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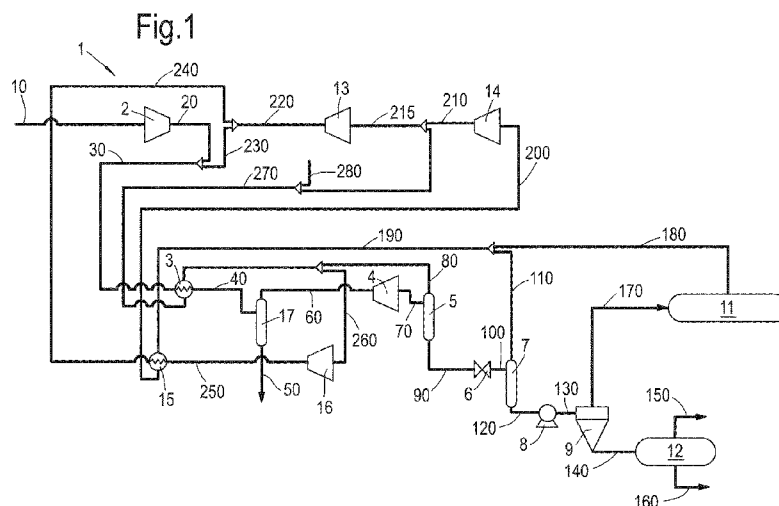
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(54) Title: METHOD OF LIQUEFYING A CONTAMINATED HYDROCARBON-CONTAINING GAS STREAM



(57) Abstract: The present invention provides a method for liquefying a hydrocarbon-containing gas stream, comprising cooling the hydrocarbon-containing gas stream (20) in a first heat exchanger (3), wherein the pressure of the cooled hydrocarbon-containing stream (40) is below the cricondenbar being a liquid-vapour multiphase flow and is separated in a liquid bottom stream (50) and a gaseous top stream (60). The gaseous top stream (60) is cooled in an expander (4) and separated in a separator (5) obtaining a gaseous stream (80) and a liquid stream (90). The liquid stream (90) is passed to a pressure reduction and separation stage (91) to obtain one or more further gaseous streams (110, 180) and a liquid hydrocarbon stream (170). The gaseous stream (80) is passed through the first heat exchanger (3) and a compressor obtaining a compressed gas stream (220). At least part of the compressed gas stream (220) obtained in step (h) is combined with the hydrocarbon-containing gas stream (20) provided in step (a). The liquid bottom stream (50) enriched in C3+-hydrocarbons is passed to a NGL-fractionation stage to obtain one or more gaseous streams enriched in C1 and/or C2 which are recycled to at least partially be combined with the hydrocarbon-containing gas stream (20).



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METHOD OF LIQUEFYING A CONTAMINATED HYDROCARBON-
CONTAINING GAS STREAM

The present invention relates to a method of liquefying a hydrocarbon-containing gas stream, in particular a methane-containing gas stream such as natural gas.

Methods of liquefying hydrocarbon-containing gas streams are well known in the art. It is desirable to liquefy a hydrocarbon-containing gas stream such as natural gas stream for a number of reasons. As an example, natural gas can be stored and transported over long distances more readily as a liquid than in gaseous form, because it occupies a smaller volume and does not need to be stored at high pressures. Typically, before being liquefied, the contaminated hydrocarbon-containing gas stream is treated to remove one or more contaminants such as H₂O, CO₂, H₂S and the like) which may freeze out during the liquefaction process.

W02014/166925 describes a method of liquefying a contaminated hydrocarbon-containing gas stream, a process scheme of which is schematically depicted in Fig. 1. The method comprising at least the steps of:

(1) providing a contaminated hydrocarbon-containing gas stream 20;

(2) cooling the contaminated hydrocarbon-containing gas stream in a first heat exchanger 3 thereby obtaining a cooled contaminated hydrocarbon-containing stream 40;

(3) cooling the cooled contaminated hydrocarbon-containing stream 40 in an expander 4 thereby obtaining a partially liquefied stream 70;

(4) separating the partially liquefied stream 70 in a separator 5 thereby obtaining a gaseous stream 80 and a liquid stream 90;

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(5) expanding the liquid steam 90 obtained in step (4) thereby obtaining a multiphase stream 100, the multiphase stream 100 containing at least a vapour phase, a liquid phase and a solid phase;

5 (6) separating the multiphase stream in a separator 7 thereby obtaining a gaseous stream 110 and a slurry stream 120 (comprising solid CO₂ and liquid hydrocarbons);

(7) separating the slurry stream 120 in a solid/liquid separator 9 thereby obtaining a liquid hydrocarbon stream 170
10 and a concentrated slurry stream 140;

(8) passing the gaseous stream 80 obtained in step (4) through the first heat exchanger 3 thereby obtaining a heated gaseous stream 200; and

(9) compressing the heated gaseous stream 200 thereby
15 obtaining a compressed gas stream 210; and

(10) combining the compressed gas stream 210 obtained in step (9) with the contaminated hydrocarbon-containing gas stream 20 provided in step (1).

W02014/166925 further describes and shows an optional
20 methanol separator 17'. The cooled contaminated hydrocarbon-containing stream 40 obtained in step (2) may be passed to the methanol separator 17' to separate methanol (as stream 50') that has been previously injected (e.g. into stream 20) to prevent hydrate formation.

25 The further elements of Fig. 1 will be discussed in more detail below with reference to Fig.'s 2 - 5.

An advantage of the method according to W02014/166925 is that it has a surprisingly simple design and can be standardized to treat and liquefy a wide range of feed gas
30 compositions. Further, there is relatively limited utility and chemicals requirement resulting in a significant OPEX and CAPEX reduction. Furthermore, the design is more robust with

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respect to trace contaminants such as rust and oil particles, compared to designs with amine treating systems.

As the method according to W02014/166925 does not require connection to the grid (as the gaseous stream obtained in
5 step (4) is combined with the contaminated hydrocarbon-containing stream provided in step (1)), the application of the method is very flexible. The method is in particular suitable for small scale operations (e.g. LNG production rate of about 0.1 mtpa), but may also be applied at scale up to 4
10 mtpa.

An important aspect of W02014/166925 is that the liquid hydrocarbon product stream obtained in step (5) may have a different composition, e.g. containing more CO₂ (such as at least 250 ppm-mol) and more C₅+ (such as above 0.1 mol%) than
15 usual.

In step (2) of W02014/166925, the contaminated hydrocarbon-containing gas stream is cooled in a first heat exchanger thereby obtaining a cooled contaminated hydrocarbon-containing stream. The heat exchanger is not
20 particularly limited, but is preferably an indirect heat exchanger. Preferably, in step (2) no solids are formed; hence, the cooled contaminated hydrocarbon-containing gas stream (40) is preferably free of solids. Typically, the cooled contaminated hydrocarbon-containing gas stream is a
25 gas stream possibly containing some liquid methanol, if previously injected.

According to W02014/166925 the cooled contaminated hydrocarbon-containing stream obtained in step (2) has a temperature of at most -40°C, preferably at most -50°C, more
30 preferably at most -60°C.

The process scheme according to W02014/166925 is operated such that the precooling in the first heat exchanger is performed at a pressure that is higher than

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the cricondenbar. The cricondenbar is the maximum pressure at which vapour and liquid phase can coexist. At higher pressures than the cricondenbar pressure, dense phase conditions occur.

5 This has the advantage that the precooling in the first heat exchanger operates with a single phase flow.

 However, this has the drawback that all C3+-hydrocarbons (i.e. hydrocarbons containing 3 or more carbon atoms per molecule) end up in the LNG product stream thereby possibly
10 leading to a (too) high Gross Heating Value (GHV) of the LNG product. This makes the process according to WO2014166925 unsuitable for processing relatively rich hydrocarbon-containing gas streams as this would result in off-spec LNG. The process according to WO2014166925 does not allow
15 controlling the composition of the LNG, hence its gross heating value.

 So, it is an object to provide a method and system for liquefying a hydrocarbon-containing gas stream, in particular of the type described in WO2014166925, that is better
20 suitable for treating rich hydrocarbon-containing gas streams comprising more C3+-hydrocarbons than are allowed in the LNG.

