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(54) [Title of the Invention]

Device and Method For Concentrating Methane Gas, and Device and Method For Producing Fuel Gas

(57) [Abstract]

[Problem]

To provide a methane gas concentrating device which is able to obtain high-concentration methane gas at a high recovery rate.

[Solution]

The methane gas concentrating device 1 of the present invention at least separates carbon dioxide from a mixed gas containing methane gas and carbon dioxide and concentrates the methane gas. The methane gas concentrating device comprises: a first concentrating device 11 for concentrating methane gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas; a second concentrating device 12 for further concentrating the methane gas by using a separating membrane allowing the carbon dioxide to preferentially permeate from the non-permeating gas of the first concentrating device 11; and a recovery device 13 for recovering the methane gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating device 11. In this way, high-concentration methane gas can be obtained at a high recovery rate.

[Selected Drawing] FIG. 1

[Claims]

[Claim 1]

A methane gas concentrating device for at least separating carbon dioxide from a mixed gas containing methane gas and carbon dioxide and concentrating the methane gas, the methane gas concentrating device comprising:

- a first concentrating device for concentrating methane gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas;

- a second concentrating device for further concentrating the methane gas by using a separating membrane allowing the carbon dioxide to preferentially permeate from the non-permeating gas of the first concentrating device; and

- a recovery device for recovering the methane gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating device.

[Claim 2]

The methane gas concentrating device according to claim 1, wherein the permeating gas of the second concentrating device and the non-permeating gas of the recovery device are returned to the introduction side of the first concentrating device.

[Claim 3]

The methane gas concentrating device according to claim 1 or claim 2, wherein the surface areas of the separating membranes of the first concentrating device and the second concentration device are equal.

[Claim 4]

The methane gas concentrating device according to any one of claims 1 through 3, wherein the surface area of the separating membrane of the recovery device is smaller than the surface area of the separating membrane of the first concentrating device.

[Claim 5]

A methane gas concentrating method for at least separating carbon dioxide from a mixed gas containing methane gas and carbon dioxide and

concentrating the methane gas, the methane gas concentrating method comprising:

- a first concentrating step for concentrating methane gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas;

- a second concentrating step for further concentrating the methane gas by using a separating membrane allowing the carbon dioxide to preferentially permeate from the non-permeating gas of the first concentrating step; and

- a recovery step for recovering the methane gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating step.

[Claim 6]

A device for producing a fuel gas containing methane gas and a high-calorie gas for adjusting the calorific value, the fuel gas producing device comprising:

- a high-calorie gas adding means for adding a high-calorie gas to biogas obtained from degraded organic matter to create a mixed gas containing biogas and high-calorie gas;

- a first concentrating device for concentrating methane gas and high-calorie gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas; and

- a recovery device for recovering the methane gas and the high-calorie gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating device.

[Claim 7]

The fuel gas producing device according to claim 6, wherein the adding means adds high-calorie gas to the biogas upstream from a boosting means for boosting the pressure of the gas introduced to the first concentrating device.

[Claim 8]

The fuel gas producing device according to claim 6 or claim 7, wherein the surface area of the separating membrane of the recovery device is smaller than the surface area of the separating membrane of the first concentrating device.

[Claim 9]

A method for producing a fuel gas containing methane gas and a high-calorie gas for adjusting the calorific value, the fuel gas producing method comprising:

- a high-calorie gas adding step for adding a high-calorie gas to biogas obtained from degraded organic matter to create a mixed gas containing biogas and high-calorie gas;

- a first concentrating step for concentrating methane gas and high-calorie gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas; and

- a recovery step for recovering the methane gas and the high-calorie gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating step.

[Detailed Description of the Invention]

[Technical Field]

[0001]

The present invention relates to a methane gas concentrating device and method for separating carbon dioxide from a mixed gas containing methane gas and carbon dioxide to concentrate the methane gas, and to a producing device and method for a fuel gas containing methane gas and a high-calorie gas used to adjust the calorific level.

