

METHOD FOR LIQUEFYING A GAS

TECHNICAL FIELD

The present disclosure relates to the technical field of processes and
5 devices for the liquefaction of a gas, such as natural gas or biomethane.

PRIOR ART

Gas liquefaction facilities, such as those for natural gas or biomethane,
allow a gas to be liquefied for storage so that the transport of the liquefied gas is
10 carried out at a pressure slightly above atmospheric pressure. Currently, several
technologies and processes exist for gas liquefaction, comprising liquefaction
processes based on the Linde cycle. The principle of the Linde cycle is to divide the
gas stream to obtain a secondary stream intended for cooling the main stream, so
that the gas stream is subdivided in order to self-cool.

15 In this context, there is still a need for improved solutions for gas
liquefaction.

SUMMARY

A method for liquefying a gas is proposed. The method comprises
20 compressing a main stream of the gas. The method further comprises cooling the
compressed main stream. Cooling the main stream comprises firstly subdividing the
compressed main stream. The first subdivision provides a first cooling stream.
Cooling the main stream further comprises subsequently subdividing the
compressed main stream at least once. The at least one subsequent subdivision of
25 the compressed main stream provides at least one subsequent cooling stream.
Cooling the main stream further comprises cooling the first cooling stream via the at
least one subsequent cooling stream. Cooling the main stream further comprises
cooling the compressed main stream via the first cooling stream and cooling the
main stream via the at least one subsequent cooling stream.

30 As discussed later, the method provides the gas in liquid form at the output
(i.e., after executing the steps of the method, comprising the cooling steps), i.e., the
gas has been liquefied.

The cooling of the first cooling stream may comprise pre-cooling the first cooling stream by the at least one subsequent cooling stream. The cooling of the first cooling stream may further comprise expanding the pre-cooled first cooling stream.

5 The cooling of the compressed main stream may comprise using the expanded first cooling stream in a heat exchanger.

The method may further comprise expanding the at least one subsequent cooling stream, after the at least one subsequent subdivision and before pre-cooling the first cooling stream.

10 The pre-cooling of the first cooling stream by the at least one subsequent cooling stream may comprise using the expanded subsequent cooling stream in a heat exchanger.

The method may further comprise recycling the expanded cooling streams.

15 The method may further comprise, before the subdivisions, a first cooling of the main stream using water-glycol, and a pre-cooling of the main stream using a cooling unit or a cold source (e.g., at -45°C).

The method may further comprise, after cooling the compressed main stream by the first cooling stream, expanding the cooled main stream.

20 The method may further comprise, after expanding the cooled main stream, the storage of the cooled and expanded main stream in a bulk unit.

The method can be automated, i.e., implemented via the use of any technology suitable for automating a gas liquefaction process.

25 An installation for liquefying a gas according to the method is also proposed. The installation is thus a device or system adapted to implement the method, for implementing the method, and comprises the necessary equipment for executing the method. The installation comprises:

- a main stream line intended for the compression, subdivision and cooling of the main stream;
 - a first subdivision line intended for cooling the first cooling stream and cooling the main stream; and
 - at least one second subdivision line intended for cooling the first cooling stream and the main stream.
- 30

The main stream line may comprise:

- a high-pressure 4-stage compressor for compressing the main stream;
- a cooling device using water-glycol for the first cooling of the main stream using water-glycol;
- a cooling unit for pre-cooling the main stream using the cooling unit;
- 5 - a control valve for the first subdivision;
- at least one other control valve for the at least one subsequent subdivision;
- a heat exchanger for cooling the main stream by the first cooling stream;
- an expander for expanding the cooled main stream; and
- 10 - a bulk unit for storing the cooled and expanded main stream.

The first subdivision line may comprise:

- a heat exchanger for pre-cooling the first cooling stream by the at least one subsequent cooling stream; and
- an expander for expanding the pre-cooled first cooling stream.

15 The at least one second subdivision line may comprise:

- an expander for expanding the at least one subsequent cooling stream.
- a heat exchanger for pre-cooling the first cooling stream by the at least one subsequent cooling stream;

20 The installation can be automated, i.e., can comprise any automation technology suitable for implementing the method in an automated manner.

