

NATURAL GAS LIQUEFACTION SYSTEM AND METHOD FOR PRODUCING LIQUEFIED NATURAL GAS

BACKGROUND OF THE INVENTION

5 FIELD OF THE INVENTION

[0001]

The present invention relates to a natural gas liquefaction system and to a method for producing liquefied natural gas.

10 DESCRIPTION OF RELATED ART

[0002]

Natural gas produced from a gas field contains acidic gas such as carbon dioxide. Because of this, the natural gas is subjected to gas purification at a gas well in order to remove carbon dioxide and then the resultant natural gas is transported to a plant via a
15 pipeline. At the plant, the natural gas is liquefied and shipped in the form of liquefied natural gas (LNG). Generally known methods for gas purification are chemical absorption to bring the natural gas into vapor-liquid contact with an amine-based absorbing solution for removing carbon dioxide, physical absorption, and membrane separation with a CO₂ permselective membrane.

20 [0003]

JP 2004-77075 A discloses a method for producing liquefied natural gas, which uses an amine-based absorbing solution to remove CO₂ from natural gas in advance of liquefaction of the natural gas.

SUMMARY OF THE INVENTION

[0004]

If natural gas produced from a gas field contains carbon dioxide at high concentration, the amine-based absorption requires large amounts of energy for restoring an amine-based absorbing solution that has absorbed carbon dioxide. Also, in the case of transporting natural gas containing carbon dioxide in a pipeline, there arises a problem that more power is required for transportation, leading to remarkable decline in economic efficiency.

[0005]

The present invention has been made in view of the foregoing problem, and an object of the present invention is to provide a natural gas liquefaction system and a method for producing liquefied natural gas, by which when natural gas produced from a gas field contains carbon dioxide at high concentration, the carbon dioxide can be removed from the natural gas using only a small amount of energy to liquefy the natural gas.

[0006]

In order to achieve the above object, one aspect of the present invention is to provide a natural gas liquefaction system, comprising: a vapor-liquid separator configured to remove carbon dioxide in liquid state from natural gas containing carbon dioxide; a precooling device configured to use the removed carbon dioxide to precool the natural gas containing carbon dioxide; and a natural gas liquefying device configured to cool the natural gas from which the carbon dioxide has been removed, so as to produce liquefied natural gas (LNG).

[0007]

The vapor-liquid separator is preferably configured to compress and cool the natural gas to partially liquefy carbon dioxide in the natural gas, as well as to further cool the natural gas by utilizing vaporization heat of the liquefied carbon dioxide to partially liquefy the

remaining carbon dioxide in the natural gas, and to perform vapor-liquid separation between methane gas as a main component of the natural gas and the liquid carbon dioxide. The natural gas liquefaction system according to the present invention may further comprise vaporizing means configured to vaporize the carbon dioxide removed by the vapor-liquid separator and to supply the vaporized carbon dioxide to the precooling device. In this case, the system may further comprise a vapor-liquid separator configured to separate carbon dioxide gas generated at the vaporizing means from the liquid carbon dioxide. Alternatively, in the natural gas liquefaction system according to the present invention, the precooling device may be configured to use the removed carbon dioxide in liquid state for the precooling.

[0008]

The natural gas liquefaction system according to the present invention may further comprise a carbon dioxide absorbing and removing device configured to further bring the natural gas from which the carbon dioxide has been removed by the vapor-liquid separator into contact with a carbon dioxide absorbing solution so as to further remove carbon dioxide from the natural gas.

[0009]

Another aspect of the present invention is to provide a method for producing liquefied natural gas, comprising the steps of: removing carbon dioxide in liquid state from natural gas containing carbon dioxide; using the removed carbon dioxide to precool the natural gas containing carbon dioxide; and cooling the natural gas from which the carbon dioxide has been removed, so as to produce liquefied natural gas (LNG).