[Background Art]

[0002]

Technologies have been developed for generating biogas containing primarily methane gas and carbon dioxide by breaking down and anaerobically fermenting organic waste such as human waste, livestock waste, sludge, sewage and garbage using methane-fermenting bacteria, and for effectively utilizing this biogas.

[0003]

Several recovery techniques have been developed for separating this biogas into high-concentration methane and carbon dioxide. Membrane separation can be used in small- to mid-sized facilities.

[0004]

In membrane separation, polymer membranes separate the gas components by taking advantage of the different permeation rates of the components. Pressurized gas can be separated into gas components simply by passing the components through a membrane, the separation membrane can be selected based on the type of gas and the amount of gas to be treated, and multiple separation membranes can be arranged if necessary in parallel (see Patent Documents 1-3) or in series (see Patent Document 4).

[Patent Document 1] JP11-003723A

[Patent Document 2] JP2001-000949A

[Patent Document 3] JP2006-507385A

[Patent Document 4] JP2007-254572A

[Disclosure of the Invention]

[Problem Solved by the Invention]

[0005]

However, when multiple separation membranes are arranged in parallel, the recovery rate can be improved but high-concentration methane gas is difficult to obtain. When multiple separation membranes are arranged in parallel, high-concentration methane gas can be obtained, but the recovery rate is difficult to raise. There are currently no methane gas concentrating devices that can obtain high-concentration methane gas at a high recovery rate. When a fuel gas is to be obtained in which biogas containing primarily carbon dioxide and methane is used as the raw material gas, a sufficiently high calorific value cannot be obtained from the methane gas alone.

[0006]

In light of this problem, it is an object of the present invention to provide a methane gas concentrating device and method, and a fuel gas producing device and method which are able to obtain high-concentration methane gas at a high recovery rate.

[Means of Solving the Problem]

[0007]

In order to achieve this object, the present invention is a methane gas concentrating device for at least separating carbon dioxide from a mixed gas containing methane gas and carbon dioxide and concentrating the methane gas, the methane gas concentrating device including:

- a first concentrating device for concentrating methane gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas;

- a second concentrating device for further concentrating the methane gas by using a separating membrane allowing the carbon dioxide to preferentially permeate from the non-permeating gas of the first concentrating device; and

- a recovery device for recovering the methane gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating device.

[0008]

In order to achieve this object, the present invention is also a methane gas concentrating method for at least separating carbon dioxide from a mixed gas containing methane gas and carbon dioxide and concentrating the methane gas, the methane gas concentrating method including:

- a first concentrating step for concentrating methane gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas;

- a second concentrating step for further concentrating the methane gas by using a separating membrane allowing the carbon dioxide to preferentially permeate from the non-permeating gas of the first concentrating step; and

- a recovery step for recovering the methane gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating step.

[0009]

In order to achieve this object, the present invention is also a device for producing a fuel gas containing methane gas and a high-calorie gas for adjusting the calorific value, the fuel gas producing device including:

- a high-calorie gas adding means for adding a high-calorie gas to biogas obtained from degraded organic matter to create a mixed gas containing biogas and high-calorie gas;

- a first concentrating device for concentrating methane gas and high-calorie gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas; and

- a recovery device for recovering the methane gas and the high-calorie gas by using a separating membrane allowing the carbon dioxide to further

preferentially permeate from the permeating gas of the first concentrating device.

[0010]

In order to achieve this object, the present invention is also a method for producing a fuel gas containing methane gas and a high-calorie gas for adjusting the calorific value, the fuel gas producing method comprising:

- a high-calorie gas adding step for adding a high-calorie gas to biogas obtained from degraded organic matter to create a mixed gas containing biogas and high-calorie gas;

- a first concentrating step for concentrating methane gas and high-calorie gas by using a separating membrane allowing carbon dioxide to preferentially permeate from the mixed gas; and

- a recovery step for recovering the methane gas and the high-calorie gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating step.