BRIEF DESCRIPTION OF THE FIGURES

Non-limiting examples will now be discussed with reference to the figures, where:

- 25 - Figures 1 to 4 show schematic illustrations of examples of the method and installation.

DETAILED DESCRIPTION

30 A method for liquefying a gas is proposed. The method comprises compressing a main stream of the gas. The method further comprises cooling the compressed main stream. Cooling the main stream comprises firstly subdividing the compressed main stream. The first subdivision provides a first cooling stream. Cooling the main stream further comprises subsequently subdividing the

compressed main stream at least once, the at least one subsequent subdivision of the compressed main stream providing at least one subsequent cooling stream. Cooling the main stream further comprises cooling the first cooling stream via the at least one subsequent cooling stream. Cooling the main stream further comprises cooling the compressed main stream via the first cooling stream and cooling the main stream via the at least one subsequent cooling stream.

This constitutes an improved method for gas liquefaction.

Indeed, unlike a cooling process based on a classic Linde cycle, the method is based on a modified Linde cycle wherein the main stream is subdivided a first time, resulting in the main stream and a first cooling stream, then (at least) a second time, the at least one subsequent cooling stream resulting from the at least one subsequent subdivision being used to cool the first cooling stream, which itself cools the main stream. The at least one subsequent cooling stream also cools the main stream. This plurality of subdivisions allows reducing the stream required in the cooling stream of the first subdivision, compared to a normal Linde cycle where this subdivision would be the only one and where this cooling stream alone would be used to cool the main stream. This reduction in the stream of the first cooling stream allows increasing the stream of the main stream, which improves the efficiency of the liquefaction process as well as the efficiency of the installation.

The at least one subsequent subdivision may consist of a single subsequent subdivision, then called "second subdivision." In this case, the at least one subsequent cooling stream consists of a single subsequent cooling stream, called "second cooling stream," which is used to cool the first cooling stream. Alternatively, the at least one subsequent subdivision may consist of N subsequent subdivisions, each of the respective main stream into the main stream and a respective subsequent cooling stream, with N a natural integer strictly greater than 1. In this case, the subsequent cooling stream $n-1$ (i.e., corresponding to the subsequent subdivision n with n a natural integer belonging to $[2;N]$) is cooled by the subsequent cooling stream n and itself cools the subsequent cooling stream $n-2$, the subsequent cooling stream 1 being the first cooling stream and cooling the main stream.

An installation for liquefying a gas according to the method is also proposed. The installation is thus a device or system adapted to implement the method, for implementing the method. The installation comprises:

- a main stream line intended for the compression, subdivisions, and cooling of the main stream;
- a first subdivision line intended for cooling the first cooling stream and cooling the main stream; and
- 5 - at least one second subdivision line intended for cooling the first cooling stream.

In the case where there is only one second subdivision, i.e., the second subdivision, the at least one second subdivision line consists of a single second subdivision line, called "second subdivision line".

10 The method and installation will now be described in more detail with reference to the figures. In the following, the at least one subsequent subdivision may consist of a single subsequent subdivision called "second subdivision," but it should be understood that the following discussion applies equally to the case of several subsequent subdivisions. It should be understood that Figures 1 to 4 are
15 purely schematic illustrations of the installation and its lines, and the steps of the method executed therein. These illustrations are intended to illustrate the succession of steps of the method and the technologies used in the various steps. These illustrations are in no way limiting as to the arrangement of technologies in the installation and as to the technologies that constitute the installation.

20 Unless otherwise indicated, all temperatures given below are in degrees Celsius and all pressures are in bar and are absolute pressures. The notation "bar" in the present disclosure is therefore equivalent to the notation "bar a" or "bara" (designating absolute pressure). The numerical values given in the description below of the figures are specific to the case where the gas is methane or
25 biomethane. For other gases, the numerical values must be suitably adapted. In particular, all the values presented below can be adapted according to the knowledge of the skilled person so that the gas is liquefied at 100% depending on the saturation pressure of the gas.

