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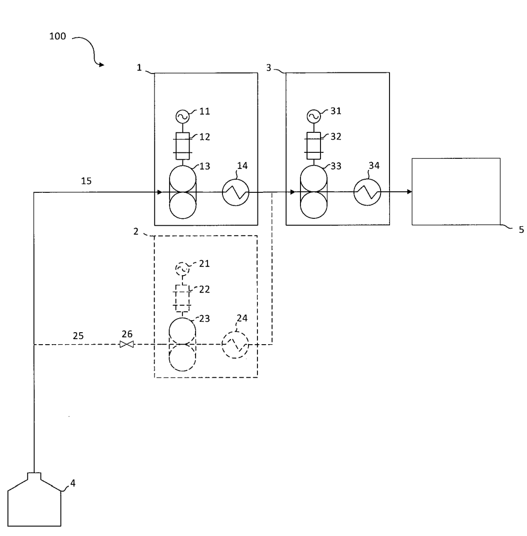
(54) **MODULAR COMPRESSION APPARATUS AND METHOD**

(57) The invention relates to a method for providing pressurized gas from a source of liquefied gas to a consumer, wherein vaporized gas is supplied via a first line from the source of liquefied gas to a compressor arrangement for pressurizing the vaporized gas, the compressor arrangement comprising a first screw compressor module and a second screw compressor module which are designed according to the redundancy concept each comprising an own screw compressor, an own motor for driving the screw compressor and further own equipment being necessary for driving the motor and the screw compressor, wherein the first screw compressor module, being arranged at the first line and being fed with vaporized gas via the first line, is arranged in parallel to the second screw compressor module, the second screw compressor module being arranged at a bypass-line, the bypass-line branching off the first line upstream of the second screw compressor module, wherein the compressor arrangement is operated such that in a first mode of operation the vaporized gas is fed through the first line to the first screw compressor module and through the bypass-line to the second screw compressor module and the first screw compressor module and the second compressor module are in operation, and in a second mode of operation, the bypass-line is closed with a valve at a position upstream of the second screw compressor module and the second screw compressor module is not in operation.

Figure 1



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Description

[0001] The present invention relates to a method for providing pressurized gas from a source of liquefied gas to a consumer. The invention also relates to a compressor arrangement for providing pressurized gas from a source of liquefied gas to a consumer and to a ship for transporting liquefied gas comprising a compressor arrangement according to the invention.

[0002] The invention is of particular relevance to the supply of fuel gas from a source of liquefied natural gas (LNG), especially in ocean-going tankers and is primarily described herein with the reference to this application. It is, however, to be understood that it is also applicable to other cryogenic liquids or liquid mixtures.

State of the Art

[0003] While natural gas is conveniently stored and transported in liquid state, it is generally used, however, in the gaseous state, e.g. for propulsion of the tanker. To this end, a flow of LNG can be vaporized and/or boil-off gas, i. e. evaporated LNG from the ullage space of the container can be used. Such vaporized gas is supplied from the source of liquefied gas through a main input line to a compressor for pressurizing the vaporized gas. Over the past decades, fuel gas supply to LNG carrier propulsion has namely being achieved using multi-stage compressors (stage number ranging from 2 to 6 stages), in which typically each stage is integrated in one single gearbox including several highspeed shafts. For example, 4-stage compressors have progressively replaced 2-stage compressors for DFDE (Dual Fuel Diesel Electric) 4-stroke propulsion, since 4-stage compressors are able to maintain the required fuel gas (FG) pressure (6 bara) even with warm boil off gas (BOG) at suction. Recently, 6-stage compressors have been developed to cope with 2-stroke dual fuel propulsion requirements for 17 Bara fuel gas pressure level (XDF). A 2-stage compressor is mainly used in laden voyage when BOG is cold (typically -90°C). However, when the BOG temperature warms-up (especially during ballast voyage), performance limitations are reached and it becomes difficult to maintain the required fuel gas pressure. 4-stage compressors can be used either in cold (laden) or in warm (ballast and heel-out) BOG conditions. Thus, different BOG conditions (laden, ballast or heel-out) and different consumers (2 or 4-stroke dual fuel engines) require different multi-stage compressors leading to a cumbersome and costly compressor arrangement.

