the tank **50**.

[0063] The boil off gas stream **01** can be passed to a compression system **60**, such as the three stage compressor shown in FIG. **1** which comprises a first compression stage **65**, a second compression stage **70** and a third compression stage **75**. The three-stage compressor **60** produces a compressed discharge stream **06** which can be passed to a condenser **100**, in which the compressed discharge stream **06** is cooled against seawater. The condenser **100** produces a cooled compressed discharge stream **07**, such as an at least partially, typically fully, condensed compressed discharge stream and a warmed seawater stream (not shown).

[0064] The cooled compressed discharge stream **07** may be optionally passed to a discharge stream gas/liquid separation device, such as a knock-out drum or accumulator to allow the separation of uncondensed components from the cooled compressed discharge stream **07**. The uncondensed components would normally be vented, while the condensed compressed discharge stream is passed from the gas/liquid separation device for further cooling.

[0065] The cooled compressed discharge stream **07** can be passed to a discharge stream pressure reduction device **120**, such as an expander or Joule-Thomson valve, where it is expanded to provide an expanded cooled discharge stream **17**. The expanded cooled discharge stream **17** can then be passed to a first stage heat exchanger **80**, to provide a cooled return stream **08**, which is typically a partially, more typically a fully condensed stream.

[0066] The cooled return stream **08** may then be passed to a return expansion device **130**, such as an expander or Joule-Thomson valve, to provide an expanded cooled return stream **10**. The expanded cooled return stream **10** may be a sub-cooled condensed return stream. Typically, the return expansion device **130** will reduce the pressure of the cooled return stream **08** to close to that of the LPG and BOG in the tank **50**, such as a pressure just above that of the BOG in the tank, sufficient to ensure an adequate flow of the expanded cooled return stream **10** to the tank **50**.

[0067] The first stage **65** of the three-stage compressor **60** provides a first intermediate compressed BOG stream **02**, which is passed to first stage heat exchanger **80**. The first intermediate compressed BOG stream **02** can be heat exchanged against the expanded cooled discharge stream **17** in the first stage heat exchanger **80** to provide a cooled first intermediate compressed BOG stream **03**. It will be apparent that the discharge stream pressure reduction device **120** should reduce the pressure of the cooled compressed discharge stream **17** to at or near that of the first intermediate compressed BOG stream **02**. The cooled compressed discharge stream **17** and the first intermediate compressed BOG stream **02** are mixed in the shell side of the first stage heat exchanger **80**. A vapor stream can be withdrawn from the first stage heat exchanger **80** as cooled first intermediate compressed BOG stream **03**.

[0068] The cooled first intermediate compressed BOG stream **03** can then be passed to the suction of the second stage **70** of the three-stage compressor **60**. The second stage **70** compresses the cooled first intermediate compressed BOG stream **03** to provide a second intermediate compressed BOG stream **04**.

[0069] The second intermediate compressed BOG stream **04** can then be passed to the suction of a third stage **75** of the three-stage compressor **60**, where it is compressed to provide the compressed discharge stream **06**.

[0070] The method and apparatus disclosed herein seeks to improve the system of reliquefying BOG according to FIG. **1**. An embodiment of the method and apparatus according to the present disclosure is given in FIG. **2**. Where appropriate, identical stream and component names and reference numerals to that of FIG. **1** have been used for corresponding streams and components in FIG. **2**.

[0071] FIG. **2** shows a liquefied cargo storage tank **50** in a floating transportation vessel, such as an LPG carrier. The liquefied cargo may be LPG and the boil off gas may be petroleum gas. In order to cool, particularly reliquefy, evaporated cargo from the storage tank **50**, a boil off gas stream **01**, comprising evaporated cargo, is passed to a compression system **60** having three or more stages of compression. The boil off gas stream **01** may have a pressure (the "BOG pressure") in the range of from above 0 to 500 kPa gauge. The compression system **60** may be a multi-stage compressor comprising three of more stages. By "multi-stage compressor" it is meant that each compression stage in the compressor is driven by the same drive shaft. Alternatively, the compression system **60** may comprise independently driven compressors for each of the stages of compression. When the compression system **60** is a multi-stage compressor, it is typically a reciprocating compressor.