Figure 1 shows a schematic illustration of the installation and the method.
30 The installation comprises a main stream line P, a first subdivision line Sub2, and a second subdivision line Sub3. As illustrated in the figure, the method comprises, after compressing the main stream, cooling the compressed main stream, comprising: the first subdivision S40 of the main stream into the main stream and a

first cooling stream, the second subdivision S50 of the main stream into the main stream and a second cooling stream (subsequent cooling stream), the cooling S55-S555 of the first cooling stream by the second, and the cooling S60 of the main stream by the first cooling stream and the cooling S60' of the main stream by the at
 5 least one subsequent cooling stream.

Figure 2 shows a schematic illustration of the main line P of the installation and the steps of the method performed in the main line P. The main stream FP of gas (for example, natural gas, for example, biomethane), is supplied (step S0) at a constant pressure of between 2 and 8 bar. The method then comprises the
 10 compressing S10 of the main stream FP up to 250 bar using a 4-stage HP (high pressure) compressor 10. The method may then comprise the cooling S20 of the main stream FP to 0°C using water-glycol, via any suitable device or system 20 for cooling using water-glycol. The method may then comprise the pre-cooling S30 of the main stream FP to -40°C using a cooling unit 30. The method then comprises
 15 the first subdivision S40, using a valve 50, of the main stream FP into the main stream FP and the first cooling stream FSub2. The method also comprises the cooling S60 of the main stream FP by the first cooling stream FSub2 and S60' by the second cooling stream FSub3, and the cooling (S55, Figure 3) of FSub2 by FSub3, then the second subdivision S50, using another valve 50, of the main stream
 20 FP into the main stream FP and the second cooling stream FSub3. The cooling S60 of the main stream is up to -157°C in an exchanger using the first cooling stream FSub2, which has itself been cooled using the second cooling stream FSub3. The method may then comprise the expanding S70 of the main stream FP to a saturation temperature of -150°C (equivalent to a pressure of 2.3 bar), in an expander 70. It
 25 should be noted that the stream FSub2 does not mix with the Stream FP before expansion, but after compressor suction cooling after exchanging with glycolated water to recover its coldness. The method may then comprise the storing S80 of the main stream FP in the bulk unit 80. A small amount of BOG may be generated during the last expansion S70 and/or due to thermal infiltration in the bulk unit 80.

30 For executing steps S0 to S80 described above, the main stream line P of the installation may comprise the following devices:

- Heat exchangers;
- A HP (high pressure) compressor with cooling;

- A LP (low pressure) compressor to recompress the gas from FSub3 and go from 1 bar to a pressure of between 2 and 8 bar;
- An oil separator;
- A buffer volume;
- 5 – Expanders;
- An all-or-nothing (AON) valve;
- A bulk unit; and
- Isolation valves.

Figure 3 shows a schematic illustration of the first subdivision line Sub2 and its use for executing the method. As shown in the figure, the method comprises the cooling S55-S555 of the first cooling stream FSub2 by the second cooling stream FSub3. This may comprise, in a heat exchanger 55, the pre-cooling S55 of the first cooling stream FSub2 by the second cooling stream FSub3, then the expanding S555, in an expander 555, of the pre-cooled first cooling stream FSub2. Alternatively, the heat exchanger 55 may be part of the at least one second subdivision line. The expansion may be at the MP pressure which is the pressure at the HP compressor suction, and which is between 2 and 8 bar depending on the application. This reduces compression costs. The temperature of FSub2 is then between -128°C and -152°C. The cooling S60 of the compressed main stream (FP) may then comprise using the first cooling stream FSub2 in an exchanger. In other words, the cold energy of cooled FSub2 is used to cool the main stream in the exchanger, considering a pinch of 3°C. The stream exiting the exchanger is at a temperature of about -40°C. Therefore, at S65 the method may comprise recovering what remains of cold energy in a heat exchanger to partially cool the chilled water, then recycling the FSub2 stream, which joins FSub3 and is recycled in the system.

For executing the steps described above, the first subdivision line Sub2 of the installation may comprise the following devices:

- Heat exchangers;
- Expanders; and
- 30 - Isolation valves.