[0010]

Preferably, the step of removing carbon dioxide in liquid state further comprises the substeps of: compressing and cooling the natural gas to partially liquefy the carbon dioxide in the natural gas; further cooling the natural gas by utilizing vaporization heat of the liquefied

carbon dioxide to partially liquefy the remaining carbon dioxide in the natural gas; and performing vapor-liquid separation between methane gas as a main component of the natural gas and the liquid carbon dioxide. In the method for producing natural gas according to the present invention, the removed carbon dioxide may be used in vaporized state or still in liquid state for precooling.

[0011]

The method for producing natural gas according to the present invention may further comprise a step of further bringing the natural gas into contact with a carbon dioxide absorbing solution to further remove carbon dioxide from the natural gas after the step of removing carbon dioxide in liquid state.

[0012]

According to the present invention, when natural gas contains carbon dioxide at high concentration, the natural gas is cooled to a temperature that brings about liquefaction of carbon dioxide, to enable vapor-liquid separation between liquid carbon dioxide and methane gas as a main component of the natural gas. Further, by using the thus-removed liquid carbon dioxide to precool natural gas prior to the removal of carbon dioxide, requisite energy for removing carbon dioxide from the natural gas as well as requisite energy for producing LNG from natural gas produced from a gas field can be reduced considerably compared to removing carbon dioxide by amine-based absorption only.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Fig. 1 is a schematic diagram showing an embodiment of a natural gas liquefaction system according to the present invention.

Fig. 2 is a schematic diagram showing another embodiment of the natural gas

liquefaction system according to the present invention.

Fig. 3 is a schematic diagram showing a natural gas liquefaction system given as Comparative Example.

5 DESCRIPTION OF PREFERRED EMBODIMENTS

[0014]

Referring to the accompanying drawings, a description will be given below of a natural gas liquefaction system and a method for producing liquefied natural gas according to an embodiment of the present invention.

10 [0015]

As shown in Fig. 1, the natural gas liquefaction system of this embodiment includes, as main components, a heat exchanger 20 for precooling natural gas produced from a gas field 10, a CO₂ removing unit 30 for removing carbon dioxide from the precooled natural gas, and a natural gas liquefying unit 40 for liquefying the natural gas from which the carbon dioxide
15 has been removed so as to produce liquefied natural gas (LNG). As will be detailed below, the CO₂ removing unit 30 includes a CO₂ liquefying and removing device 31 and an optional CO₂ absorber 50. The natural gas liquefying unit 40, as will be detailed later, includes a natural gas cooler 41 for cooling natural gas from which carbon dioxide has been removed, and a natural gas liquefying device 43 for converting the cooled natural gas into distributable
20 LNG.

[0016]

The present invention is directed to treatment of natural gas mainly containing carbon dioxide at high concentration. Here, the high concentration is, for example, 10 to 90 mol%, particularly 30 to 70 mol%. The gas field 10 that produces such a high content of
25 carbon dioxide may often be an offshore gas field. The natural gas liquefaction system of

the present invention is meant to be applied to a floating production plant for purifying, liquefying, storing, and shipping out natural gas on the ocean, called a floating-LNG.

Needless to say, the system is also applicable to a stationary offshore production plant that is fixed to the seabed or an LNG production plant at an onshore gas field.

5 [0017]

The natural gas supply line 11 from the gas field 10 at first leads to the heat exchanger 20. The heat exchanger 20 is for performing heat exchange between natural gas produced from the gas field 10 and carbon dioxide gas that has been removed from the natural gas and collected in order to precool the natural gas.

10 [0018]

The heat exchanger 20 and the CO₂ liquefying and removing device 31 are connected via a natural gas supply line 21 for supplying the precooled natural gas. The CO₂ liquefying and removing device 31 compresses and cools the natural gas and utilizes vaporization heat of a liquefied portion of CO₂ to further cool the natural gas, thereby liquefying most of the carbon dioxide contained in the natural gas to prompt vapor-liquid separation between methane gas as a main component of the natural gas and liquid carbon dioxide. The carbon dioxide has a vapor pressure of about 3.4 MPa(G) at 0°C and is easier to liquefy when being compressed and cooled. This enables vapor-liquid separation between the carbon dioxide and methane as a main component of the natural gas.