[0072] The embodiment of FIG. **2** shows a compression system **60** having a first stage **65**, a second stage **70** and a third stage **75**, although the method and apparatus described herein is also applicable to compressors having four or more stages. The first stage, second and third stages **65**, **70**, **75** provide low, intermediate and high pressure streams respectively at their discharge.

[0073] The compression system **60** compresses the boil off gas stream **01** to provide a compressed discharge stream **06**. The compressed discharge stream **06** may have a pressure (the "third stage pressure") in the range of from 2.0 to 3.5 MPa gauge. The compressed discharge stream **06** can be passed to a discharge stream heat exchanger **200**, such as a condenser. The compressed discharge stream **06** is cooled against a heat exchange fluid, such as seawater, to provide a cooled compressed discharge stream **07** and warmed heat exchange fluid (not shown). Typically, the seawater used as the heat exchange fluid would have a temperature of +36° C. or below, more typically +32° C. or below.

[0074] The cooled compressed discharge stream **07** is typically a partially, more typically a fully condensed, compressed discharge stream. It is preferred that the cooled compressed discharge stream **07** is further cooled. This can be achieved by passing the cooled compressed discharge stream **07** to one or more further heat exchangers **190**, **180**, such as an intermediate stage economizer for cooling the intermediate BOG streams. These are discussed in more detail below.

[0075] For instance, the cooled compressed discharge stream **07** can be cooled against an expanded portion of the cooled compressed discharge stream in the first further heat exchanger **190**. In the embodiment shown in FIG. **2**, a discharge stream splitting device **110** divides the cooled compressed discharge stream **07** into a continuing cooled compressed discharge stream **07***a* and a cooled compressed discharge side stream **09**. The cooled compressed discharge side stream **09** can be passed to a first discharge stream pressure reduction device **120**, such as an expander or Joule-Thomson valve, where it is expanded to provide an expanded cooled discharge side stream **19**, which can then be heat exchanged against the continuing compressed discharge stream **07***a* to provide a further cooled compressed discharge stream **108**.

[0076] The first further heat exchanger **190**, which can be a second intermediate stage economizer, may be a shell and tube or a shell and coil heat exchanger in which the cooled compressed discharge stream **07** is passed through one or more tubes or coils **195** (FIG. **2** shows a coil) in which it is cooled against the expanded cooled discharge side stream **19** injected into the shell side of the first heat exchanger. The cooled compressed discharge side stream **09** can be expanded to a pressure close to the pressure of the discharge of the second stage of the multi-stage compressor, as is discussed in more detail below.

[0077] In a further embodiment not shown in FIG. **2**, the discharge stream splitting device **110** can be provided downstream of the first further heat exchanger **190**, such that the fluid providing the cooling duty is obtained by the expansion of a portion of the further cooled compressed discharge stream **108**, rather than the expansion of a portion of the cooled compressed discharge stream **07**.

[0078] The further cooled compressed discharge stream **108** can then be passed to a second further heat exchanger **180**, such as first intermediate stage economizer, typically of the shell and tube or shell and coil type. For instance, the further cooled compressed discharge stream **108** can be cooled against an expanded portion of the further cooled compressed discharge stream. In the embodiment shown in FIG. **2**, a further cooled discharge stream splitting device **210** divides the further cooled compressed discharge stream **108** into a continuing further cooled compressed discharge stream **108***a* and a further cooled compressed discharge side stream **11**. The further cooled compressed discharge side stream **11** can be passed to a second discharge stream pressure reduction device **220**, such as an expander or Joule-Thomson valve, where it is expanded to provide an expanded further cooled discharge side stream **21**, which can then be heat exchanged against the continuing further cooled compressed discharge stream **108***a* to provide a cooled return stream **08**, typically as a sub-cooled stream. Typically, this heat exchange is carried out by injecting the expanded further cooled discharge side stream **21** into the shell side of the second further heat exchanger **180**, with the continuing further cooled compressed discharge stream **108***a* present in one or more second further heat exchanger tubes or coils **185** (a coil is shown in FIG. **2**) within the shell of the heat exchanger.

[0079] In an embodiment not shown in FIG. **2**, the stream providing the cooling duty to the second further heat exchanger **180** may be drawn as a side stream from the cooled return stream **08**, and then expanded and injected into the second further heat exchanger **180**. In this case, the splitting device would be provided in the cooled return stream **08**, rather than in the further cooled compressed discharge stream **108**.

