METHOD OF COOLING BOIL OFF GAS AND AN APPARATUS THEREFOR

Technical Field

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

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.

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.

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.

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.

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.

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

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.

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:

- 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 to provide a cooled compressed discharge stream;
- 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

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

In one embodiment, the method comprises 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.

In a further embodiment, the method further comprises the steps of:

- splitting the cooled 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 an expanded cooled discharge stream.

In another embodiment, the method further comprises 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.

In yet another embodiment, the method comprises 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.

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.

In another embodiment, the method comprises 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.

In a further embodiment, the method comprises 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.

In a still further embodiment, the method comprises 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.

In another embodiment, the method comprises 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.

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.

In a further embodiment, the method comprises 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.

In another embodiment, the method comprises the further step of:

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

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

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.

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

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:

- 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,

- a first heat exchanger to cool the compressed discharge stream to provide a cooled compressed discharge stream; and

- 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.

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

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

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.

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.

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.

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.

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.

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.

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

The accompanying drawings facilitate an understanding of the various embodiments.

Figure 1 shows a schematic diagram of one possible known system of reliquefying boil off gas from a cargo tank in an LPG carrier;

Figure 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

Figure 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

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).

Figure 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.

The boil off gas stream 01 can be passed to a compression system 60, such as the three stage compressor shown in Figure 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).

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.

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.

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.

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.

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.

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.

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

Figure 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.

The embodiment of Figure 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.

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.

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.

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 Figure 2, a discharge stream splitting device 110 divides the cooled compressed discharge stream 07 into a continuing cooled compressed discharge stream 07a 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 07a to provide a further cooled compressed discharge stream 108.

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 (Figure 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.

In a further embodiment not shown in Figure 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.

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 Figure 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 108a 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 108a 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 108a present in one or more second further heat exchanger tubes or coils 185 (a coil is shown in Figure 2) within the shell of the heat exchanger.

In an embodiment not shown in Figure 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.

In a similar manner to the scheme of Figure 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.

Returning to the first and second further heat exchangers 190 and 180, as well as cooling continuing compressed discharge stream 07a and continuing further cooled compressed discharge stream 108a, 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.

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.

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.

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.

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 Figure 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.

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 Figure 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 Figure 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.

In particular with regard to Figure 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'.

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.

The continuing cooled compressed discharge stream 07a 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 Figure 2.

Although not shown in Figure 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.

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

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 Figure 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. Figure 2 without a first further heat exchanger/ second intermediate stage economizer).

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.

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

Table 1

Stage no.	Suction		Discharge	
	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

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

Stage no.	Suction		Discharge	
	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

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.

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.

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

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.

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.

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.

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.

CLAIMS

1. A method of cooling a boil off gas stream (01) 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 (07a, 108a), 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).

2. The method of claim 1 comprising at least the steps of:
   - compressing the boil off gas stream (01) in a first stage (65) of compression to provide a first intermediate compressed BOG stream (02) as an intermediate compressed BOG stream;
   - compressing the first intermediate compressed BOG stream (02), optionally after heat exchange to provide a cooled first intermediate compressed BOG stream (03), in a second stage (70) of compression to provide a second

intermediate compressed BOG stream (04) as an intermediate compressed BOG stream.

3. The method of claim 1 or claim 2 further comprising the steps of:
- splitting the cooled compressed discharge stream (07) into a continuing cooled compressed discharge stream (07a) and a cooled compressed discharge side stream (09);
- expanding the cooled compressed discharge side stream (09) to provide a expanded cooled discharge stream (19).

4. The method of claim 3 further comprising the step of:
- heat exchanging the expanded cooled discharge stream (19) with an intermediate compressed BOG stream (04) from consecutive stages selected from between the second and final stages (70, 75) of compression to provide a cooled intermediate compressed BOG stream (05).

5. The method of claim 3 comprising the further step of:
- flashing the expanded cooled discharge stream (19) to provide an overhead expanded cooled discharge stream;
- heat exchanging the overhead expanded cooled discharge stream (21) with an intermediate compressed BOG stream (04) from consecutive stages selected from between the second and final stages (70, 75) of compression to provide a cooled intermediate compressed BOG stream (05).

6. The method of claim 4 or claim 5 wherein the intermediate compressed BOG stream (04) is a second intermediate compressed BOG stream and the cooled intermediate compressed BOG stream (05) is a cooled second intermediate compressed BOG stream.

7. The method of any one of claims 3 to 6 comprising the further step of:

- heat exchanging the expanded cooled discharge stream (19) with the continuing cooled compressed discharge stream (07a) to provide a further cooled compressed discharge stream (108).

8. The method of claim 7 comprising the further steps of:
- splitting the further cooled compressed discharge stream (108) into a continuing further cooled compressed discharge stream (108a) and a further cooled compressed discharge side stream (11);
- expanding the further cooled compressed discharge side stream (11) to provide an expanded further cooled discharge stream (21).

9. The method of claim 8 comprising the further step of:
- heat exchanging the expanded further cooled discharge stream (21) with an intermediate compressed BOG stream (02) from consecutive stages selected from between the first and final stages (65, 70, 75) of compression to provide a cooled intermediate compressed stream (03).

10. The method of claim 8 comprising the further step of:
- flashing the expanded further cooled discharge stream (21) to provide an overhead expanded further cooled discharge stream;
- heat exchanging the overhead expanded further cooled discharge stream with an intermediate compressed BOG stream (02) from consecutive stages selected from between the first and final stages (65, 70, 75) of compression to provide a cooled intermediate compressed BOG stream (03).

11. The method of claim 9 or claim 10 wherein the intermediate compressed BOG stream (02) is a first intermediate compressed BOG stream and the cooled intermediate compressed BOG stream (03) is a cooled first intermediate compressed BOG stream.

12. The method of any one of claims 9 to 11 comprising the further step of:

- heat exchanging the expanded further cooled discharge stream (21) with the continuing further cooled compressed discharge stream (108a) to provide a cooled return stream (08).

13. The method of claim 12 further comprising the step of:
- expanding the cooled return stream (08) to provide an expanded cooled return stream (10).

14. The method according to any of the preceding claims wherein the liquefied cargo is LPG, such as LPG comprising at least 3.5 mol% ethane.

15. The method of any of the preceding claims wherein the compressed discharge stream (06) is cooled against a water stream, such as a seawater stream, to provide the cooled compressed discharge stream (07).

16. The method of any of the preceding claims wherein the first stage (65), second stage (70) and final stage (75) of compression are stages of a multi-stage compressor (60).

17. An apparatus to cool a boil off gas stream (01) 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:
- a compression system (60) to compress a boil off gas stream (01) from a liquefied cargo, said compression system comprising 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,
- a first heat exchanger (200) to cool the compressed discharge stream (06) to provide a cooled compressed discharge stream (07);

- one or more further heat exchangers (190) to heat exchange 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) to the next stage of compression (75) and optionally (ii) one or more portions (07a, 108a), optionally after further cooling, of the cooled compressed discharge stream (07).

18. An apparatus according to claim 17 which is operable using the method of any one of claims 1 to 16.