[Effect of the Invention]

[0011]

The device and method for concentrating methane gas in the present invention are able to obtain high-concentration methane gas by separating out the carbon dioxide and concentrating the methane gas using separating membranes in two stages: a first stage and a second stage. Because carbon dioxide is separated out and methane gas is recovered by passing permeable gas through the separating membrane in the first stage, the methane gas recovery rate can be improved significantly. High-concentration methane gas can be obtained at a high recovery rate even when the mixed gas contains less than 60% methane gas, and the mixed gas has been contaminated with impure gases such as air. After methane gas has been recovered at a high recovery rate, a high-concentration of carbon dioxide gas can be obtained as an exhaust gas. In other words, the device can simultaneously function as a carbon dioxide gas recovery device.

[0012]

When, in the methane gas concentrating device and method of the present invention, the permeating gas of the second concentrating device (or step) and the non-permeating gas of the recovery device are returned to the introduction side of the first concentrating device (or step), the carbon dioxide gas and methane gas passing through the second concentrating

device (or step) can be reintroduced to the first concentrating device (or step), the methane gas that has not passed through the recovery device can be reintroduced to the first concentrating device (or step), and the methane gas concentration and recovery rate can be improved.

[0013]

When, in the methane gas concentrating device and method of the present invention, the surface areas of the separating membranes of the first concentrating device (or step) and the second concentrating device (or step) are substantially equal, the substantially equal surface areas of the separating membranes of the first concentrating device (or step) and the second concentrating device (or step) advantageously improve efficiency because the first concentrating device and the second concentrating device are concentrating devices using similar separating membranes. Also, because the difference between the introduction pressure of the first concentrating device (or step) and the introduction pressure of the second concentrating device (or step) is small, the substantially equal surface areas of the separating membranes mean the concentration performance of the first concentrating device (or step) and the concentration performance of the second concentrating device (or step) are nearly identical. In this way, the methane gas concentration and recovery rate can be improved.

[0014]

When, in the methane gas concentrating device and method of the present invention, the surface area of the separating membrane of the recovery device (or step) is smaller than the surface area of the separating membrane of the first concentrating device (or step), methane gas permeates the separating membrane of the recovery device (or step) less easily, and the methane gas concentration and recovery rate are improved.

[0015]

When, in the methane gas concentrating device and method of the present invention, the pressure difference before and after the separating membrane of the recovery device (or step) is 0.1 MPa or less, methane gas permeates the separating membrane of the recovery device (or step) less easily, and the methane gas concentration and recovery rate are improved.

[0016]

In the fuel gas producing device and method of the present invention, a high-calorie gas is added to the biogas to obtain a mixed gas containing

biogas and high-calorie gas, and carbon dioxide is separated out of the mixed gas to concentrate the methane gas and high-calorie gas. By adding high-calorie gas to the biogas at a predetermined mixing ratio, a fuel gas of a specific calorific value can be obtained in which methane gas and high-calorie gas have been mixed together at a predetermined ratio. In this way, the stable production of high-quality fuel gas with a sufficient calorific value from biogas raw materials is easily managed.

[0017]

When, in the fuel gas producing device and method of the present invention, the adding means adds a high-calorie gas to biogas upstream from the boosting means for boosting the pressure of the gas introduced to the first concentrating device (or step), the high-calorie gas is added to the low-pressure biogas and liquefaction of the high-calorie gas is prevented. This prevents changes in the mixing ratio of the methane gas and the high-calorie gas after permeation of the separating membrane, and the stable production of high-quality fuel gas is easily managed.

[0018]

When, in the fuel gas producing device and method of the present invention, the surface area of the separating membrane of the recovery device (or step) is smaller than the surface area of the separating membrane of the first concentrating device (or step), methane gas permeates the separating membrane of the recovery device (or step) less easily, and the methane gas concentration and recovery rate are improved.