 According to an aspect there is provided a method of liquefying a hydrocarbon-containing gas stream, the method comprising at least the steps of:

25 **(a)** providing a hydrocarbon-containing gas stream (20), the hydrocarbon-containing gas stream comprising a mixture of hydrocarbons including C1, C2 and C3+- hydrocarbons;

(b) cooling the hydrocarbon-containing gas stream (20) in a first heat exchanger (3) thereby obtaining a
30 cooled hydrocarbon-containing stream (40), wherein the pressure of the cooled hydrocarbon-containing stream (40) is below the cricondenbar pressure of the mixture of

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hydrocarbons and contaminants, the cooled hydrocarbon-containing stream (40) being a liquid-vapour multiphase flow;

(c) separating the cooled hydrocarbon-containing stream
5 (40) in a liquid bottom stream (50) and a gaseous top stream (60), the liquid bottom stream (50) being enriched in C3+-hydrocarbons;

(d) cooling the gaseous top stream (60) in an expander (4) thereby obtaining a partially liquefied stream (70);

10 (e) separating the partially liquefied stream (70) in a separator (5) thereby obtaining a gaseous stream (80) and a liquid stream (90);

(f) passing the liquid stream (90) obtained in step (e) to a pressure reduction and separation stage (91) to
15 obtain one or more further gaseous streams (110, 180) and a liquid hydrocarbon stream (170),

(g) passing the gaseous stream (80) obtained in step (e) through the first heat exchanger (3) thereby obtaining a heated gaseous stream (270);

20 (h) compressing the heated gaseous stream (270) thereby obtaining a compressed gas stream (220); and

(i) combining at least part of the compressed gas stream (220) obtained in step (h) with the hydrocarbon-containing gas stream (20) provided in step (a);

25 wherein the method further comprises:

(j) passing the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained in step (c) to a NGL-fractionation stage to obtain a liquid product stream enriched in C3+ and one or more gaseous streams enriched in
30 C1 and/or C2;

(k) compressing the one or more gaseous streams enriched in C1 and/or C2 thereby obtaining one or more compressed gaseous stream enriched in C1 and/or C2;

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(1) recycling the one or more compressed gaseous streams enriched in C1 and/or C2 by adding at least part of the one or more compressed gaseous streams enriched in C1 and/or C2 to the hydrocarbon-containing gas stream (20) provided in
5 step (a).

According to a further aspect there is provided a system for liquefying a hydrocarbon-containing gas stream, the system comprising:

- a feed conduit (20) for providing a hydrocarbon-containing gas stream, the hydrocarbon-containing gas stream comprising a mixture of hydrocarbons including C1, C2 and C3+- hydrocarbons;
- 10 - a first heat-exchanger (3) arranged to receive the hydrocarbon containing gas stream from the feed conduit (20) and which is further arranged to cool the hydrocarbon-containing gas stream (20) and discharge a cooled hydrocarbon-containing stream (40), wherein the pressure of
15 the cooled hydrocarbon-containing stream (40) is below the cricondenbar pressure of the mixture of hydrocarbons and contaminants, the cooled hydrocarbon-containing stream (40) being a liquid-vapour multiphase flow;
- a gas-liquid separator (17) arranged to receive the
20 cooled hydrocarbon-containing stream (40) from the first heat exchanger (3) being arranged to separate the cooled hydrocarbon-containing stream (40) in a liquid bottom stream (50) and a gaseous top stream (60), the liquid bottom stream (50) being enriched in C3+-hydrocarbons;
- 25 - an expander (4) arranged to receive the gaseous top stream (60) and expand and thereby cool the gaseous top stream (60) thereby obtaining a partially liquefied stream (70);
- a separator (5) arranged to receive the partially
30 liquefied stream (70) and separate the partially liquefied

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stream (70) thereby obtaining a gaseous stream (80) and a liquid stream (90);

- a pressure reduction and separation stage (91) arranged to receive the liquid stream (90) from the separator (5) further being arranged to obtain one or more further gaseous streams (110, 180) and a liquid hydrocarbon stream (170) from the liquid stream (90),

- conduit (80) to pass the gaseous stream (80) obtained from the separator (5) to the first heat exchanger (3) and a conduit (270) to obtain a heated gaseous stream (270) from the first heat exchanger (3); and

- one or more compressors (13, 14) arranged to receive the heated gaseous stream (270) to obtain a compressed gas stream (220); and

- a combiner arranged to combine at least part of the compressed gas stream (220) with the hydrocarbon-containing gas stream (20);

wherein the system further comprises:

- a NGL-fractionation stage arranged to receive the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained from the gas-liquid separator (17), the NGL-fractionation stage being arranged to obtain a liquid product stream enriched in C3+ and one or more gaseous streams enriched in C1 and/or C2 from the liquid bottom stream (50) being enriched in C3+-hydrocarbons;

- one or more recycle conduits (330, 331) arranged to recycle the one or more gaseous streams enriched in C1 and/or C2 to the one or more compressors (13, 14).

This way the one or more gaseous streams enriched in C1 and/or C2 are at least partially recycled by at least partially adding the one or more gaseous streams enriched in C1 and/or C2 to the hydrocarbon-containing gas stream provided via feed conduit (20).

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Hereinafter the invention will be further illustrated by the following non-limiting drawing:

Fig.'s 2 - 5 schematically show process schemes
5 according to different embodiments,

Fig. 6 schematically shows a phase-diagram of a typical mixture of hydrocarbons.

For the purpose of this description, same reference numbers refer to same or similar components. Furthermore, a
10 single reference number will be used to identify a conduit or line as well as the stream conveyed by that line. The embodiments described here disclose a method and system for liquefying a hydrocarbon-containing gas stream, in particular a methane-containing gas stream such as natural gas.

15 The method and system, as will be explained in more detail further below, cool and liquefy a hydrocarbon-containing gas stream by expansion-cooling and self-refrigeration. Preferably, no use is made of refrigerant cycles. The now proposed method and scheme allow separating
20 the majority of the C3+-hydrocarbons from the hydrocarbon-containing gas stream within such a scheme.

Different embodiments are shown in and will be described in detail below with reference to Figures 2 - 5. These Figures show systems and process schemes for performing a
25 method of liquefying a hydrocarbon-containing gas stream. The system and process scheme is generally referred to with reference number 1.

The process scheme 1 comprises a feed compressor 2, a heat exchanger 3 ("the first heat exchanger"), an expander 4,
30 a first separator 5, a JT-valve 6, a second separator 7, a pump 8, a third (solid/liquid separator 9, an LNG storage tank 11, a CO2 slurry heater 12, further compressors 13 and

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14, a second heat exchanger 15, a second expander 16 and gas-liquid separator 17. The process scheme may comprise further heat exchangers in addition to the first heat exchanger 3 and second heat exchanger 15. Preferably, the first heat
5 exchanger 3 and second heat exchanger 15 are separate heat exchangers. Preferably, the first heat exchanger 3 and second heat exchanger 15 are indirect heat exchangers in which the streams exchanging heat do not mix.

A hydrocarbon-containing gas stream 20 is provided (step
10 a), which is cooled (step b) thereby creating a cooled hydrocarbon-containing stream 40 being a liquid-vapour multiphase flow. The cooled hydrocarbon-containing stream 40 is separated to form a liquid bottom stream 50 and a gaseous top stream 60. The liquid bottom stream 50 is enriched in
15 C3+-hydrocarbons.

In step (j) the liquid bottom stream enriched in C3+-hydrocarbons obtained in (c) is passed to a NGL-fractionation stage to obtain a liquid product stream enriched in C3+ and one or more gaseous streams enriched in C1 and/or C2.

20 The liquid product stream enriched in C3+ can be passed to a suitable storage tank, can be sold separately or can be subject to further treatment and/or separation steps. The storage tank may be a pressurized storage vessel.

The one or more gaseous streams enriched in C1 and/or C2
25 can be recycled to be added to the hydrocarbon-containing gas stream (20) provided in step (a). Different embodiments will be described below with reference to Fig.'s 2 - 5.

Compared to WO2014/166925 a hydrocarbon dewpoint is achieved in stream 60 by operating a low temperature gas-
30 liquid separator 17 to separate the cooled hydrocarbon-containing stream 40 in a liquid bottom stream 50 and a gaseous top stream 60 at a suitable pressure and temperature, i.e. gas-liquid separator 17 is operated at a pressure and

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temperature in the liquid-vapour regime of the phase envelope.

It is noted that the gas-liquid separator 17 is different from the optional methanol separator 17' described in W02014/166925. It will be understood that a separate methanol separator (not shown) may still be provided or a three-phase separator 17 may be provided, as described in more detail below.

Furthermore, a NGL-fractionation stage is operated at a suitable pressure and temperature to obtain a liquid product stream enriched in C3+ (liquid heavies stream) that satisfies the Reid Vapor Pressure specification (condensate sale product).

The one or more gaseous streams enriched in C1 and/or C2 obtained in step (j) are recycled back into the process preferably by integration with compressors already present in the process scheme.

The embodiments have the advantage that only the liquid bottom stream 50 enriched in C3+-hydrocarbons is let down in pressure in NGL-fractionation stage and only the one or more gaseous streams enriched in C1 and/or C2 obtained in the NGL-fractionation stage need to be recompressed.

The different steps will now be described in more detail.

In step (a) a hydrocarbon-containing gas stream (20) is provided, the hydrocarbon-containing gas stream comprising a mixture of hydrocarbons including C1, C2 and C3+-hydrocarbons, the mixture further comprising contaminants.

The terms C1, C2 etc. are known to the skilled person. Ci refers to hydrocarbon molecules comprising i carbon atoms per molecule.