20 [0019]

The CO₂ liquefying and removing device 31 and the CO₂ absorber 50 are connected via a natural gas supply line 32 for supplying the natural gas from which carbon dioxide has been removed. Also, provided between the CO₂ liquefying and removing device 31 and the heat exchanger 20 are a CO₂ recovery line 33 for supplying liquefied carbon dioxide, i.e., liquid carbon dioxide, a vapor-liquid separator 34 for vapor-liquid separation between the

25

liquid carbon dioxide and vaporized carbon dioxide, i.e., carbon dioxide gas, and a CO₂ supply line 35 for supplying the vaporized, carbon dioxide gas. Moreover, a CO₂ return line 36 for supplying the liquid carbon dioxide is provided between the vapor-liquid separator 34 and the CO₂ liquefying and removing device 31. The liquid carbon dioxide undergoes vaporization in the CO₂ liquefying and removing device 31, and vaporization heat thereof enables liquefaction and separation of CO₂ in the natural gas. The CO₂ liquefying and removing device 31 is further provided with a CO₂ discharge line 38 for discharging carbon dioxide gas utilized for this liquefaction and separation.

[0020]

The vapor-liquid separator 34 can separate carbon dioxide gas that has been produced by vaporization due to any pressure loss or heat radiation in the line 33. After the decompression and expansion, the temperature of carbon dioxide is further decreased to about -100°C, for example. Accordingly, the vapor-liquid separator 34, the CO₂ supply line 35, and the CO₂ return line 36 have to be those capable of supplying such low-temperature carbon dioxide gas to the heat exchanger 20. The heat exchanger 20 is further provided with a CO₂ discharge line 37 for discharging carbon dioxide gas used for heat exchange.

[0021]

The CO₂ absorber 50 is optionally provided aiming to remove small amounts of carbon dioxide that could not be removed by the CO₂ liquefying and removing device 31.

The CO₂ absorber 50 can be a conventional device that sprays a carbon dioxide absorbing solution into natural gas to prompt vapor-liquid contact so that the absorbing solution can absorb and remove the carbon dioxide in the natural gas. In general, the CO₂ absorber 50 includes equipment such as an absorption tower (not shown) that brings natural gas into contact with an absorbing solution, and a regeneration tower (not shown) that heats the absorbing solution that has absorbed carbon dioxide, to release the carbon dioxide thereby to

restore the absorbing solution. The carbon dioxide absorbing solution can be an amine-based absorbing solution such as a monoethanolamine solution. In this embodiment, most carbon dioxide is removed by the CO₂ liquefying and removing device 31 before being processed in the CO₂ absorber 50. Accordingly, compared to the configuration not equipped with the CO₂ liquefying and removing device 31, requisite energy for restoring the absorbing solution can be reduced considerably.

[0022]

The CO₂ absorber 50 and the natural gas cooler 41 are connected via a natural gas supply line 51 for supplying natural gas from which even the slight amount of carbon dioxide has been removed. If the CO₂ absorber 50 is not provided, the CO₂ liquefying and removing device 31 and the natural gas cooler 41 are connected via the aforementioned natural gas supply line 32.

[0023]

The natural gas cooler 41 is to cool natural gas in pressurized state by means of a refrigerant, and can be any known device for cooling natural gas. The natural gas cooler 41 is equipped with a compressor to pressurize and cool a refrigerant for repeated use. The refrigerant can be any known refrigerant for cooling natural gas, e.g., a mixed refrigerant of propane, ethane, etc.

[0024]

The natural gas cooler 41 and the natural gas liquefying device 43 are connected via a natural gas supply line 42 for supplying cooled natural gas. The natural gas liquefying device 43 is to let the cooled natural gas expand to near atmospheric pressure to obtain distributable, liquefied natural gas (LNG) at near atmospheric pressure. This device can be any known device for liquefying natural gas. The natural gas liquefying device 43 is provided with an LNG supply line 44 for storing and shipping out LNG.