[Best Mode of Carrying Out the Invention]

[0019]

The following is an explanation of the best mode of carrying out the present invention.

[0020]

FIG. 1 is a diagram showing the methane gas concentration device and fuel gas producing device in an embodiment of the present invention.

[0021]

This fuel gas producing device includes a methane gas concentrating device 1 which separates out carbon dioxide from a mixed gas containing at least

methane gas and carbon dioxide to concentrate the methane gas, and produces fuel gas containing this methane gas and a high-calorie gas for adjusting the calorific value.

[0022]

The fuel gas producing device uses biogas obtained by breaking down organic matter as the raw material gas. The biogas is generated in a digestion tank (not shown) used to break down organic waste with anaerobic microorganisms such as methane bacteria in an anaerobic atmosphere, and the biogas contains carbon dioxide in addition to a high concentration of methane.

[0023]

The digestion tank can be cylindrical, rectangular or egg-shaped. The digestion tank can have a single-stage structure in which a stirring device is provided to stir and circulate the generated digestion gas, or can have a dual-stage structure including an acid fermentation tank for breaking down high molecular weight organic matter such as proteins into low molecular weight organic matter such as organic acids using facultative anaerobes, and a solubilization tank for breaking down and dissolving the oil and fat content at high temperatures.

[0024]

A propane gas addition passage 5 communicating with a compressed LPG cylinder 4 is connected to the raw material gas introduction passage 3 to introduce the raw material gas to the methane gas concentrating device 1, and to add propane gas as high-calorie gas to the biogas obtained by breaking down organic matter, resulting in a mixed gas containing biogas and propane gas. The compressed LPG cylinder 4 and the propane gas addition passage 5 function as the high-calorie gas adding means of the present invention. A propane gas addition passage 5a can be provided as indicated by the dashed lines in the drawing in place of the propane gas addition passage 5 to add the high-calorie gas downstream from the compressor 6.

[0025]

The high-calorie gas does not have to be propane gas. Ethane gas or butane gas can be used. These high-calorie gases can be used alone or in combinations of two or more.

[0026]

The high-calorie gas for adjusting the calorific value is added to biogas containing methane gas and carbon dioxide to obtain a mixed gas. By separating out the carbon dioxide from the mixed gas, a fuel gas can be obtained which includes a high-calorie gas added to the methane gas at a predetermined percentage. Here, the percentage of high-calorie gas added is established so that the calorific value of the final fuel gas meets, for example, town gas standards.

[0027]

After propane gas has been added to the biogas at a predetermined ratio, the resulting propane gas is raised to a predetermined pressure (gauge pressure) from 0.5 to 0.9 MPa using a compressor 6, and then introduced to a methane gas compressing device 1. In the present embodiment, the high-calorie gas adding means is used to add the high-calorie gas to the biogas upstream from the compressor 6 serving as the boosting means for boosting the pressure of the gas introduced to the first concentrating device 11 described below.

[0028]

The methane gas concentrating device 1 is used to separate out the carbon dioxide from mixed gas containing methane gas and carbon dioxide in order to concentrate the methane gas. The mixed gas in the present embodiment includes propane gas added as a high-calorie gas in addition to the methane gas and carbon dioxide, so the methane gas and high-calorie gas are concentrated by separating out the carbon dioxide from the mixed gas. In addition to methane gas, high-calorie gas and carbon dioxide, the mixed gas sometimes includes other gases such as air.

[0029]

The methane gas concentrating device 1 includes a first concentrating device 11, a second concentrating device 12 and a recovery device 13. Each of these devices contains a separating membrane.