Although the hydrocarbon-containing gas stream is not particularly limited, it preferably is a methane-rich gas

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stream such as natural gas. According to a preferred embodiment, the hydrocarbon-containing gas stream comprises at least 50 mol% methane, preferably at least 80 mol%. Preferably, the hydrocarbon fraction of the hydrocarbon-
5 containing gas stream comprises especially at least 75 mol% of methane, preferably at least 90 mol%. The hydrocarbon fraction in the natural gas stream may suitably contain from between 0 and 10 mol% of C2+-hydrocarbons (i.e. hydrocarbons containing 2 or more carbon atoms per molecule), preferably
10 between 0 and 5 mol% of C2-C6 hydrocarbons, more preferably between 0.1 and 3 mol% of C2-C4 hydrocarbons, especially between 0.05 and 2 mol% of ethane.

The contaminant is also not particularly limited. Typically, the contaminant is one or more of CO₂, H₂S,
15 H₂O, C₆+ hydrocarbons, aromatic compounds, but is in particular CO₂.

The amount of contaminant in the contaminated hydrocarbon-containing gas stream is suitably between 0.1 and 90 mol%, preferably above 0.5 mol% and preferably below 10
20 mol%.

Before cooling in step (b), the hydrocarbon-containing gas stream may have been treated. As an example, if the hydrocarbon-containing gas stream contains water (e.g. more than 1 ppmv), then the hydrocarbon-containing gas stream may
25 be dehydrated to prevent hydrate formation in the subsequent cooling steps. As the person skilled in the art is familiar with dehydration of gas streams (e.g. using adsorption by desiccants) this is not further discussed here. Preferably, methanol is injected into the hydrocarbon-containing gas
30 stream to prevent the formation of hydrates.

According to the embodiments, the hydrocarbon-containing gas stream 20 as provided in step (a) has a pressure below

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the cricondenbar pressure of the mixture of hydrocarbons and contaminants, i.e. typically in the range of 60 - 100 bar.

The cricondenbar pressure P_c is defined as the maximum pressure at which vapour and liquid phase can coexist. Fig. 6
5 schematically shows a phase-diagram of a typical mixture of hydrocarbons including C1, C2 and C3+-hydrocarbons, the mixture further comprising contaminants as provided in (a). The cricondenbar pressure P_c is indicated in Fig. 6.

Providing the hydrocarbon-containing gas stream 20 in
10 step (a) may comprise compressing the hydrocarbon-containing gas stream to a pressure that does not exceed the cricondenbar pressure.

Providing the hydrocarbon-containing gas stream 20 in step (a) may comprise compressing the hydrocarbon-containing
15 gas stream to a pressure such that the pressure of the cooled hydrocarbon-containing stream (40) is below the cricondenbar pressure of the mixture of hydrocarbons and contaminants

In step (b) the hydrocarbon-containing gas stream (20) is cooled in a first heat exchanger (3). The heat exchanger
20 is not particularly limited, but is preferably an indirect heat exchanger. This results in a cooled hydrocarbon-containing stream (40), wherein the pressure of the cooled hydrocarbon-containing stream (40) is below the cricondenbar pressure of the mixture of hydrocarbons and contaminants. The
25 cooling in the first heat exchanger 3 is controlled to ensure that the temperature of the cooled hydrocarbon-containing stream 40 is in the liquid-vapor regime. Consequently, substantially no solids are present in the cooled hydrocarbon-containing stream 40.

30 Controlling the cooling in the first heat exchanger 3 may for instance be done by controlling the flow rates of the streams entering the first heat exchanger 3 or when designing the first heat exchanger 3.

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Preferably, the pressure of the cooled hydrocarbon-containing stream (40) is at least 5 bar, preferably at least 10 bar below the cricondenbar pressure of the mixture of hydrocarbons and contaminants.

5 Typically, the pressure of the cooled hydrocarbon-containing stream is below 100 bar, preferably below 80 bar.

The method may comprise controlling the discharge pressure of the feed compressor 2 to ensure that the pressure
10 of the cooled hydrocarbon-containing stream 40 is below the cricondenbar pressure. Controlling the discharge pressure of the feed compressor 2 may be done by a controller in response to a measured pressure of at least one of the cooled hydrocarbon-containing stream 40, the hydrocarbon-containing
15 gas stream 20 as provided in step (a) and the pressure inside gas-liquid separator 17.

According to an embodiment step (a) comprises controlling a feed compressor (2) which provides the hydrocarbon-containing gas stream (20) to provide the
20 hydrocarbon-containing gas stream (20) at a pressure that is below the cricondenbar pressure of the mixture of hydrocarbons and contaminants.

Additionally, the temperature of the cooled hydrocarbon-containing stream 40 is selected and controlled such that the
25 cooled hydrocarbon-containing stream 40 is in the liquid-vapour regime of the phase envelope. Preferably the cooled hydrocarbon-containing stream 40 comprises more than 2 mol% liquid phase.

Preferably, the cooled hydrocarbon-containing stream
30 obtained in step (b) has a temperature of at most -40°C , preferably at most -50°C , more preferably at most -60°C .

Consequently, the cooled hydrocarbon-containing stream (40) is a liquid-vapour multiphase flow.

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Preferably, the cooled hydrocarbon-containing stream (40) being a liquid-vapour multiphase flow obtained in (b) comprises a liquid fraction in the range of 1 - 10 mass%. The mass% is defined with respect to the cooled hydrocarbon-
5 containing stream 40 representing 100%. Typically the liquid fraction is 5 mass%, pressure is below 80 bar and temperature is between -80°C and - 40°C.

In step (c) the cooled hydrocarbon-containing stream (40) is separated in a liquid bottom stream (50) and a
10 gaseous top stream (60), the liquid bottom stream (50) being enriched in C3+-hydrocarbons.

The separation in step (c) can be performed with any suitable gas-liquid separator, shown in the figures as gas-liquid separator 17.

15 The gas-liquid separator 17 may be a distillation column or a knock-out vessel, from which the liquid stream 50 is obtained as bottom stream and the gaseous stream 60 is obtained as top stream.

The liquid bottom stream 50 is enriched in C3+-
20 hydrocarbons and the gaseous top stream 60 is depleted in C3+.

The term enriched is used to indicate that the mol fraction of the indicated component in the enriched stream is higher than the mol fraction of the indicated component in
25 the stream from which the enriched stream is obtained. The term deriched or depleted is used to indicate that the mol fraction of the indicated component in the deriched or depleted stream is lower than the mol fraction of the indicated component in the stream from which the
30 deriched/depleted stream is obtained.

If desired, preferably if methanol has been injected upstream to avoid hydrate formation, the cooled hydrocarbon-containing gas stream 40 may be subjected to a methanol

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separation step before being cooled in the expander in step (d).

This may be done by providing a separate methanol separator (not shown) or by providing a three-phase separator
5 17 that has three outlets for a gaseous product, a liquid hydrocarbon product, and a water/methanol product respectively, such as a vessel comprising a weir from which the gaseous stream 60 is obtained as top stream, the liquid bottom stream 50 is obtained downstream of the weir, and a
10 water-methanol is obtained upstream of the weir.

In step (d) the gaseous top stream (60) is cooled in an expander (4) thereby obtaining a partially liquefied stream (70).

In step (e) the partially liquefied stream (70) is
15 separated in a separator (5) thereby obtaining a gaseous stream (80) and a liquid stream (90).

In step (f) the liquid stream (90) is passed to a pressure reduction and separation stage to obtain one or more gaseous streams (110, 180) and a liquid hydrocarbon stream
20 (170).

Step (f) may be embodied in different ways. Below an example of step (f) will be described with reference to the figures, but it will be understood that alternative embodiments of step (f) can be implemented instead.

25 Step (f) may be embodied by the following steps:

(f1) expanding the liquid stream (90) obtained in step (e) thereby obtaining a multiphase stream (100), the multiphase stream (100) containing at least a vapour phase, a
30 liquid phase and a solid phase;

(f2) separating the multiphase stream (100) in a separator (7) thereby obtaining a gaseous stream (110) and a slurry stream (120);

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(f3) separating the slurry stream (120) in a solid/liquid separator (9) thereby obtaining a liquid hydrocarbon stream (170) and a concentrated CO₂ slurry stream (140).

In step (f1), the liquid stream obtained in step (e) is expanded thereby obtaining a multiphase stream 100. Step (f1) may involve an expander, such as a (throttle) valve 6. Typically, the multiphase stream 100 contains at least 20 mol% vapour.

Although the expander 6 as used in step (f1) is not particularly limited (and may include a JT valve an orifice, a liquid-expander, etc.), it is preferred that in the expander enthalpy is withdrawn from the cooled hydrocarbon-containing gas stream. A suitable expander for withdrawing enthalpy whilst expanding is a liquid expander. Preferably, the cooled hydrocarbon-containing gas stream as fed into the expander 4 has a pressure of from 40 to 100 bara, more preferably from 60 to 80 bara. The multiphase stream as removed from the expander 4 typically has a pressure of from 10 to 30 bara, preferably between 17 and 25 bara.

Preferably, the multiphase stream obtained in step (f1) has a temperature of at most -100°C (i.e. not warmer than -100°C), preferably at most -120°C, more preferably at most -140°C, most preferably at most -150°C.