[0004] Very often, a standard approach selected during ship design is to provide one fuel gas (FG) compressor (with a spare one) sized to supply gas to the consumers with the most constraining suction conditions. At fixed discharge pressure dictated by the FG consumer, the variability of suction conditions (pressure, temperature and composition) can lead to a FG compressor design, which is not optimized in all possible operating cases.

[0005] Typical temperature levels met at compressor suction are ranging from 40°C to -140°C (covering heel-out to laden operations) which has a great impact on fuel gas density. The compressor design features required to cope with this fuel gas density range often leads to a lower compressor efficiency at cold temperature. This is because, in cold suction conditions, the required head of the overall compressor is lower. The technical term "compressor head" basically corresponds to the pressure of the pressurized fluid, more specifically to the pressure divided by the product of fluid density and the gravitation constant. This corresponds to the height of a column of the fluid exerting said pressure on its bottom.

[0006] Typical FG compressor suction pressure levels met on LNG carriers are ranging from 1.03 to 1.7 Bara, which has even a greater impact on compressor performance than the suction temperature range. At fixed discharge pressure, the poorest performances are met at high suction pressure since it leads to a lower required head of the compressor. Often low temperature and high-pressure conditions at compressor suction are combined.

[0007] The typical composition of BOG is ranging from pure methane to a C1/N2 mixture containing up to 20 % mol N2. BOG from the tanks is usually found in the range of 40/-140°C. 40°C BOG is met when the tanks are operated with very few liquid (dead heel). -140°C is often met after tank loading when BOG flow is high. Intermediate temperature levels (-50/-80°C) can be found in ballast operations. The pressure ranges from 1.03 to 1.7 Bara. Typical LNG carriers have tank operating pressure levels ranging from 1.03 to 1.26 bara whereas vessels with reinforced tank containments have operating pressures reaching 1.6 bara or slightly above.

[0008] LP (Low Pressure) consumers usually require FG at around 6 Bara and 20/40°C. MP (Medium Pressure) consumers usually require FG at pressure levels of 15 and 40 Bara and 20/40°C. HP (High Pressure) consumers usually require FG at a pressure above 100 bar (up to 400 Bara) and a temperature range 40/20°C.

[0009] It is therefore an object of the present invention to provide an efficient method for providing pressurized gas from a source of liquefied gas to a consumer, especially providing the possibility of using vaporized gas of different temperature and/or pressure and/or mass flow levels and/or of varying composition and/or supplying different consumers requiring pressurized gas at different temperature and/or pressure levels, with pressurized gas, especially with fuel gas from an LNG source.

Summary of the present invention

[0010] The object is solved by a method for providing pressurized gas from a source of liquefied gas to a consumer according to claim 1, a compressor arrangement for providing pressurized gas from a source of liquefied gas to a consumer according to claim 7 and a LNG carrier comprising a compressor arrangement according to claim 14.

[0011] According to the present invention there is provided a method for providing pressurized gas from a source of liquefied gas to a consumer, wherein vaporized gas is supplied via a first line from the source of liquefied gas to a compressor arrangement for pressurizing the vaporized gas, the compressor arrangement comprising a first screw compressor module and a second screw compressor module which are designed according to the redundancy concept each comprising an own screw compressor and an own motor for driving the screw compressor, wherein the first screw compressor module, being arranged at the first line and being fed with vaporized gas via the first line, is arranged in parallel to the second screw compressor module, the second compressor module being arranged at a bypass-line, the bypass-line branching off the first line upstream of the second screw compressor module, wherein the compressor arrangement is operated such that in a first mode of operation the vaporized gas is fed through the first line to the first screw compressor module and through the bypass-line to the second screw compressor module and the first screw compressor module and the second screw compressor module are in operation, and in a second mode of operation, the bypass-line is closed with a valve at a position upstream of the second screw compressor module and the second screw compressor module is not in operation.

[0012] The terms first and second do not indicate the arrangement with regards to the flow of compressed gas but are merely used for clarity of enumeration.