[0030]

The first concentrating device 11 concentrates methane gas by using a separating membrane which allows carbon dioxide to preferentially permeate it from the mixed gas. The pressure of the mixed gas introduced to the first concentrating device 11 ranges from 0.5 to 0.9 MPa (gauge pressure). The

permeating gas of the separating membrane in the first concentrating device 11 is gas containing methane gas and high-calorie gas which has passed through the separating membrane in addition to the carbon dioxide which has passed through the separating membrane. This gas is introduced to the recovery device 13. The non-permeating gas of the separating membrane in the first concentrating device 11 is gas containing some carbon dioxide which has not passed through the separating membrane in addition to the methane gas and the high-calorie gas. This gas is introduced to the second concentrating device 12.

[0031]

The second concentrating device 12 further concentrates the methane gas and the high-calorie gas by using a separating membrane which allows carbon dioxide to preferentially permeate from the non-permeating gas of the first concentrating device 11. The pressure at which the mixed gas is introduced to the second concentrating device 12 is as close as possible to the introduction pressure to the first concentrating device 11 considering the flow rate cannot be adjusted and is from 0.005 to 0.05 MPa lower than the introduction pressure to the first concentrating device 11. The permeation gas of the separating membrane in the second concentrating device 12 is gas containing methane gas in addition to the carbon dioxide passing through the separating membrane. This gas is returned to the introduction side of the first concentrating device 11 upstream from the compressor 6 and is reintroduced to the first concentrating device 11. The non-permeating gas of the separating membrane in the second concentrating device 12 is mixed gas in which methane gas and high-calorie gas have been mixed at a predetermined ratio. This gas is sent to the post-production stage as the product gas.

[0032]

In this example, the surface areas of the separating membrane in the first concentrating device 11 and the separating membrane in the second concentrating device 12 are nearly equal. This makes installation more efficient because the first concentrating device 11 and the second concentrating device 12 use the same separating membrane.

[0033]

The recovery device 13 recovers the methane gas and high-calorie gas by using a separating membrane allowing the carbon dioxide to further preferentially permeate from the permeating gas of the first concentrating device 11. In other words, the gas introduced to the recovery device 13 is

gas containing the carbon dioxide, methane gas and high-calorie gas which has passed through the first concentrating device 11. The carbon dioxide is preferentially allowed to pass through this separating membrane from this gas in order to recover the methane gas and the high-calorie gas.

[0034]

The non-permeating gas of the separating membrane in the recovery device 13 is gas containing recovered methane gas and high-calorie gas. This gas is returned to the introduction side of the first concentrating device 11 upstream from the compressor 6 and is reintroduced to the first concentrating device 11. The permeating gas of the separating membrane in the recovery device 13 is gas primarily containing a high-concentration of carbon dioxide. This is discharged from the exhaust passage 14 or stored in a carbon dioxide tank 15 as a carbon dioxide product.

[0035]

The introduction pressure for introducing the gas to the recovery device 13 is the pressure of the permeating gas of the first concentrating device 11 which is equal to or less than 0.1 MPa (gauge pressure). Preferably, the difference in pressure before and after the separating membrane in the recovery device 13 is 0.1 MPa or less.

[0036]

The surface area of the separating membrane in the recovery device 13 can be the same as the surface area of the separating membrane in the first concentrating device 11. This makes installation more efficient because the recovery device 13 and the second concentrating device 12 use the same separating membrane.

[0037]

The surface area of the separating membrane of the recovery device 13 can be smaller than the surface area of the separating membrane in the first concentrating device 11. This makes it more difficult for the methane gas to pass through the separating membrane of the recovery device 13, and increases the methane gas recovery rate of the recovery device 13.

[0038]

Separating membranes that can be used in the first concentrating device 11, the second concentrating device 12 and the recovery device 13 include

polyimide membranes, polysulfone membranes, cellulose triacetate membranes, polytetrafluoroethylene membranes, polyethersulfone membranes and other polymer gas-separating membranes, as well as carbon membranes and microporous glass composite membranes. Among these, polyimide membranes are preferred because of their high separation coefficients for methane gas and carbon dioxide, and their hydrogen sulfide resistance.

[0039]

The non-permeating gas of the second concentrating device 12 is mixed gas in which methane gas and high-calorie gas have been mixed at a predetermined ratio. This fuel gas is refined and discharged from the product gas discharge passage 16.