In step (f2), the multiphase stream is separated in a separator 7 thereby obtaining a gaseous stream 110 and a CO₂ slurry stream 120. It is preferred that the slurry stream 120 obtained in step (f2) is pressurized, e.g. using pump 8, before being separated in step (f3), to minimize vapour generation in the solid/liquid separator 9 in step (f3). Also, pressurizing the slurry stream obtained in step (f2) prevents solids formation in a pressurized storage vessel (if any) in which the liquid hydrocarbon stream obtained in step

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(f3) is stored. Preferably the slurry stream is pumped to at least 6 bara.

In step (f3), the slurry stream 140 is separated in a solid/liquid separator 9 thereby obtaining a liquid
5 hydrocarbon stream 170 and a concentrated slurry stream 140. Typically, the concentrated slurry stream 140 is rich in contaminants. The concentrated slurry stream 140 may comprise more than one contaminant. The concentrated slurry stream 140 usually contains at least 20 mol% contaminant(s) and at most
10 80 mol% methane. If (one of) the contaminant(s) in the concentrated slurry stream is CO₂, then the concentrated slurry stream 140 preferably comprises at least 25 mol% CO₂. Preferably, the concentrated slurry stream 140 is heated to melt and/or evaporate the contaminant(s). Preferably, the
15 concentrated slurry stream 140 is melted (preferably in a heated vessel) to obtain a liquid contaminant stream 160 and a gaseous contaminant stream 150. As the gaseous contaminant stream 150 may still comprise some hydrocarbons, it may be recycled to be used as (part of) a fuel stream.

20 As indicated above, the above description of step (f) is an example and alternative pressure reduction and separation stages may be used.

For instance, a pressure reduction and separation stage may be used in which use is made of a direct contact heat
25 exchanger to cool the liquid stream and obtain a multiphase stream comprising a liquid phase and a solid CO₂ phase, a solid liquid separator to obtain a CO₂ depleted liquid stream from the multiphase stream, a further cooling, pressure reduction and separation stage to generate a further CO₂
30 enriched slurry stream, in which at least part of the further CO₂ enriched slurry stream is passed to the direct contact heat exchanger to provide cooling duty to and mix with the

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liquid stream 90. Upstream of direct contact heat exchanger may be a (throttle) valve.

According to such an embodiment the pressure reduction and separation stage may comprise

5 **(f1')** expanding the liquid steam (90) obtained in step (e) thereby obtaining a multiphase stream (100), the multiphase stream (100) containing at least a liquid phase and a solid phase;

10 **(f2')** cooling the multiphase stream (100) in a direct contact heat exchanger obtaining a multiphase stream containing at least a liquid phase and a solid CO₂ phase; separating the multiphase stream in a solid-liquid separator (202) obtaining a CO₂ depleted liquid stream; passing the CO₂ depleted liquid stream to a further cooling, pressure
15 reduction and separation stage to generate a further CO₂ enriched slurry stream; passing at least part of the further CO₂ enriched slurry stream to the direct contact heat exchanger to provide cooling duty to and mix with the liquid stream.

20 According to a further example, a pressure reduction and separation stage may be used in which use is made of a crystallization chamber. According to such an embodiment, the pressure reduction and separation stage may comprise

25 **(f1'')** expanding the liquid stream (90) obtained in step (e) thereby obtaining a multiphase stream (100), the multiphase stream (100) containing at least a vapour phase, a liquid phase and a solid phase;

30 **(f2'')** separating the multiphase stream (100) in a separator thereby obtaining a gaseous stream and a slurry stream;

(f3'') feeding the slurry to a crystallization chamber comprising CO₂ seed particles, obtaining a concentrated slurry 140 from the crystallization chamber, removing the

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concentrated slurry from the crystallization chamber by means of an extruder, thereby obtaining solid CO₂; obtaining a feedback stream from the solid CO₂ comprising CO₂ seed particles preferably having an average size greater than 100
5 micron and passing the feedback stream into the crystallization chamber 91 to provide the CO₂ seed particles.

In step (g) the gaseous stream (80) obtained in step (e) is passed through the first heat exchanger (3) thereby obtaining a heated gaseous stream 270. The heated gaseous
10 stream 270 typically comprises at least 80 mol% methane and at most 20 mol% N₂.

In step (h) the heated gaseous stream 270 is compressed thereby obtaining a compressed gas stream 220. Compression is done by compressor 13. In step (i) at least part of the
15 compressed gas stream 220 obtained in step (h) is combined with the hydrocarbon-containing gas stream 20 provided in step (a). This may be done with a combiner, which may be embodied in any suitable manner, such as by T-piece or the like.

20 Typically, the heated gaseous stream obtained in step (g) is compressed to a pressure equal to the pressure of the hydrocarbon-containing gas stream (20) provided in step (a), to allow combination of therewith. An advantage of combining the (lean) heated gaseous stream with the hydrocarbon-
25 containing gas stream 20 is that the contaminant level in stream 30 is lower than that in stream 20, allowing operating separator 5 at lower temperature, thus increasing the LNG yield.

The contaminated hydrocarbon-containing gas stream
30 provided in step (a) has typically been compressed by feed compressor 2 before being cooled in step (b) and combined in step (i).

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According to an embodiment, the method further comprises cooling a part (240) of the compressed gas stream (220) obtained in step (h) through a second heat exchanger (15) thereby obtaining a cooled compressed gas stream (250);
5 expanding the cooled compressed gas stream (250) thereby obtaining an expanded an expanded gas stream (260); and combining the expanded gas stream (260) with the gaseous stream (80) obtained in step (e).

Expansion of the cooled compressed gas stream 250
10 thereby obtaining an expanded gas stream 260 is done by a second expander 16. Although the second expander 16 is not limited (and may include a JT valve, an orifice, an expander), it is preferred that a rotating equipment type expander is used.

15 According to an embodiment, the method further comprises: passing one of the gaseous streams (110) obtained in step (f) through the second heat exchanger (15) thereby obtaining a second heated gaseous stream (200); compressing the second heated gaseous stream (200) thereby obtaining a
20 second compressed gas stream (210); and combining the second compressed gas stream (210) with the heated gaseous stream (270) obtained in step (g).

Compressing the second heated gaseous stream 200 may be done by a compressor 14.

25 In step (j) the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained in step (c) is passed to a NGL-fractionation stage to obtain a liquid product stream enriched in C3+ and one or more gaseous streams enriched in C1 and/or C2.

30 The term NGL-fractionation stage refers to a Natural Gas Liquid-fractionation stage. The NGL-fractionation stage can be embodied in different manners but serves to separate the majority of the C3+ molecules from the liquid bottom stream

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50 to be discharged and to retrieve C1 and/or C2 molecules from the liquid bottom stream 50 to be recycled.

Different embodiments of the NGL-fractionation stage will be described in more detail below. The NGL-fractionation stage may comprise a single separator such as a distillation column (e.g. Fig.'s 2, 3). The NGL-fractionation stage may alternatively comprise a plurality of distillation columns positioned in series (e.g. Fig. 4, 5), each distillation column being arranged to separate a different C_i-molecule. Such separators positioned in series are usually referred to as a demethanizer and a de-ethanizer.

From the one or more separators one or more gaseous streams enriched in C1 and/or C2 are obtained. When one distillation column is used, typically one gaseous stream enriched in C1 and C2 is obtained; when two distillation column in series are used, typically one gaseous stream enriched in C1 and one gaseous stream enriched in C2 are obtained.

In step (k) the one or more gaseous streams enriched in C1 and/or C2 are compressed, thereby obtaining one or more compressed gaseous stream enriched in C1 and/or C2. Compression may at least partially be done using further compressors 13 and 14, which are also used to compress

- the gaseous stream (80) obtained in step (e) and
- one or more of the gaseous streams (110, 180) obtained in step (f).

In step (l) the one or more compressed gaseous streams enriched in C1 and/or C2 are recycled to be comprised in the hydrocarbon-containing gas stream (20) provided in step (a). Fig.'s 2 - 5 show different embodiments of embodying the NGL-fractionation stage, in particular of embodying steps (j), (k) and (l).

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According to the embodiments depicted in Fig. 2 - 5 step (j) comprises

(j1) passing the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained in step (c) through a pressure reduction device (300) and subsequently

(j2) into a separator (320), such as a distillation column or gravity based separator.

The pressure reduction device 300 is preferably a valve, such as a Joule Thomson valve. The pressure reduction device 300 serves to control the Reid Vapour Pressure of the liquid product stream enriched in C3+ (340).

According to the embodiments depicted in Fig.'s 2 and 3 step (j2) comprises obtaining the liquid product stream enriched in C3+ (340) as bottom stream from the separator (320) and obtaining a gaseous stream (330) enriched in C1 and C2 as top stream from the separator (320).

The gaseous stream 330 enriched in C1 and C2 is recycled in an advantageous manner by adding this stream to the hydrocarbon-containing gas stream 20 which is passed to the first heat exchanger 3.

According to the embodiment shown in Fig.'s 2 and 3, step (l) comprises recycling the gas stream (330) enriched in C1 and C2 obtained in step (j2) by adding the gas stream (330) enriched in C1 and C2 obtained in step (j2) to the second heated gaseous stream (200). This has the advantage that the C1/C2 can be recovered as LNG.