[0025]

According to the thus-configured natural gas liquefaction system, natural gas produced from the gas field 10 is first supplied to the heat exchanger 20 via the temperature natural gas supply line 11. At this time, the natural gas generally has a pressure of about 1 to 5 9 MPa(G) and a temperature of about 0 to 200°C. If the pressure is insufficient, the natural gas may be compressed by any compressor (not shown). The natural gas is then precooled by the heat exchanger 20 using carbon dioxide gas supplied from the CO₂ supply line 35.

[0026]

Next, the precooled natural gas is supplied to the CO₂ liquefying and removing 10 device 31 in the CO₂ removing unit 30 via the natural gas supply line 21. The natural gas is first compressed and cooled there so as to partially liquefy carbon dioxide in the natural gas and separate the liquefied carbon dioxide from the natural gas through vapor-liquid separation. Then, vaporization heat of the liquefied carbon dioxide is utilized to further cool the natural gas. This makes it possible to decrease a carbon dioxide concentration in the natural gas 15 down to about 10 mol% or lower, for example.

[0027]

The separated liquid carbon dioxide is supplied to the vapor-liquid separator 34 via the CO₂ recovery line 33 to separate carbon dioxide gas that has been vaporized due to a pressure loss or heat radiation in the line 33. The separated carbon dioxide gas, being at 20 saturated vapor temperature, can be utilized as cold energy. Thus, it is supplied to the heat exchanger 20 via the CO₂ supply line 35 to cool the natural gas. Also, the low-temperature liquefied carbon dioxide, which has been separated by the vapor-liquid separator 34, is supplied to the CO₂ liquefying and removing device 31 via the CO₂ return line 36, and vaporized there and used to liquefy carbon dioxide in the natural gas. The carbon dioxide 25 gases, which have been used for cooling in the heat exchanger 20 and the CO₂ liquefying

removing device 31, are released to the outside via the CO₂ discharge lines 37 and 38, respectively, or are transported to predetermined recovery equipment (not shown).

[0028]

The natural gas, from which liquefied carbon dioxide has been separated, is supplied to the CO₂ absorber 50 via the natural gas supply line 32 in order to further lower its carbon dioxide concentration. The carbon dioxide in the natural gas is removed there by an absorbing solution. The CO₂ absorber 50 can lower the carbon dioxide concentration in the natural gas to near 0 to less than 0.5 mol%, for example.

[0029]

The natural gas, from which the carbon dioxide has been thus removed, is supplied to the natural gas cooler 41 and natural gas liquefying device 43 of the natural gas liquefying unit 40 via the natural gas supply line 51, and then cooled and liquefied using a refrigerant. The natural gas liquefying unit 40 follows a general process for liquefying natural gas and thus, its detailed description is omitted here.

[0030]

According to the natural gas liquefaction system of this embodiment, since natural gas contains carbon dioxide at high concentration, the CO₂ liquefying and removing device 31 liquefies and removes the carbon dioxide. Then, the removed liquid carbon dioxide is vaporized to lower its temperature and in turn used to precool natural gas prior to the removal of carbon dioxide, thus making it possible to save a significant amount of energy necessary for producing LNG from natural gas produced from a gas field, compared to removing carbon dioxide by amine-based absorption only.

[0031]

In the above embodiment, the liquid carbon dioxide, which has been obtained by separation in the CO₂ liquefying and removing device, is further separated by the vapor-liquid

separator 34 and only the resultant carbon dioxide gas is supplied to the heat exchanger 20.

However, the present invention is not limited to such a configuration and instead, the liquid carbon dioxide, which has been obtained by separation in the CO₂ liquefying and removing device, can be supplied to the heat exchanger 20 via a liquid CO₂ supply line 39 so as to cool the natural gas, as shown in Fig. 2.

[0032]

According to the above configuration, although the carbon dioxide is at a relatively high temperature because of not being vaporized, requisite energy for producing LNG from natural gas produced from a gas field can be significantly reduced compared to removing carbon dioxide by amine-based absorption only. To give another advantage thereof, carbon dioxide which has been used for cooling in the heat exchanger 20 is discharged via the CO₂ discharge line 37 in the form of a mixture of gas and liquid and thus is easily applicable to CCS (Carbon dioxide Capture and Storage), EOR (Enhanced Oil Recovery), etc.