[0080] In a similar manner to the scheme of FIG. **1**, the cooled return stream **08** can then be passed to a return expansion device **130**, such as an expander or Joule-Thomson valve, to provide an expanded cooled return stream **10**, which may be a sub-cooled condensed return stream. This can then be returned to the storage tank **50**.

[0081] Returning to the first and second further heat exchangers **190** and **180**, as well as cooling continuing compressed discharge stream **07***a* and continuing further cooled compressed discharge stream **108***a*, they can also cool intermediate compressed streams from the first and second compressor stages **65**, **70**. In such an embodiment, the first and second heat exchangers **190**, **180** can be economizers. This heat exchange can lead to an increased coefficient of performance.

[0082] In particular, the boil off gas stream **01** can be compressed by first stage **65** to a first intermediate compressed BOG stream **02** at a first stage pressure. The first intermediate compressed BOG stream **02** can then be heat exchanged against the expanded further cooled discharge side stream **21** to provide a cooled first stage compressed BOG stream **03**. This heat exchange can be carried out in second further heat exchanger **180**, which is typically a first intermediate stage economizer. When the first intermediate stage economizer is of the shell and tube type, the first intermediate compressed BOG stream **02** and the expanded further cooled discharge side stream **21** can both be injected into the shell-side of the heat exchanger. This is known as liquid subcooling. During the heat exchange process, these streams will mix such that the cooled first stage compressed BOG stream **03** will be a combination of these streams. It will be apparent that the further cooled compressed discharge side stream **11** should therefore be expanded to a pressure at or slightly above that provided by the discharge of the first stage **65**, namely the first stage pressure. This will provide an acceptable pressure balance within the second further heat exchanger **180**.

[0083] The cooled first stage compressed BOG stream **03** can then be passed to the suction of the second stage **70** of the compression system **60**, where it is compressed to provide a second intermediate compressed BOG stream **04** at a second stage pressure. In order to provide the benefits of the method and apparatus disclosed herein, the second stage compressed BOG stream **04** should be cooled prior to passing it to the suction of the third stage **75** of the multi-stage compressor **60**. The cooling of the steam **04** therefore leads to a reduction in the temperature of the stream provided at the discharge of the third stage **75**. This can enable a reduction in the size of the discharge stream heat exchanger **200**, which can be a condenser.

[0084] The second intermediate compressed BOG stream **04** can be heat exchanged against the expanded further cooled discharge side stream **19** to provide a cooled second intermediate compressed BOG stream **05**. This heat exchange can be carried out in first further heat exchanger **190**, which is typically a second intermediate stage economizer. When the second intermediate stage economizer is of the shell and tube type, the second intermediate compressed BOG stream **04** and the expanded cooled discharge side stream **19** can both be injected into the shell-side of the heat exchanger. During the heat exchange process, these streams will mix such that the cooled second stage compressed BOG stream **05** will be a combination of these streams to provide liquid subcooling of the second intermediate compressed BOG stream **04**. It will be apparent that the cooled compressed discharge side stream **110** should therefore be expanded to a pressure at or slightly above that provided by the discharge of the second stage **70**, namely the second stage pressure. This will provide an acceptable pressure balance within the first further heat exchanger **190**.

[0085] In an alternative embodiment of the method and apparatus disclosed herein, rather than the use of liquid subcooling in which the discharge vapor from a previous compressor stage is passed into the further heat exchanger where it mixes with the vapor before being passed to the suction of the next stage of the compressor as shown in FIG. **2**, a flash liquid subcooling process may be used. In the flash liquid subcooling process, the discharge vapor from the previous compressor stage, is not passed through the further heat exchanger but is mixed with the vapor produced in the heat exchanger at or before the suction to the next stage of the compression cycle.

[0086] This embodiment is shown in relation to a first further heat exchanger **190'**, such as a second intermediate stage economizer which can be of the shell and tube type, in FIG. **3**. The second intermediate compressed BOG stream **04**, is not passed through the first further heat exchanger **190'** as it is in the embodiment of FIG. **2**, but is mixed with the vapor produced in the second intermediate stage economizer at or before the suction to the next stage of the compression cycle.