Fig. 4 and 5 show an alternative embodiment of embodying steps (j), (k) and (l), i.e. by providing a NGL-fractionation stage comprising two separators.

According to this embodiment, step (j2) comprises obtaining a gaseous stream (330') enriched in C1 as top stream from the separator (320) and obtaining a liquid stream

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(323) as bottom stream from the separator (320), the method further comprising

(j3) passing the bottom stream from the separator (320) obtained in (j2) through a further pressure reduction device
5 (324) and subsequently

(j4) into a further separator (321), such as a distillation column or gravity based separator, to obtain the liquid product stream enriched in C3+ (340) as bottom stream from the further separator (321) and obtaining a gaseous
10 stream (331) enriched in C2 as top stream from the further separator (321).

Fig. 4 further depicts an advantageous embodiment of recycling both the gaseous stream (330') enriched in C1 and the gaseous stream (331) enriched in C2. The advantage is
15 that the operating pressure of separators 320 and 321 are matched to the suction pressures of compressors 13 and 14 already present in the system, respectively, as this minimizes the compression power required.

According to this embodiment, step (1) comprises
20 - adding the gaseous stream (330') enriched in C1 obtained as top stream from the separator (320) in step (j2) to the second compressed gas stream (210), and
- adding the gaseous stream (331) enriched in C2 obtained as top stream from the further separator (321) in
25 step (j4) to the second heated gaseous stream (200).

Further efficiency can be obtained by providing a third heat exchanger 310 to the NGL-fractionation stage to provide cooling duty. This has the advantage that separation can be achieved with a smaller pressure reduction. Consequently,
30 less compression duty is needed to recycle the one or more compressed gaseous streams enriched in C1 and/or C2 by adding the one or more compressed gaseous streams enriched in C1

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and/or C2 to the hydrocarbon-containing gas stream (20) provided in step (a).

Embodiments comprising a third heat exchanger are shown in Fig. 3 and 5, where Fig. 3 is a variation of Fig. 2 and
5 Fig. 5 is a variation of Fig. 4.

According to such an embodiment step (j) comprises passing at least part of the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained in step (c) through a third heat exchanger (310) to obtain a cooled liquid bottom
10 stream (50) being enriched in C3+-hydrocarbons.

In the embodiments in which the NGL-fractionation stage comprises a single separator (320), the third heat exchanger 310 is preferably positioned upstream of the single separator 320 and downstream of the pressure reduction device 300. The
15 cooled liquid bottom stream (50) being enriched in C3+-hydrocarbons is passed to the separator 320. An example of such an embodiment is depicted in Fig. 3.

In the embodiments in which the NGL-fractionation stage comprises a two separators (320, 321), the third heat
20 exchanger 310 is preferably positioned in the fluid connection between the separator 320 and the further separator 321, preferably upstream of the further separator 321 and the further pressure reduction device 324. In this embodiment the liquid stream 323 obtained as bottom stream
25 from the separator 320 is passed to the third heat exchanger 310.

Advantageously, cooling duty for the third heat exchanger 310 is obtained from one of the processing streams and without introducing the need for a separate refrigerant
30 and refrigerant cycle.

According to an embodiment the method further comprises obtaining a split stream (81) from the gaseous stream (80) obtained in step (e) and pass the split stream (81) through

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the third heat exchanger (310) to provide cooling duty to the at least part of the liquid bottom stream (50) being enriched in C3+-hydrocarbons that is passed through the third heat exchanger.

5 The method may further comprise storing the liquid hydrocarbon stream 170 obtained in step (f) in a LNG storage tank 11, obtaining a boil-off gas stream 180 from the LNG storage tank 11 and combining the boil-off gas stream 180 with one of the one or more gaseous streams enriched in C1
10 and/or C2 obtained from the NGL-fractionation stage. This may be part of step (f).

Alternatively, the boil-off gas stream 180 may be compressed separately and sent to a fuel system.

According to an advantageous embodiment, the operating
15 pressure of the separators 320, 321 used in the NGL-fractionation stage are selected to match the suction pressures of the compressors 13, 14 used to compress heated gaseous stream (270) obtained in step (g) and second heated gaseous stream (200) obtained from the second heat exchanger
20 15.

The person skilled in the art will readily understand that many modifications may be made without departing from the scope of the invention.

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C L A I M S

1. Method of liquefying a hydrocarbon-containing gas stream, the method comprising at least the steps of:

5 **(a)** providing a hydrocarbon-containing gas stream (20), the hydrocarbon-containing gas stream comprising a mixture of hydrocarbons including C1, C2 and C3+- hydrocarbons;

(b) cooling the hydrocarbon-containing gas stream (20) in a first heat exchanger (3) thereby obtaining a cooled
10 hydrocarbon-containing stream (40), wherein the pressure of the cooled hydrocarbon-containing stream (40) is below the cricondenbar pressure of the mixture of hydrocarbons and contaminants, the cooled hydrocarbon-containing stream (40) being a liquid-vapour multiphase flow;

15 **(c)** separating the cooled hydrocarbon-containing stream (40) in a liquid bottom stream (50) and a gaseous top stream (60), the liquid bottom stream (50) being enriched in C3+- hydrocarbons;

(d) cooling the gaseous top stream (60) in an expander
20 (4) thereby obtaining a partially liquefied stream (70);

(e) separating the partially liquefied stream (70) in a separator (5) thereby obtaining a gaseous stream (80) and a liquid stream (90);

(f) passing the liquid stream (90) obtained in step (e)
25 to a pressure reduction and separation stage (91) to obtain one or more further gaseous streams (110, 180) and a liquid hydrocarbon stream (170),

(g) passing the gaseous stream (80) obtained in step (e) through the first heat exchanger (3) thereby obtaining a
30 heated gaseous stream (270); and

(h) compressing the heated gaseous stream (270) thereby obtaining a compressed gas stream (220); and

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(i) combining at least part of the compressed gas stream (220) obtained in step (h) with the hydrocarbon-containing gas stream (20) provided in step (a);

wherein the method further comprises:

5 (j) passing the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained in step (c) to a NGL-fractionation stage to obtain a liquid product stream enriched in C3+ and one or more gaseous streams enriched in C1 and/or C2;

10 (k) compressing the one or more gaseous stream enriched in C1 and/or C2 thereby obtaining one or more compressed gaseous streams enriched in C1 and/or C2 (330; 331);

(l) recycling the one or more compressed gaseous streams enriched in C1 and/or C2 by adding at least part of the one
15 or more compressed gaseous streams enriched in C1 and/or C2 to the hydrocarbon-containing gas stream (20) provided in step (a).

2. The method according to claim 1, wherein the pressure of
20 the cooled hydrocarbon-containing stream (40) is at least 5 bar, preferably at least 10 bar below the cricondenbar pressure of the mixture of hydrocarbons and contaminants.

3. Method according to any one of the preceding claims,
25 wherein step (a) comprises controlling a feed compressor (2) which is involved in providing the hydrocarbon-containing gas stream (20) to provide the hydrocarbon-containing gas stream (20) at a pressure that is below the cricondenbar pressure of the of the mixture of hydrocarbons and contaminants.

30 4. Method according to any one of the preceding claims, wherein the cooled hydrocarbon-containing stream (40) being a

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liquid-vapour multiphase flow obtained in (b) comprises a liquid fraction in the range of 1 - 10 mass%.

5. Method according to any one of the preceding claims,

5 wherein (f) comprises

(f1) expanding the liquid steam (90) obtained in step (e) thereby obtaining a multiphase stream (100), the multiphase stream (100) containing at least a vapour phase, a liquid phase and a solid phase;

10 (f2) separating the multiphase stream (100) in a separator (7) thereby obtaining a gaseous stream (110) and a slurry stream (120);

(f3) separating the slurry stream (120) in a solid/liquid separator (9) thereby obtaining a liquid hydrocarbon stream (170) and a concentrated slurry stream (140).

6. The method according to any one of claims 1-5, further comprising: cooling a part (240) of the compressed gas stream

20 (220) obtained in step (h) through a second heat exchanger (15) thereby obtaining a cooled compressed gas stream (250); expanding the cooled compressed gas stream (250) thereby obtaining an expanded an expanded gas stream (260); and combining the expanded gas stream (260) with the gaseous stream (80) obtained in step (e).

7. The method according to claim 6, further comprising: passing one of the gaseous streams (110) obtained in step (f) through the second heat exchanger (15) thereby obtaining a second heated gaseous stream (200); compressing the second heated gaseous stream (200) thereby obtaining a second compressed gas stream (210); and combining the second

30

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compressed gas stream (210) with the heated gaseous stream (270) obtained in step (g).

8. Method according to any one of the preceding claims, wherein step (j) comprises

- 5 **(j1)** passing the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained in step (c) through a pressure reduction device (300) and subsequently
 (j2) into a separator (320), such as a distillation column or gravity based separator.

10

9. Method according to claim 8, wherein step (j2) comprises obtaining the liquid product stream enriched in C3+ (340) as bottom stream from the separator (320) and obtaining a gaseous stream (330) enriched in C1 and C2 as top stream from
15 the separator (320).