[0013] The redundancy concept means that each screw compressor module design includes its own screw compressor and all own equipments, like valves, electrical motor for driving the compressor and instruments as an independent screw compressor system. As the screw compressor within each screw compressor module is driven by its own electrical motor, each screw compressor can then be separately driven from the screw compressor of another screw compressor module. Therefore each screw compressor module is able to be independently operated from any other screw compressor module of the compressor arrangement, which is particularly advantageous if one of the compressor modules must be stopped for example for maintenance because the other compressor module can still be operated and purveying compressed gas to the consumer.

The second compressor module can also be deactivated and bypassed when not needed. With such a compressor train modularization, it is not necessary to run all the screw compressors modules when only a part of them is required. As an example, the first screw compressor module could be operated only in cold suction conditions whereas the additional screw second compressor module could be started in case of warm suction conditions in order to maintain the required fuel gas pressure. This is an improvement in terms of power consumption of the compressor arrangement.

[0014] To keep the efficiency of the compressor arrangement near the optimum point of best efficiency, the motor driving the screw compressor of at least one of the screw compressor modules is an electrical motor whose speed of rotation can be adjusted, when the screw compressor module is in operation, with a variable frequency drive depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer, hence adjusting the speed of rotation of the screw compressor of at least one of the screw compressor modules to the gas conditions. As at least one of the screw compressors is driven by a variable speed electrical motor, the speed of rotation of at least one of the screw compressor can be permanently adjusted to the conditions of the gas to be compressed, without wasting energy in recycling gas around the compressor.

[0015] In a preferred embodiment, a third screw compressor module is connected in series downstream the first and/or the second screw compressor module.

The terms "upstream" and "downstream" means about the direction of flow of the compressed gas through the compressor arrangement.

[0016] In another preferred embodiment, the speed of rotation of the electrical motor driving the screw compressor of the third screw compressor module is adjusted with a variable frequency drive, depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer.

[0017] In a further embodiment, boil-off gas from the ullage space of the container/source of liquefied gas where the stored liquefied gas changes its stage from liquid to vapor can be used as the vaporized gas.

[0018] Additionally, the gas compressed by one of the screw compressor modules can be cooled by conducting the gas through a cooling unit arranged at an outlet of at least one screw compressor, i.e. downstream of the at least one screw compressor.

[0019] The proposed approach according to the present invention is to provide a modular compressor train philosophy with a limited footprint. Compressor efficiency is maintained over the whole range of suction conditions. Optimization of gas compressor efficiency is achieved by selecting the numbers of screw compressor modules put in operation according to the required load (mass flow), pressure level head and/or temperature of the gas that is provided to the consumer. The possibility of bypassing one or more of the screw compressor modules of the compressor arrangement allows for a flexible operation depending on the suction conditions to reach the required gas pressure level. At the same time, it is possible to deactivate compressor modules that are presently not needed. Furthermore, the compressor arrangement according to the present invention allows for spare screw compressor modules what be used as redundancy is case one of the screw compressors modules had to be stopped, for example for maintenance.

[0020] According to a second aspect, the present invention relates to a compressor arrangement for providing pressurized gas from a source of liquefied gas to a consumer, wherein vaporized gas is supplied from the source of liquefied gas to a compressor arrangement for pressurizing the vaporized gas, the compressor arrangement comprising a first screw compressor module and a second screw compressor module which are designed according to the redundancy concept each comprising an own screw compressor and an own motor for driving the screw compressor, wherein the first screw compressor module, being arranged at the first line and being fed with vaporized gas via the first line, is arranged in parallel to the second screw compressor module, the second screw compressor module being arranged at a bypass-line, the bypass-line branching off the first line upstream of the second screw compressor module, wherein the compressor arrangement is operable such that in a first mode of operation the vaporized gas is fed through the first line to the first screw compressor module and through the bypass-line to the second screw compressor module and the first screw compressor module and the second screw compressor module are in operation, and in a second mode of operation, the bypass-line is closed with a valve at a position upstream of the second screw compressor module and the second screw compressor module is not in operation..

[0021] Additionally, at least one of the screw compressor modules comprises a variable frequency drive for adjusting the speed of rotation of the electrical motor driving the screw compressor when the screw compressor module is in operation, depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer.

[0022] In a preferred embodiment, the compressor arrangement comprises a third screw compressor module connected in series downstream the first and/or the second screw compressor module.