[0087] In particular with regard to FIG. **3**, the expanded cooled discharge side stream **19** can be injected into the first further heat exchanger **190'**, such as the second intermediate stage economizer, to provide an overhead expanded cooled discharge stream **31** which is withdrawn from the heat exchanger. The overhead expanded cooled discharge stream **31** can be produced by flashing the expanded cooled discharge side stream **19** into the shell of the first further heat exchanger **190'**.

[0088] The overhead expanded cooled discharge stream **31** is then mixed with, typically by comingling, the second intermediate compressed BOG stream **04** to provide a cooled second intermediate compressed BOG stream **05**, which is then passed to the suction of the third stage **75** of the compression system **60**.

[0089] The continuing cooled compressed discharge stream **07***a* can be cooled in the first further heat exchanger **190'** by heat exchange with the expanded cooled discharge side stream **19** in a similar manner to the embodiment of FIG. **2**.

[0090] Although not shown in FIG. **3**, a similar flash liquid subcooling process can be carried out in the second further heat exchanger, which can be a first intermediate stage economizer, typically of the shell and tube or shell and coil type. Thus, rather than passing the first intermediate compressed BOG stream **02** to the second further heat exchanger **180**, the overhead stream (an overhead expanded further cooled discharge stream) withdrawn from the second further heat exchanger produced by flashing the expanded further cooled discharge side stream **21** into the shell side of the second further heat exchanger **180** can be mixed with the first intermediate compressed BOG stream **02** to provide a cooled first intermediate compressed BOG stream.

[0091] In a further alternative embodiment not shown in the Figures, the cooled compressed discharge stream **07** can, instead of being passed through the further heat exchangers **190**, **180** in series in the order of those operating at the highest pressure (first further heat exchanger **190**) to lowest pressure (second further heat exchanger **180**), be provided to all the heat exchangers in parallel. In such a situation, the cooling duty would be supplied by cooled compressed discharge side stream **09** or drawn as side streams from the cooled return streams, after expansion to pressures appropriate for each heat exchanger.

EXAMPLE

[0092] This Example provides a hypothetical calculation of the power requirements, cooling capacity and coefficient of performance of two LPG re-liquefaction systems, namely a system according to the present disclosure in which flash liquid subcooling is carried out on the first and second intermediate compressed BOG streams (i.e. the embodiment of FIG. **3** in which flash liquid subcooling is also carried out in the first intermediate stage economizer) and a comparative system in which flash liquid subcooling is only carried out on the first compressed intermediate stream (i.e. FIG. **2** without a first further heat exchanger/second intermediate stage economizer).

[0093] Compression system data was based upon a three-stage compressor (Burckhardt Compression AG, Winterthur, Switzerland). The liquefied petroleum gas cargo comprised 5.0 mol % ethane and 95.0 mole % propane in the liquid phase. The vapor phase composition of the boil off gas at a tank storage pressure of 0.4 bar gauge was calculated to be 24.23 mole % ethane and 75.77 mole % propane, based upon Peng Robinson Stryjek-Vera equations of state.

[0094] Table 1 shows the calculated suction and discharge pressures and temperatures at the three stages of compression of the comparative Example.

TABLE 1

	Suction		Discharge	
Stage no.	Pressure (bar abs)	Temperature (° C.)	Pressure (bar abs)	Temperature (° C.)
1	1.40	−20.0	4.73	46.2
2	4.73	26.5	10.82	67.3
3	10.82	67.3	24.00	103.8

[0095] Table 2 shows the suction and discharge pressures and temperatures at the three stages of compression of the Example according to the present disclosure.

TABLE 2

	Suction		Discharge	
Stage no.	Pressure (bar abs)	Temperature (° C.)	Pressure (bar abs)	Temperature (° C.)
1	1.40	−20.0	4.33	42.8
2	4.33	30.9	11.09	75.3
3	11.09	65.5	24.00	101.3

[0096] In both the comparative Example and the Example according to the present disclosure, a third stage discharge pressure of 24 bar abs provides a condensing temperature of +40° C.

[0097] Table 3 shows the calculated power, reliquefaction capacity and coefficient of performance of the system according to the comparative Example and the Example according to the present disclosure.

[0098] It is apparent from Table 3 that the introduction of a flash liquid heat exchange step between the second and third stages of the three-stage compressor results in a reduction in overall compressor driver power, together with an increase in cooling capacity and coefficient of performance, compared to a system in which there is no cooling of the discharge from the second stage compressor in a second stage economizer.