10. Method according to claim 7 and 9, wherein step (l) comprises recycling the gas stream (330) enriched in C1 and C2 obtained in step (j2) by adding the gas stream (330)
20 enriched in C1 and C2 obtained in step (j2) to the second heated gaseous stream (200).

11. Method according to claim 8, wherein step (j2) comprises obtaining a gaseous stream (330') enriched in C1 as top
25 stream from the separator (320) and obtaining a liquid stream (323) as bottom stream from the separator (320), the method further comprising

- (j3)** passing the bottom stream from the separator (320) obtained in (j2) through a further pressure reduction device
30 (324) and subsequently

(j4) into a further separator (321), such as a distillation column or gravity based separator, to obtain the

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liquid product stream enriched in C3+ (340) as bottom stream from the further separator (321) and obtaining a gaseous stream (331) enriched in C2 as top stream from the further separator (321).

5

12. Method according to claim 7 and 11, wherein (1) comprises

- adding the gaseous stream (330') enriched in C1 obtained as top stream from the separator (320) in step (j2) to the

10 second compressed gas stream (210), and

- adding the gaseous stream (331) enriched in C2 obtained as top stream from the further separator (321) in step (j4) to the second heated gaseous stream (200).

15 13. Method according to any one of the preceding claims, wherein step (j) comprises passing at least part of the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained in step (c) through a third heat exchanger (310) to obtain a cooled liquid bottom stream (50) being enriched in
20 C3+-hydrocarbons.

14. Method according to claim 13, wherein the method further comprises obtaining a split stream (81) from the gaseous stream (80) obtained in step (e) and pass the split stream
25 (81) through the third heat exchanger (310) to provide cooling duty to the liquid bottom stream (50) being enriched in C3+-hydrocarbons.

15. Method according to any one of the preceding claims,
30 wherein the method comprises storing the liquid hydrocarbon stream (170) obtained in step (f) in a LNG storage tank 11, obtaining a boil-off gas stream (180) from the LNG storage tank 11 and combining the boil-off gas stream (180) with one

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of the one or more gaseous streams enriched in C1 and/or C2 obtained from the NGL-fractionation stage.

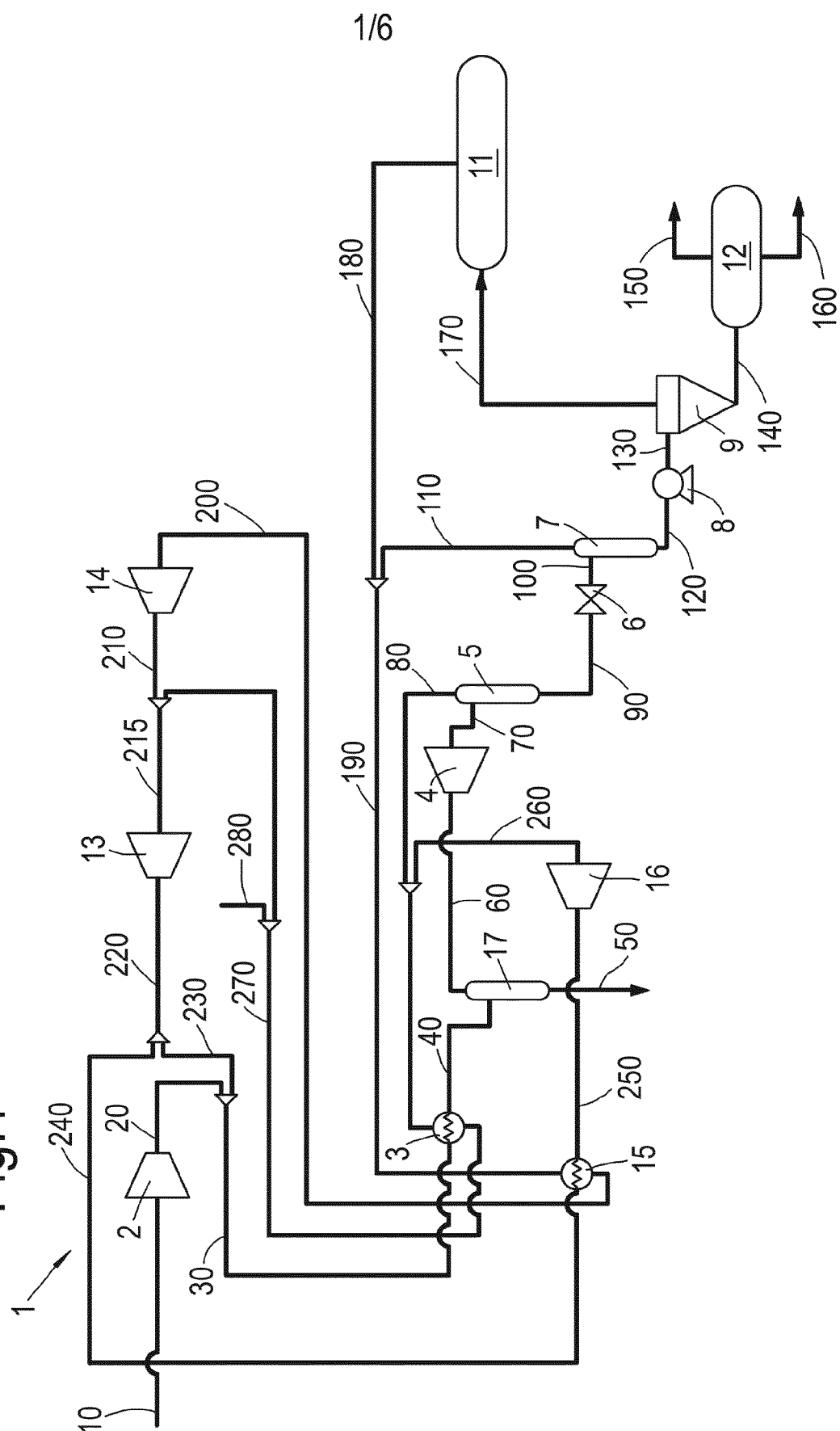
16. System for liquefying a hydrocarbon-containing gas stream, the system comprising:

- a feed conduit (20) for providing a hydrocarbon-containing gas stream, the hydrocarbon-containing gas stream comprising a mixture of hydrocarbons including C1, C2 and C3+- hydrocarbons;
- a first heat-exchanger (3) arranged to receive the hydrocarbon containing gas stream from the feed conduit (20) and which is further arranged to cool the hydrocarbon-containing gas stream (20) and discharge a cooled hydrocarbon-containing stream (40), wherein the pressure of the cooled hydrocarbon-containing stream (40) is below the cricondenbar pressure of the mixture of hydrocarbons and contaminants, the cooled hydrocarbon-containing stream (40) being a liquid-vapour multiphase flow;
- a gas-liquid separator (17) arranged to receive the cooled hydrocarbon-containing stream (40) from the first heat exchanger (3) being arranged to separate the cooled hydrocarbon-containing stream (40) in a liquid bottom stream (50) and a gaseous top stream (60), the liquid bottom stream (50) being enriched in C3+-hydrocarbons;
- an expander (4) arranged to receive the gaseous top stream (60) and expand and thereby cool the gaseous top stream (60) thereby obtaining a partially liquefied stream (70);
- a separator (5) arranged to receive the partially liquefied stream (70) and separate the partially liquefied stream (70) thereby obtaining a gaseous stream (80) and a liquid stream (90);

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- a pressure reduction and separation stage (91) arranged to receive the liquid stream (90) from the separator (5) further being arranged to obtain one or more further gaseous streams (110, 180) and a liquid hydrocarbon stream (170) from the liquid stream (90),
5
 - conduit (80) to pass the gaseous stream (80) obtained from the separator (5) to the first heat exchanger (3) and a conduit (270) to obtain a heated gaseous stream (270) from the first heat exchanger (3); and
10
 - one or more compressors (13, 14) arranged to receive the heated gaseous stream (270) to obtain a compressed gas stream (220); and
 - a combiner arranged to combine at least part of the compressed gas stream (220) with the hydrocarbon-containing
15 gas stream (20);
- wherein the system further comprises:
- a NGL-fractionation stage arranged to receive the liquid bottom stream (50) being enriched in C3+-hydrocarbons obtained from the gas-liquid separator (17), the NGL-fractionation stage being arranged to obtain a liquid product
20 stream enriched in C3+ and one or more gaseous streams enriched in C1 and/or C2 from the liquid bottom stream (50) being enriched in C3+-hydrocarbons;
 - one or more recycle conduits (330, 331) arranged to
25 recycle the one or more gaseous streams enriched in C1 and/or C2 to the one or more compressors (13, 14).