[0023] To adjust the capacity of the third compressor module to the operation of the upstream first and / or second compressor module, the third compressor module can comprise a variable frequency drive for adjusting the speed of rotation of the electrical motor driving the screw compressor of the third screw compressor module, depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer.

[0024] To simplify maintenance, it is also possible that all screw compressor modules use screw compressors having identical actual inlet volume flows.

To reduce spare parts inventory, it is also possible to uses identical electrical motors of identical power rating

[0025] Additionally, at least one of the screw compressor modules comprises a cooling unit at an outlet downstream the screw compressor for cooling the compressed gas. Preferably, all the screw compressor modules have identical motors of identical power.

[0026] Optionally, at least one of the screw compressor modules comprises a cooling unit downstream the screw compressor for cooling the compressed gas, thus removing the heat of compression of the compression stage and thus further improving the efficiency of the compression arrangement.

[0027] A third aspect for which protection is sought, but which also represents an embodiment of the present invention according to the first and second aspects, is directed to ship for transporting liquefied gas comprising a compressor arrangement according to the invention.

[0028] Regarding further explanations as to the advantages of the compressor arrangement and its embodiments, reference is explicitly made to the statements in connection with the method according to the present invention above.

[0029] Further advantages and preferred embodiments of the invention are disclosed in the following description and figures.

[0030] It is understood by a person skilled in the art that the preceding and the following features are not only disclosed in the detailed combinations as discussed or showed in a figure, but that also other combinations of the features can be used without exceeding the scope of the present invention.

[0031] The invention will now be further described with reference to the accompanying drawings showing preferred embodiments.

Brief description of the drawings

[0032]

Fig. 1 schematically shows a first embodiment of a compressor arrangement for implementing the method according to the present invention

Fig. 2 schematically shows a second embodiment of a compressor arrangement for implementing the method according to the present invention

Detailed description of the drawings

[0033] In the following, the different embodiments according to the Figures are discussed comprehensively, same reference signs indicating same or essentially same units. It is appreciated that a person skilled in the art may combine certain components like one or more compressor modules, a cooling unit, of an embodiment shown in a figure with the features of the present invention as defined in the appended claims without the need to include more than this certain component or even all other components of this embodiment shown in said figure. In other words, the following figures show different preferable aspects of the present invention, which can be combined to other embodiments. The embodiments shown in the figures all relate to the application of supplying fuel gas from an LNG source, but it is appreciated that a person skilled in the art can easily transfer the embodiments to applications involving other cryogenic gases or gas mixtures.

[0034] Figure 1 shows embodiment of a compressor arrangement 100, which receives gas from a storage tank of liquefied gas 4 through a first line 15 fluidically connecting the ullage space of the storage tank 4 and the screw compressor arrangement, and compress the gas to the pressure required by the gas consumer 5

The compressor arrangement 100 comprise two parallel trains, each train comprising one screw compressor module, i. e. the two screw compressor modules 1, 2 are arranged in parallel.

The screw compressor module 2 is receiving from the storage tank 4 through a bypass-line 25, the bypass-line 25 branching off the first line 15 upstream of the second compressor module 2, the bypass line 25 fluidically connecting the second compressor module 2 with the ullage space of the storage tank 4. A valve 26 is placed upstream of the second compressor module 2 on the bypass line 25.

Each screw compressor module 1 and 2 comprises a screw compressor 13, 23, an electrical motor 12, 22 to drive the screw compressor, and all other equipments like valves and instruments of an independent screw compressor module. An independent screw compressor module is meant to designate a screw compressor module that be operated independently because the screw compressor of each screw compressor module is driven by its own electrical motor, without sharing any common equipments with another screw compressor module.

When the vaporized gas from the source is at cold temperature and rather high pressure, the density of the gas to be compressed is high and the resulting actual inlet volume flow at the suction of the compressors is too low for simultaneously operating the two parallel screw compressor modules 1, 2 at their best efficiency point.

Thus, only the screw compressor module 1 of the two parallel screw compressor modules 1, 2 is in operation for compressing gas, the other screw compressor module 2 in dashed lines being deactivated and not compressing gas. In addition, the valve 26 disposed on the bypass line 25 is in closed position, thus isolating the second compressor module 2 from the storage tank 4.