TABLE 3

	Power (kWE)	Capacity (kWR)	C.O.P.
Comparative	381.1	394.4	1.035
Present new disclosure	375.7	422.6	1.125

[0099] The person skilled in the art will understand that any invention disclosed herein can be carried out in many various ways without departing from the scope of the appended claims. For instance, an invention may encompass the combination of one or more of the optional or preferred features disclosed herein. For example, it may not be required that there be the presence of a heat exchanger such as an economizer between the first and second stages of a multi-stage compressor. Alternatively or additionally, the present disclosure can be applicable to multi-stage compressors comprising more than three stages. Heat exchangers such as economizers may be placed between more than at least one of the second and further stages of the multi-stage compressor. For instance, in a four stage compressor, such heat exchangers may be placed between one or both of the second and third stages and third and fourth stages, as well as optionally between the first and second stages.

[0100] Also, the various embodiments described above may be implemented in conjunction with other embodiments, e.g., aspects of one embodiment may be combined with aspects of another embodiment to realize yet other embodiments. Further, each independent feature or component of any given assembly may constitute an additional embodiment.

[0101] In the foregoing description of certain embodiments, specific terminology has been resorted to for the sake of clarity. However, the disclosure is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes other technical equivalents which operate in a similar manner to accomplish a similar technical purpose. Terms such as "left" and right", "front" and "rear", "above" and "below" and the like are used as words of convenience to provide reference points and are not to be construed as limiting terms.

[0102] In this specification, the word "comprising" is to be understood in its "open" sense, that is, in the sense of "including", and thus not limited to its "closed" sense, that is the sense of "consisting only of". A corresponding meaning is to be attributed to the corresponding words "comprise", "comprised" and "comprises" where they appear.

1. A method of cooling a boil off gas stream from a liquefied cargo in a floating transportation vessel, said liquefied cargo having a boiling point of greater than −110° C. at 1 atmosphere and selected from the group consisting of liquefied petroleum gas, liquefied petrochemical gas selected from propylene, and liquefied ammonia, said method comprising at least the steps of:

compressing a boil off gas stream from said liquefied cargo in three or more stages of compression comprising at least a first stage, a second stage and final stage to provide a compressed discharge stream, wherein intermediate compressed BOG streams are provided between consecutive stages of compression;

cooling the compressed discharge stream against a water stream to provide a cooled, fully condensed, compressed discharge stream;

heat exchanging an expanded, optionally further cooled, portion of the cooled, fully condensed, compressed discharge stream, with (i) one or more intermediate compressed BOG streams from consecutive stages selected from between the second and final stages of compression to provide one or more cooled intermediate compressed BOG streams and optionally (ii) one or more portions, optionally after further cooling, of the cooled compressed discharge stream; and

passing the one or more cooled intermediate compressed BOG streams to the next stage of compression.

2. The method of claim 1 comprising at least the steps of:

compressing the boil off gas stream in a first stage of compression to provide a first intermediate compressed BOG stream as an intermediate compressed BOG stream;

compressing the first intermediate compressed BOG stream, optionally after heat exchange to provide a cooled first intermediate compressed BOG stream, in a second stage of compression to provide a second intermediate compressed BOG stream as an intermediate compressed BOG stream.

3. The method of claim 1 further comprising the steps of:

splitting the cooled, fully condensed, compressed discharge stream into a continuing cooled compressed discharge stream and a cooled compressed discharge side stream;

expanding the cooled compressed discharge side stream to provide a expanded cooled discharge stream.

4. The method of claim 3 further comprising the step of:

heat exchanging the expanded cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the second and final stages of compression to provide a cooled intermediate compressed BOG stream.

5. The method of claim 3 comprising the further step of:

flashing the expanded cooled discharge stream to provide an overhead expanded cooled discharge stream;

heat exchanging the overhead expanded cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the second and final stages of compression to provide a cooled intermediate compressed BOG stream.

6. The method of claim 4 wherein the intermediate compressed BOG stream is a second intermediate compressed BOG stream and the cooled intermediate compressed BOG stream is a cooled second intermediate compressed BOG stream.

7. The method of claim 3 comprising the further step of:

heat exchanging the expanded cooled discharge stream with the continuing cooled compressed discharge stream to provide a further cooled compressed discharge stream.