Figure 4 shows a schematic illustration of the second subdivision line Sub3, and its use for executing steps of the method. Following subdivision S50, the method may comprise the expanding S5555 of the second cooling stream FSub3 in

an expander 5555. The expansion may be at 1.1 bar (saturation temperature = -160°C), this pressure being chosen so that cooling the main stream S60 is about -157°C in the heat exchanger considering a pinch of 3°C. The method then comprises using the second cooling stream FSub3 in the heat exchanger 55 to cool
 5 the first cooling stream FSub2 (step S55). Considering a pinch of 3°C in the heat exchanger 55, the temperature of FSub3 becomes about -43°C. The method may then comprise a recycling step S655 of the FSub3 stream. The latter joins the BOG ("Boil-Off Gas") when leaving the bulk unit 80, and energy recovery is then carried out in a heat exchanger (not shown in the figures) with a glycolated water stream at
 10 ambient temperature. The BOG is at the storage tank level. Then, the temperature of the FSub3 stream increases before the FSub3 stream is compressed in low pressure (LP) compressors (not shown in the figures) up to the MP pressure so that it can be recycled in the system. The outgoing stream is then cooled to ambient temperature before being recycled in the system with the FSub2 stream.

15 The thermodynamic cycle used in the main stream line P may comprise the following technologies: instrumentation, heat exchangers, four-stage HP compressor with cooling, oil separator, buffer volume, electronic expanders, all-or-nothing (AON) valve, bulk storage and isolation valves.

The thermodynamic cycle used in the first subdivision line Sub2 may
 20 comprise the following technologies: instrumentation, heat exchangers, electronic expanders, and isolation valves.

The thermodynamic cycle used in the second subdivision line Sub3 may comprise the following technologies: instrumentation, heat exchangers, electronic expanders, two-stage LP compressor with cooling, and isolation valves.

25 The installation may also comprise a subset of auxiliaries. This subset may comprise or consist of the following automated equipment: instrumentation, switches, (e.g., two) gas detectors for CH₄, air heater for cooling refrigerant fluids, pump for the glycolated water network of the air heater, chilled water group accompanied by a pump for cooling the entire process, cooling unit for pre-cooling
 30 the main stream, and fan for extracting air from the container.

The method according to the examples described above with reference to the figures thus consists of liquefying a gas (such as biomethane or any natural gas) for storage at a saturation temperature of -150°C (2.3 bar). The process is based on

a modified Linde cycle, where the main gas stream is compressed up to 250 bar, then pre-cooled using a cold refrigerant cycle down to -40°C . In the cryogenic section, the main stream is separated into two streams: the cooling stream which is expanded using a JT (Joule Thomson) valve and the main stream which is cooled in the heat exchanger. Two stages of expansion and cooling allow obtaining a temperature below -150°C for the main stream. The main stream is then expanded to reach the saturation temperature of -150°C , then stored. A small amount of BOG may be generated and will be recycled in the system.

The examples of the installation and method described above with reference to the figures achieve the following objectives:

- Objectives for HP compression and liquefaction of the main stream:
 - Compressing the main stream using an HP compressor up to 250 bar;
 - Pre-cooling the main stream to -40°C ;
 - Liquefaction: cooling the main stream by distributing the stream into two subdivisions to then undergo expansion and be stored at -150°C ;
- Objectives of the Sub2 subset:
 - Controlling the stream in the Sub2 line and expanding the stream to BP1=MP;
 - First cooling stage of the main stream;
 - Recycling the stream in the system;
- Objectives of the Sub3 subset:
 - Controlling the stream in the Sub3 line and expanding the stream to BP2=1.1 bar;
 - Second cooling of the main stream;
 - Pre-cooling of the Sub2 stream;
 - LP (low pressure) compression of the stream to BP1.

CLAIMS

1. A method for liquefying a gas, comprising:
 - compressing (S10) a main stream (FP) of the gas;
 - 5 - cooling the compressed main stream, the cooling of the main stream (FP) comprising:
 - a first subdivision (S40) of the compressed main stream (FP), the first subdivision providing a first cooling stream (FSub2);
 - at least one subsequent subdivision (S50) of the compressed main stream (FP), the at least one subsequent subdivision of the compressed main stream (FP) providing at least one subsequent cooling stream (FSub3),
 - cooling (S55-S555) the first cooling stream (FSub2) by the at least one subsequent cooling stream (FSub3), and
 - 15 ○ cooling (S60) the compressed main stream (FP) by the first cooling stream (FSub2) and the cooling (S60') of the main stream by the at least one subsequent cooling stream (FSub3).