In some BOG conditions, however, one single compressor module may struggle to maintain the required fuel gas pressure.

To maintain this required fuel gas pressure, a third screw compressor module 3 located downstream of the first screw compressor module is operated to increase the number of compression used for fuel gas compression, thus increasing the outlet pressure of the compressor arrangement 100.

The third screw compressor module 3 also comprises a screw compressor 33, driven by an electrical motor 32 and is located downstream the two parallel screw compressor modules 1, 2.

As only the screw compressor module 1 is operated, the screw compressor module 3 is only fed with gas compressed by the screw compressor module 1, the screw compressor module 3 being in series with the screw compressor module 1.

To better adjust the speed of rotation of the screw compressor 33 within the screw compressor module 3 to the variable suction conditions of the first screw compressor module 1, the speed of the electrical motor 32 is changed by mean of a variable frequency drive 31. When the speed of the electrical motor 32 is changed according to the suction conditions by the variable frequency drive 31, the speed of rotation of the compressor 33 is also changed as the screw compressor is directly driven by the electrical motor.

[0035] The efficiency of the compressor arrangement 100 can be increased by also adjusting the speed of rotation of the electrical motor 12 driving the first screw compressor 13 with a variable frequency drive 11.

[0036] This allows reaching the best efficiency point for each compressor stage with regards to the variable suction conditions at the inlet of the compressor arrangement 100. Thanks to VFD and the downstream screw compressor module, the compression system can quickly and efficiently adapt to the new suction conditions equivalent to the first compressor module discharge (typically medium pressure level, 40°C) to efficiently provide fuel gas to the consumer 5 at the required pressure.

[0037] Optionally, a cooler 14, 24, 34 can be placed downstream each screw compressor module to remove the heat of compression of the compression stage and thus further improving the efficiency of the compression arrangement 100.

[0038] Figure 2 shows another embodiment, which is essentially based on the embodiment of Figure 1.

In this embodiment, when higher mass flow of vaporized gas must be compressed, for example when higher boil-off gas is generated inside the storage tank 4 during loading or because of rough see conditions, two parallel screw compressor modules 1, 2 are operated simultaneously, each being fed in vaporized gas from tank 1. In that case, the valve 26 placed upstream the second compressor module 2 on the bypass line 25 is in an open position, and gas to be compressed is supplied to the second screw compressor module 2 through the bypass line 25. The use of two identical screw compressor modules instead of a single one as in the first embodiment of figure 1 allows for the compression of the higher flow of gas from the storage tank.

Similarly, to the first embodiment, a third screw compressor module 3 downstream the two identical screw compressor modules 1 and 2 is operated to reach higher pressures.

Because the third screw compressor module 3 located downstream the two parallel screw compressor modules 1, 2 is equipped with a variable frequency drive 31, the speed of rotation of the screw compressor 33 located within the third screw compressor module 3 can be increased enough to cope with the additional flow of gas compressed by the two compressors modules 1, 2 located upstream.

In that second embodiment, the second screw compressor module 2 can also be arranged with its own variable frequency drive 31 to adjust the speed of rotation of the second motor 22 to get the best efficiency of the second screw compressor 23.

List of reference signs

[0039]

1	(first) compressor module
2	(second) compressor module
3	(third) compressor module
4	Tank, source of liquefied gas
5	Gas consumer
11, 21, 31	Variable frequency drive
12, 22, 32	Motor
13, 23, 33	Screw compressor
14, 24, 34	Cooler
15	First Line
25	Second line
26	Valve
100	Compressor arrangement