8. The method of claim 7 comprising the further steps of:

splitting the further cooled compressed discharge stream into a continuing further cooled compressed discharge stream and a further cooled compressed discharge side stream;

expanding the further cooled compressed discharge side stream to provide an expanded further cooled discharge stream.

9. The method of claim 8 comprising the further step of:

heat exchanging the expanded further cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the first and final stages of compression to provide a cooled intermediate compressed stream.

10. The method of claim 8 comprising the further step of:

flashing the expanded further cooled discharge stream to provide an overhead expanded further cooled discharge stream;

heat exchanging the overhead expanded further cooled discharge stream with an intermediate compressed BOG stream from consecutive stages selected from between the first and final stages of compression to provide a cooled intermediate compressed BOG stream.

11. The method of claim 9 wherein the intermediate compressed BOG stream is a first intermediate compressed BOG stream and the cooled intermediate compressed BOG stream is a cooled first intermediate compressed BOG stream.

12. The method of claim 9 comprising the further step of:

heat exchanging the expanded further cooled discharge stream with the continuing further cooled compressed discharge stream to provide a cooled return stream.

13. The method of claim 12 further comprising the step of:

expanding the cooled return stream to provide an expanded cooled return stream.

14. The method according to claim **1**, wherein the liquefied cargo is LPG, such as LPG comprising at least 3.5 mol % ethane.

15. The method of claim **1** wherein the compressed discharge stream is cooled against a seawater stream to provide the cooled compressed discharge stream.

16. The method of claim **1** wherein the first stage, second stage and final stage of compression are stages of a multi-stage compressor.

17. An apparatus to cool a boil off gas stream from a liquefied cargo in a floating transportation vessel, said liquefied cargo having a boiling point of greater than −110° C. at 1 atmosphere and selected from the group consisting of liquefied petroleum gas, liquefied petrochemical gas selected from propylene, and liquefied ammonia, said apparatus comprising at least:

a compression system to compress a boil off gas stream from a liquefied cargo, said compression system comprising three or more stages of compression comprising at least a first stage, a second stage and final stage to provide a compressed discharge stream, wherein intermediate compressed BOG streams are provided between consecutive stages of compression,

a first heat exchanger to cool the compressed discharge stream against a water stream to provide a cooled, fully condensed, compressed discharge stream;

a first discharge stream pressure reduction device to expand an optionally further cooled, portion of the cooled, fully condensed, compressed discharge stream to provide an expanded, optionally further cooled portion of the cooled, fully condensed, compressed discharge stream,

one or more further heat exchangers to heat exchange an expanded, optionally further cooled, portion of the cooled, fully condensed, compressed discharge stream, with (i) one or more intermediate compressed BOG streams from consecutive stages selected from between the second and final stages of compression to provide one or more cooled intermediate compressed BOG streams to the next stage of compression and optionally (ii) one or more portions, optionally after further cooling, of the cooled compressed discharge stream.

18. An apparatus to cool a boil off gas stream from a liquefied cargo in a floating transportation vessel, said liquefied cargo having a boiling point of greater than −110° C. at 1 atmosphere and selected from the group consisting of liquefied petroleum gas, liquefied petrochemical gas selected from propylene, and liquefied ammonia, said apparatus comprising at least:

a compression system to compress a boil off gas stream from a liquefied cargo, said compression system comprising three or more stages of compression comprising at least a first stage, a second stage and final stage to provide a compressed discharge stream, wherein intermediate compressed BOG streams are provided between consecutive stages of compression;

a first heat exchanger to cool the compressed discharge stream against a water stream to provide a cooled, fully condensed, compressed discharge stream;

a first discharge stream pressure reduction device to expand an optionally further cooled, portion of the cooled, fully condensed, compressed discharge stream to provide an expanded, optionally further cooled portion of the cooled, fully condensed, compressed discharge stream;

one or more further heat exchangers to heat exchange an expanded, optionally further cooled, portion of the cooled, fully condensed, compressed discharge stream, with (i) one or more intermediate compressed BOG streams from consecutive stages selected from between the second and final stages of compression to provide one or more cooled intermediate compressed BOG streams to the next stage of compression and optionally (ii) one or more portions, optionally after further cooling, of the cooled compressed discharge stream; and

wherein the apparatus is operable using the method of claim **1**.

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