2. The method according to claim 1, wherein the cooling of the first cooling stream (FSub2) comprises:
 - 20 - pre-cooling (S55) the first cooling stream (FSub2) by the at least one subsequent cooling stream (FSub3); and
 - expanding (S555) the pre-cooled first cooling stream (FSub2).

3. The method according to claim 2, wherein cooling (S60) the compressed main stream (FP) comprises:
 - 25 - using the expanded first cooling stream (FSub2) held in a heat exchanger.

4. The method according to claim 2 or 3, wherein the method further comprises, after the at least one subsequent subdivision (S50) and before the pre-cooling (S55) of the first cooling stream (FSub2):
 - 30 - expanding (S5555) the at least one subsequent cooling stream (FSub3).

5. The method according to claim 4, wherein the pre-cooling (S55) of the first cooling stream (FSub2) by the at least one subsequent cooling stream (FSub3) comprises:

- 5 – using the expanded subsequent cooling stream (FSub3) in a heat exchanger (55).

6. The method according to claim 5, wherein the method further comprises recycling (S65-S655) the expanded cooling streams.

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7. The method according to any one of claims 1 to 6, wherein the method further comprises, before the subdivisions (S40-S50):

- a first cooling (S20) of the main stream (FP) using water-glycol; and
 – pre-cooling (S30) the main stream (FP) using a cooling unit or a cold
 15 source (30).

8. The method according to any one of claims 1 to 7, wherein the method further comprises, after the cooling (S60) of the compressed main stream (FP) by the first cooling stream (FSub2):

- 20 – expanding (S70) the cooled main stream (FP).

9. The method according to claim 8, wherein the method further comprises, after the expansion (S70) of the cooled main stream (FP):

- storing (S80) the cooled and expanded main stream (FP) in a bulk unit
 25 (80).

10. The method according to any one of claims 1 to 9, wherein the method is automated.

30 11. An installation for liquefying a gas according to the method of any one of claims 1 to 10, wherein the installation comprises:

- a main stream line (P) intended for the compression, subdivisions and cooling of the main stream (FP);

- a first subdivision line (Sub2) intended for the cooling of the first cooling stream (FSub2) and the cooling of the main stream (FP); and
- at least one second subdivision line (Sub3) intended for the cooling of the first cooling stream (FSub2) and the main stream (FP).

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12. The installation according to claim 11, wherein the main stream line (P) comprises:

- a high-pressure compressor with 4 stages (10) for compressing (S10) the main stream (FP);
- 10 – a cooling device (20) using water-glycol for the first cooling (S20) of the main stream (FP) using water-glycol;
- a cooling unit (30) for pre-cooling (S30) the main stream (FP) using the cooling unit (30);
- a control valve (40) for the first subdivision (S40);
- 15 – at least one other control valve (50) for the at least one subsequent subdivision (S50);
- a heat exchanger for cooling (S60) the main stream (FP) by at least one subsequent cooling stream (FSub3) and a heat exchanger for cooling S60 the main stream (FP) by the first cooling stream (FSub2);
- 20 – an expander (70) for the expansion (S70) of the cooled main stream; and
- a bulk unit (80) for the storage (S80) of the cooled and expanded main stream.

25 13. The installation according to claim 11 or 12, wherein the first subdivision line (Sub2) comprises:

- a heat exchanger (55) for the pre-cooling (S55) of the first cooling stream (FSub2) by the at least one subsequent cooling stream (FSub3); and
- an expander (555) for the expansion (S555) of the pre-cooled first cooling stream (FSub2).

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14. The installation according to claim 11 or 12 or 13, wherein the at least one second subdivision line (Sub3) comprises:

- an expander 5555 for the expansion (S5555) of the at least one subsequent cooling stream (FSub3);
- a heat exchanger (55) for the pre-cooling (S55) of the first cooling stream (FSub2) by the at least one subsequent cooling stream (FSub3).

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15. The installation according to any one of claims 11 to 14, wherein the installation is automated.