Claims

1. A method for providing pressurized gas from a source of liquefied gas (4) to a consumer (5), wherein vaporized gas is supplied via a first line (15) from the source of liquefied gas (4) to a compressor arrangement (100) for pressurizing the vaporized gas, the compressor arrangement (100) comprising a first screw compressor module (1) and a second screw compressor module (2) which are designed according to the redundancy concept, each screw compressor module (1, 2) comprising an own screw compressor (13, 23) and an own motor (12, 22) for driving the screw compressor (13, 23), wherein the first screw compressor module (1), being arranged at the first line (15) and being fed with vaporized gas via the first line (15), is arranged in parallel to the second screw compressor module (2), the second screw compressor module (2) being arranged at a bypass-line (25), the bypass-line (25) branching off the first line (15) upstream of the second screw compressor module (2), wherein the compressor arrangement (100) is operated such that in a first mode of operation the vaporized gas is fed through the first line (15) to the first screw compressor module (1) and through the bypass-line (25) to the second screw compressor module (2) and the first screw compressor module (1) and the second screw compressor module (2) are in operation, and in a second mode of operation, the bypass-line (25) is closed with a valve (26) at a position upstream of the second screw compressor module (2) and the second screw compressor module (2) is not in operation.

2. The method of claim 1, wherein the speed of rotation of the electrical motor (12, 22) driving the screw compressor (13, 23) of at least one of the screw compressor modules (1, 2) is adjusted with a variable frequency drive (11, 21) when the screw compressor module (1, 2) is in operation, depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer (5).

3. The method of claim 1 or claim 2, wherein a third compressor module (3) is connected in series downstream the first and/or the second screw compressor module (1, 2).

4. The method of claim 3, wherein the speed of rotation of an electrical motor (32) driving a screw compressor (33) of the third screw compressor module (3) is adjusted with a variable frequency drive (31), depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer (5).

5. The method of any one of the preceding claims, wherein boil-off gas from the source of liquefied gas (4) is used as the vaporized gas.

6. The method of any one of the preceding claims, wherein gas is cooled by conducting the gas through a cooling unit (14, 24, 34) arranged downstream of at least one screw compressor (13, 23, 33).

7. A compressor arrangement (100) for providing pressurized gas from a source of liquefied gas (4) to a consumer (5), wherein vaporized gas is supplied via a first line (15) from the source of liquefied gas (4) to the compressor arrangement (100) for pressurizing the vaporized gas, the compressor arrangement (100) comprising a first screw compressor module (1) and a second screw compressor module (2) which are designed according to the redundancy concept, each screw compressor module (1, 2) comprising an own screw compressor (13, 23) and an own motor (12, 22) for driving the screw compressor (13, 23), wherein the first screw compressor module (1), being arranged at the first line (15) and being fed with vaporized gas via the first line (15), is arranged in parallel to the second screw compressor module (2), the second screw compressor module (2) being arranged at a bypass-line (25), the bypass-line (25) branching off the first line (15) upstream of the second screw compressor module (2), wherein the compressor arrangement (100) is operable such that in a first mode of operation the vaporized gas is fed through the first line (15) to the first screw compressor module (1) and through the bypass-line (25) to the second screw compressor module (2) and the first screw compressor module (1) and the second screw compressor module (2) are in operation, and in a second mode of operation, the bypass-line (25) is closed with a valve (26) at a position upstream of the second screw compressor module (2) and the second screw compressor module (2) is not in operation.

8. A compressor arrangement according to claim 7, wherein at least one of the screw compressor modules (1, 2) comprises a variable frequency drive (11, 21) for adjusting the speed of rotation of the electrical motor (12, 22) driving the screw compressor (13, 23) when the screw compressor module (1, 2) is in operation, depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer (5).

9. The compressor arrangement according to claim 7 or 8, wherein the compressor arrangement (100) comprises a third compressor module (3) connected in series downstream the first and/or the second screw compressor module (1, 2).

10. The compressor arrangement of according to claim 9, further comprising a variable frequency drive (31) for adjusting the speed of rotation of an electrical motor (32) driving a screw compressor (33) of the third screw compressor module (3), depending on at least one of pressure level, temperature level, mass flow and composition of the gas to be provided to the consumer (5).

11. The compressor arrangement according to any of claims 7 to 10, wherein all the screw compressors (13, 23, 33) of the screw compressor modules (1, 2, 3) have identical actual inlet volume flows.

12. The compressor arrangement according to any of claims 7 to 11, wherein all the screw compressor modules (1, 2, 3) have identical electrical motors (12, 22, 32) of identical power rating.

13. The compressor arrangement according to any of claims 7 to 12, wherein at least one of the screw compressor modules (1, 2, 3) comprises a cooling unit (14, 24, 34) downstream the screw compressor (13, 23, 33) for cooling the compressed gas.