EXAMPLES

[0033]

Using the natural gas liquefaction system of the illustrated embodiment in Fig. 1, requisite energy for producing LNG from natural gas produced from a gas field is simulated (Example 1). Tables 1 to 3 show simulation results. Tables 4 to 6 show simulation results with the natural gas liquefaction system of the illustrated embodiment in Fig. 2 (Example 2). Fig. 3 shows a system for removing carbon dioxide by an amine-based absorption only for comparison (Comparative Example) and corresponding simulation results are shown in Tables 7 to 9. In Fig. 3, a larger-scale CO₂ absorber 52 than the CO₂ absorber 50 of this embodiment is used to absorb and remove high content of carbon dioxide. Furthermore, a natural gas precooling device 45 is provided just upstream of the natural gas cooler 41 so as to

precool natural gas under the same conditions as in this embodiment. Similar to the natural gas cooler 41, the natural gas precooling device 45 is configured to compress and cool a refrigerant so as to cool natural gas.

[0034]

5 Table 1

	Line 11		Line 33		Line 32		Line 51		Line 44	
Composition	kmol/h	mol%	kmol/h	mol%	kmol/h	mol%	kmol/h	mol%	kmol/h	mol%
CH ₄	52582	30.0	7582	6.0	45000	92.0	45000	100.0	41575	100.0
CO ₂	122691	70.0	118778	94.0	3913	8.0	0	0.0	0	0.0
Total	175273	100.0	126360	100.0	48913	100.0	45000	100.0	41575	100.0

[0035]

Table 2

	Line 11	Line 21	Line 35	Line 32	Line 51	Line 44
Pressure (kg/cm ² (G))	64	56	0	49	49	0.4
Temperature (°C)	30	0.7	-91	-73	-63	-161

[0036]

Table 3

	Energy consumption (GJ/h)
CO ₂ liquefying and removing device 31	172.0
CO ₂ absorber 50	173.6
Heat exchanger 20 (precool)	N.A.
Natural gas cooler 41	71.1
Total	416.7

[0037]

Table 4

	Line 11		Line 39		Line 32		Line 51		Line 44	
Composition	kmol/h	mol%	kmol/h	mol%	kmol/h	mol%	kmol/h	mol%	kmol/h	mol%
CH ₄	52582	30.0	7582	6.0	45000	92.0	45000	100.0	41575	100.0
CO ₂	122691	70.0	118778	94.0	3913	8.0	0	0.0	0	0.0
Total	175273	100.0	126360	100.0	48913	100.0	45000	100.0	41575	100.0

[0038]

Table 5

	Line 11	Line 21	Line 39	Line 32	Line 51	Line 44
Pressure (kg/cm ² (G))	64	56	50	49	49	0.4
Temperature (°C)	30	0.7	0.7	-73	-63	-161

5 [0039]

Table 6

	Energy consumption (GJ/h)
CO ₂ liquefying and removing device 31	813.0
CO ₂ absorber 50	173.6
Heat exchanger 20 (precool)	N.A.
Natural gas cooler 41	71.1
Total	1,057.7

[0040]

Table 7

	Line 12		Line 46		Line 44	
Composition	kmol/h	mol%	kmol/h	mol%	kmol/h	mol%
CH ₄	52582	30.0	45000	100.0	41575	100.0
CO ₂	122691	70.0	0	0.0	0	0.0
Total	175273	100.0	45000	100.0	41575	100.0

[0041]

Table 8

	Line 12	Line 46	Line 44
Pressure (kg/cm ² (G))	64	56	0.4
Temperature (°C)	30	-52	-161

5 [0042]

Table 9

	Energy consumption (GJ/h)
CO ₂ absorber 52	1,328.9
Natural gas precooling device 45	47.7
Natural gas cooler 41	71.1
Total	1,447.7

[0043]