Fig. 1



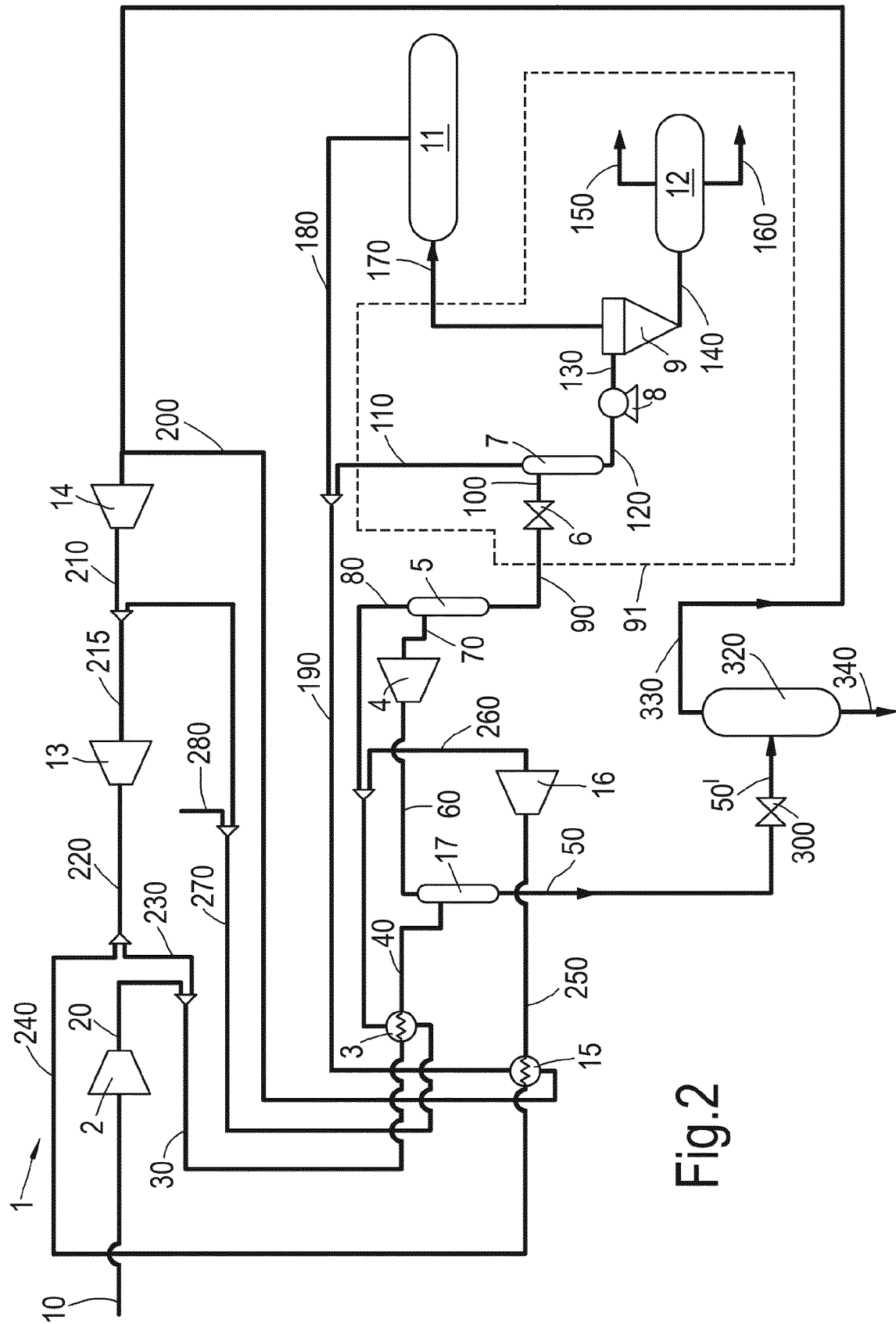


Fig.2

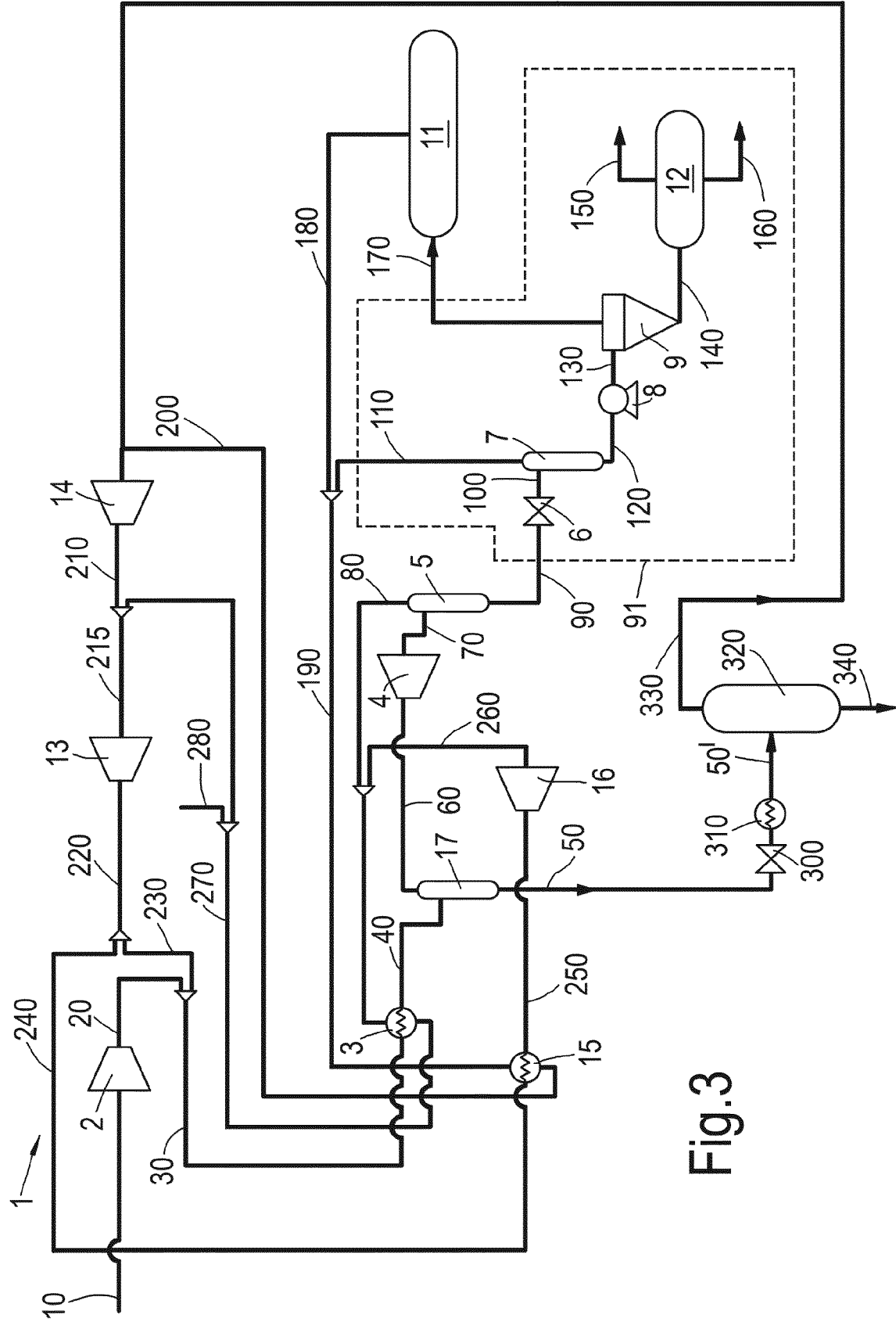


Fig.3

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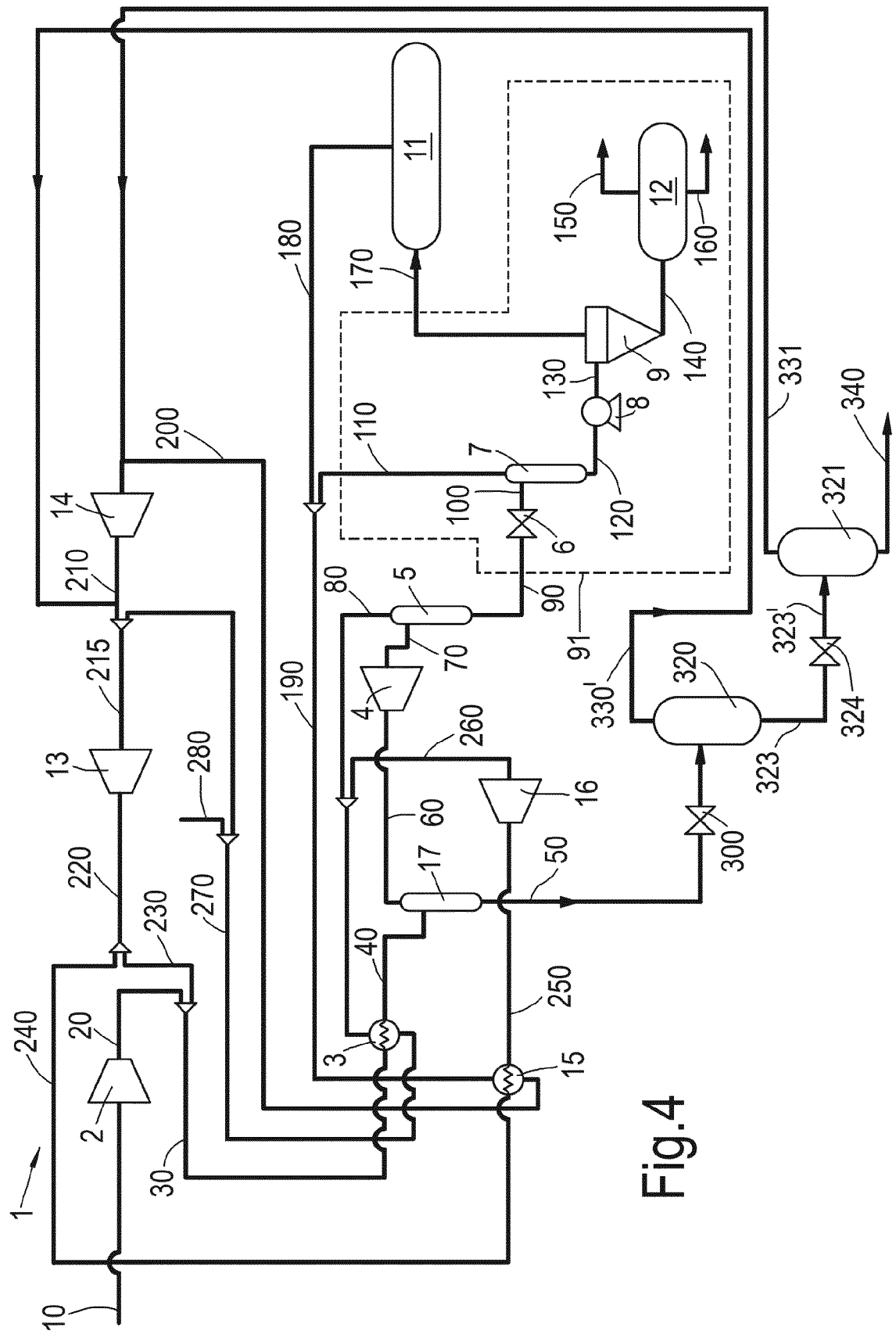


Fig. 4

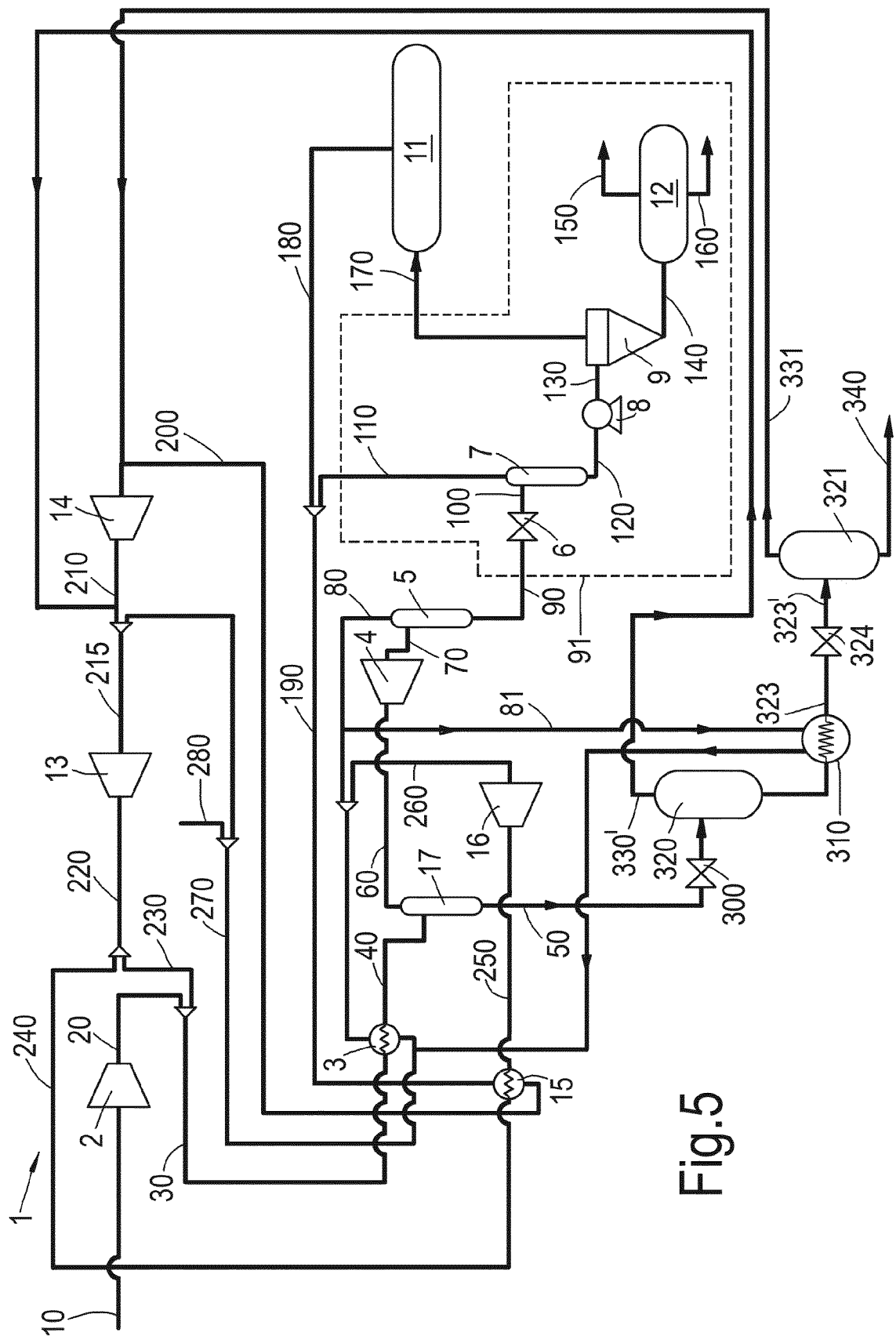
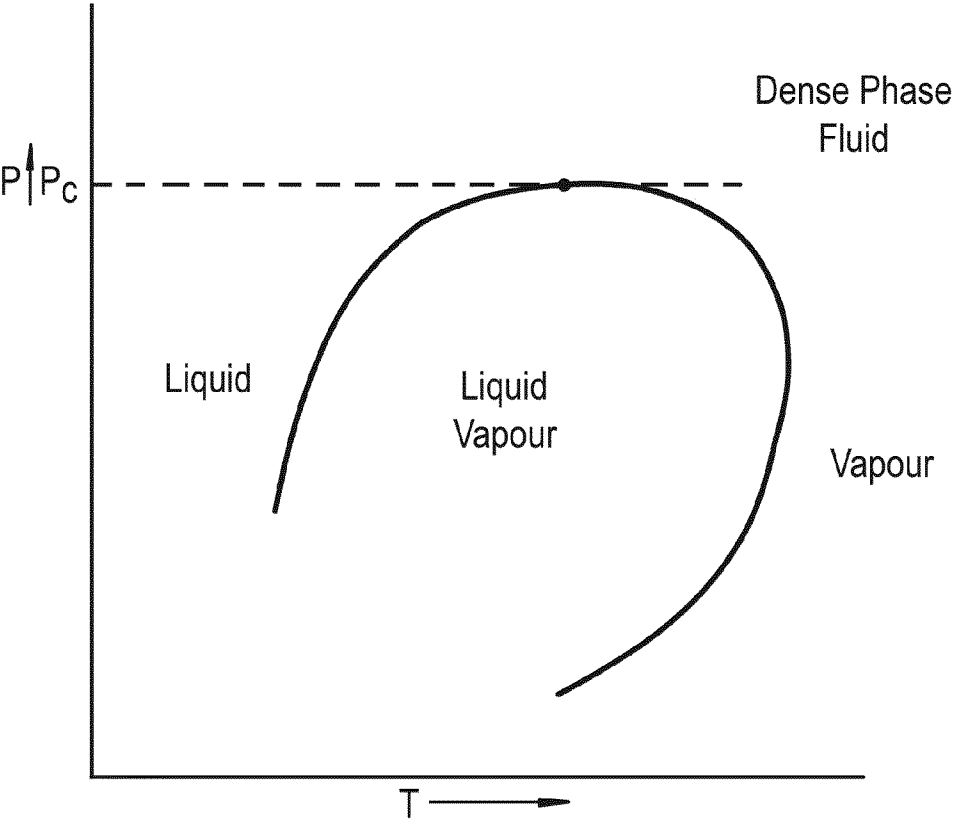


Fig.6



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/079392

A. CLASSIFICATION OF SUBJECT MATTER INV. F25J3/02 F25J3/06 F25J1/00 F25J1/02 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) F25J		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 2 789 957 A1 (SHELL INT RESEARCH [NL]) 15 October 2014 (2014-10-15) paragraph [0011]; figure 1 -----	1-16
Y	US 2003/089125 A1 (FREDHEIM ARNE OLAY [NO] ET AL) 15 May 2003 (2003-05-15) figure 3 -----	1-16
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 27 February 2017		Date of mailing of the international search report 16/03/2017
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Schopfer, Georg

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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