14. Ship for transporting liquefied comprising a compressor arrangement according to any of claims 7 to 13.

15. Ship for transporting liquefied gas according to claim 14, wherein the liquefied gas is transported at cryogenic temperatures.

Figure 1

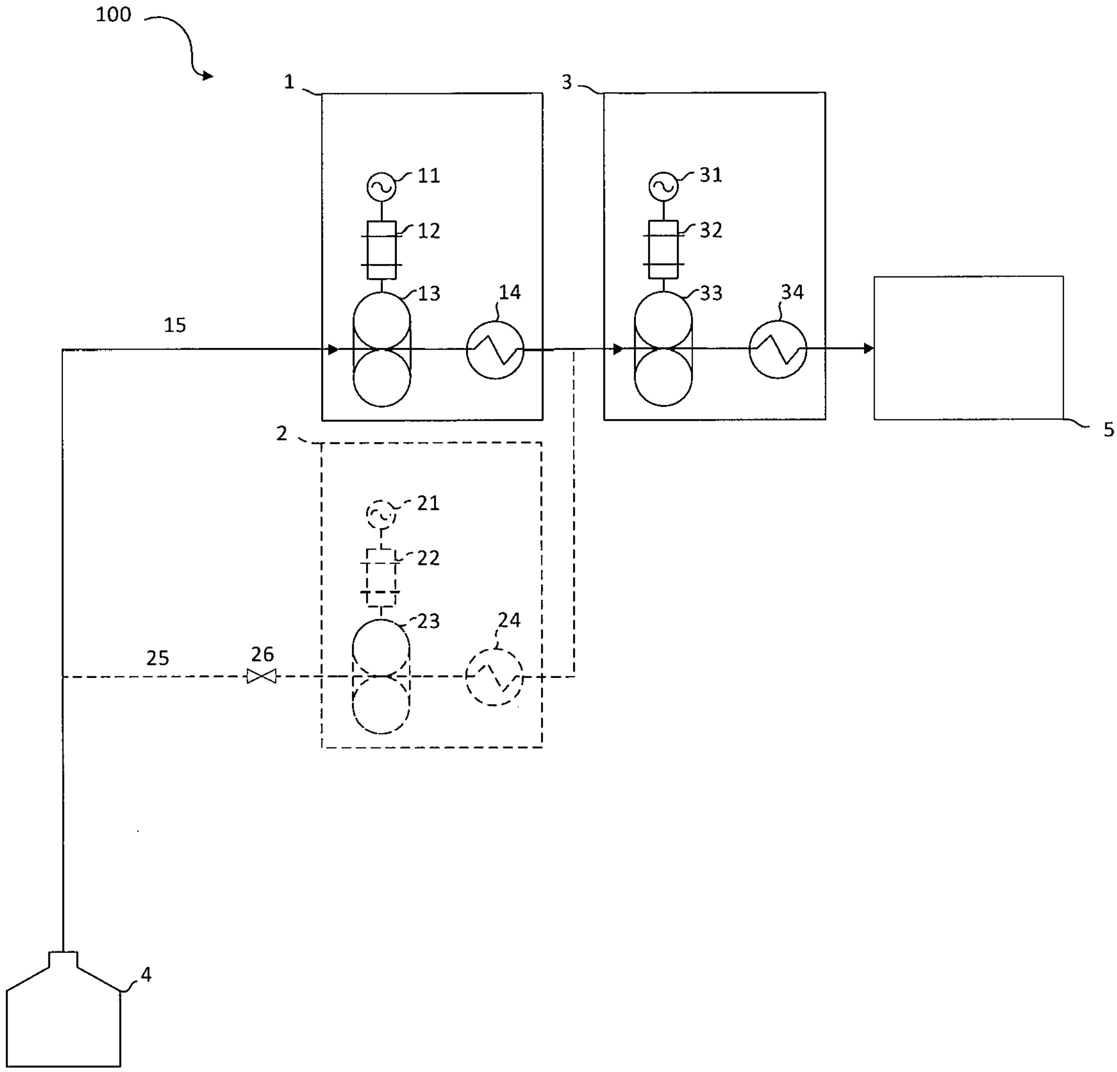
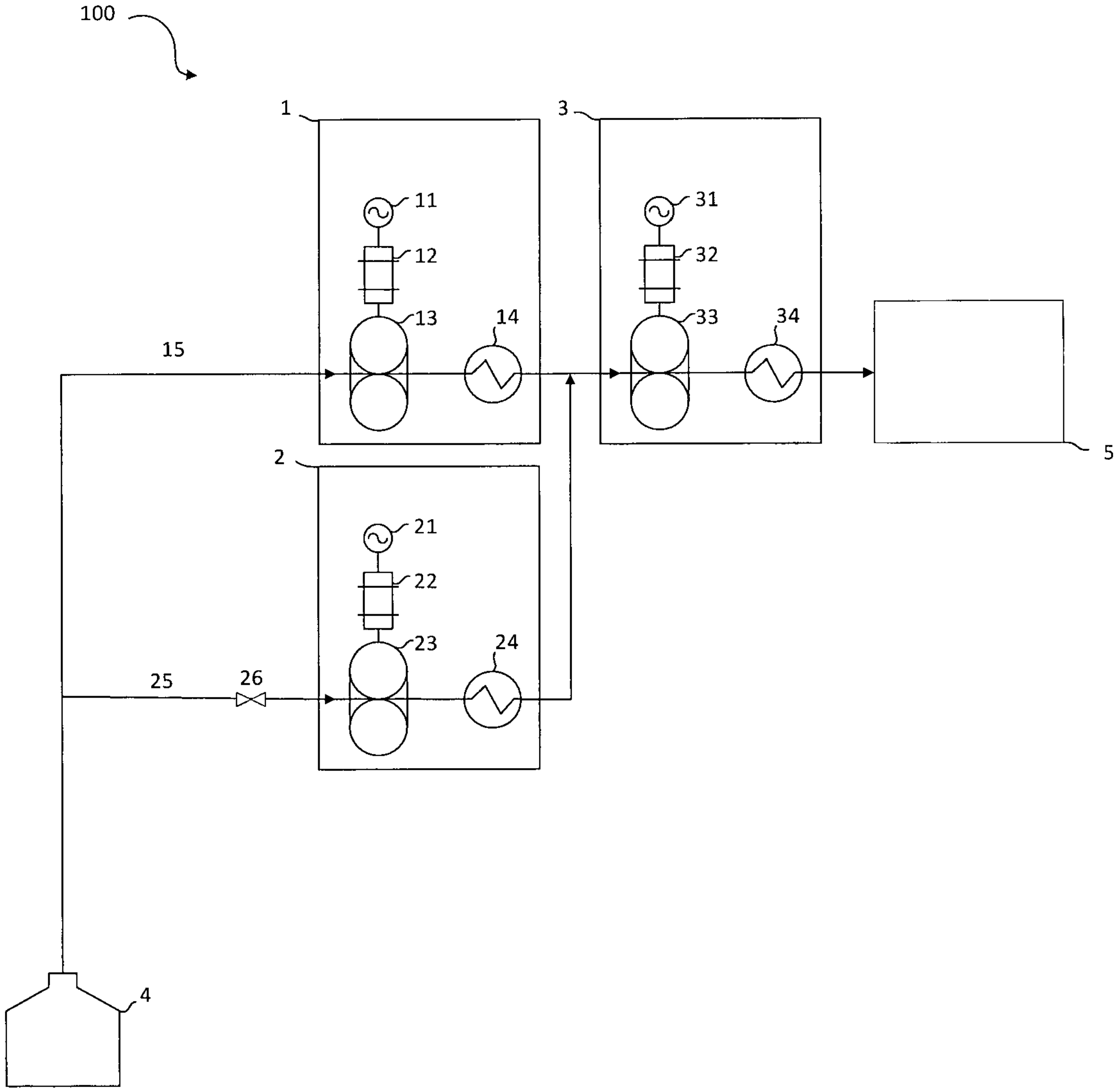


Figure 2



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EUROPEAN SEARCH REPORT

Application Number
EP 21 31 5012

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			F17C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	13 July 2021	Ott, Thomas

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