Table 1 shows compositions of gases and liquids in each of the natural gas supply lines 11, 32, and 51, the CO₂ recovery line 33, and the LNG supply line 44. Table 2 shows the pressure and temperature of gases or liquids in each line. Table 3 shows values of energy consumed by the CO₂ liquefying and removing device 31, the CO₂ absorber 50, the heat

10

exchanger 20, and the natural gas cooler 41. Tables 4 and 7 show compositions in the same manner as Table 1. Tables 5 and 8 show the pressure and temperature in the same manner as Table 2. Tables 6 and 9 show energy consumption in the same manner as Table 3. In Examples 1 and 2, simulation was conducted so that the same amount of LNG can be finally obtained, considering the fact that methane gas as a main component of natural gas may be partially removed as well upon removing carbon dioxide in liquid state from the natural gas.

[0044]

As shown in Tables 7 to 9, in Comparative Examples, provided that natural gas produced from a gas field contains carbon dioxide at very high concentration such as 70% (Line 12), large amounts of energy such as about 1300GJ/h was consumed in reducing the carbon dioxide down to near 0% by the CO₂ absorber (Line 46). In contrast, in Examples 1 and 2, as shown in Tables 1 and 4, even if the carbon dioxide concentration was also as high as 70% (Line 11), and the concentration was first reduced down to 8% by the CO₂ liquefying and removing device (Line 32) and then further reduced to 0% by the CO₂ absorber (Line 51), the energy consumption for both was only about 300GJ/h in total as shown in Tables 3 and 6.

[0045]

Also, as shown in Tables 7 to 9, in Comparative Examples, energy of about 120 GJ/h was required in total for two-stage cooling processes, i.e., precooling and cooling of natural gas for producing LNG. In contrast, in Examples 1 and 2, carbon dioxide removed from natural gas can be recycled as cold energy for precooling natural gas. Thus, as shown in Tables 3 and 6, requisite energy for cooling can be reduced compared to Comparative Examples.

REFERENCE NUMERALS

[0046]

	1	Natural gas liquefaction system
	10	Gas field
5	20	Heat exchanger
	30	CO ₂ removing unit
	31	CO ₂ liquefying and removing device
	34	Vapor-liquid separator
	40	Natural gas liquefying unit
10	41	Natural gas cooler
	43	Natural gas liquefying device
	50	CO ₂ absorber

What is claimed is:

1. A natural gas liquefaction system comprising:
a vapor-liquid separator configured to remove carbon dioxide in liquid state from
5 natural gas containing carbon dioxide;
a precooling device configured to use the removed carbon dioxide to precool the
natural gas containing carbon dioxide; and
a natural gas liquefying device configured to cool the natural gas from which the
carbon dioxide has been removed, so as to produce liquefied natural gas (LNG).

10

2. The natural gas liquefaction system according to claim 1, further comprising
vaporizing means configured to vaporize the carbon dioxide removed by the vapor-liquid
separator and supply the vaporized carbon dioxide to the precooling device.

- 15 3. The natural gas liquefaction system according to claim 1, wherein the precooling
device is configured to use the removed carbon dioxide still in liquid state for the precooling.

4. The natural gas liquefaction system according to any one of claims 1 to 3, further
comprising a carbon dioxide absorbing and removing device configured to further bring the
20 natural gas from which the carbon dioxide has been removed by the vapor-liquid separator
into contact with a carbon dioxide absorbing solution so as to further remove carbon dioxide
from the natural gas.

5. A method for producing liquefied natural gas, comprising the steps of:
25 removing carbon dioxide in liquid state from natural gas containing carbon dioxide;

using the removed carbon dioxide to precool the natural gas containing carbon dioxide; and

cooling the natural gas from which the carbon dioxide has been removed, so as to produce liquefied natural gas (LNG).

5

6. The method for producing liquefied natural gas according to claim 5, wherein the removed carbon dioxide is used in vaporized state or still in liquid state for precooling.

7. The method for producing liquefied natural gas according to claim 5 or 6, further
10 comprising a step of further bringing the natural gas into contact with a carbon dioxide absorbing solution to further remove carbon dioxide from the natural gas after the step of removing the carbon dioxide in liquid state.