[0040]

As described above, fuel gas is obtained in which high-calorie gas has been added to methane gas at a predetermined ratio by separating out carbon dioxide from mixed gas in which a high-calorie gas has been added at a predetermined ratio to biogas containing methane gas and carbon dioxide. The ratio of methane gas to high-calorie gas in the fuel gas product is determined by the initial ratio of high-calorie gas added to the biogas, and the addition ratio is adjusted using a flow regulator 26 provided in the propane gas addition passage 5.

[0041]

Here, a concentration detector 17 is provided in the raw material gas introduction passage 3 to detect the concentration of methane gas in the biogas serving as the raw material gas. When the concentration of methane gas in the raw material gas falls below a predetermined percentage, the raw material valve 18 in the raw material gas introduction passage 3 and the propane valve 19 in the propane gas addition passage 5 are closed to stop the introduction of mixed gas into the methane gas concentrating device 1. When the concentration of methane gas in the raw material gas rises above the predetermined percentage again, the raw material valve 18 and the propane valve 19 are opened, and the introduction of mixed gas into the methane gas concentrating device 1 is resumed. In this way, the concentration of high-calorie gas to methane gas in the fuel gas or product gas can be maintained at a constant level.

[0042]

A concentration detector 17a can be provided in the product gas discharge passage 16 downstream from the methane gas concentrating device 1 instead of providing a concentration detector 17 in the raw material gas introduction passage 3. When the methane gas concentration in the product gas falls outside a predetermined range, the raw material valve 18 in the raw material gas introduction passage 3 and the propane valve 19 in the propane gas addition passage 5 are closed to stop the introduction of mixed gas into the methane gas concentrating device 1 and to prevent product gas whose calorific value falls outside of the appropriate range from filling the high-pressure tank 7.

[0043]

A flow regulator 27 is provided in the product gas discharge passage 16 to regulate the flow rate of the product gas, a compressed odorant gas cylinder 20 and odorant gas addition passage 21 are connected to add an odorant gas to the refined fuel gas, and a buffer tank 22 is connected to temporarily store the product gas containing the added odorant gas. The product gas stored in the buffer tank 22 is compressed using a compressor 23, and stored in the high-pressure tanks 7 of a high-pressure tank unit 24.

[0044]

The fuel gas stored in each high-pressure tank 7 is used to fill compressed fuel gas cylinders 8, which are transported to a facility using the fuel or are supplied as fuel from a supply nozzle 9 to a vehicle with an internal combustion engine.

[0045]

The methane gas concentrating device 1 (and method) in the present embodiment are able to obtain high-concentration methane gas by separating out the carbon dioxide and concentrating the methane gas using separating membranes in two stages: a first stage and a second stage. Because carbon dioxide is separated out and methane gas is recovered by passing permeable gas through the separating membrane in the first stage, the methane gas recovery rate can be improved significantly. High-concentration methane gas can be obtained at a high recovery rate even when the mixed gas contains less than 60% methane gas, and the mixed gas has been contaminated with impure gases such as air. After methane gas has been recovered at a high recovery rate, a high-concentration of carbon dioxide gas can be obtained as an exhaust gas. In other words, the device can simultaneously function as a carbon dioxide gas recovery device.

[0046]

In the fuel gas producing device and method of the present invention, a high-calorie gas is added to the biogas to obtain a mixed gas containing biogas and high-calorie gas, and carbon dioxide is separated out of the mixed gas to concentrate the methane gas and high-calorie gas. By adding high-calorie gas to the biogas at a predetermined mixing ratio, a fuel gas of a specific calorific value can be obtained in which methane gas and high-calorie gas have been mixed together at a predetermined ratio. In this way, the stable production of high-quality fuel gas with a sufficient calorific value from biogas raw materials is easily managed.

[0047]

When the permeating gas of the second concentrating device 12 (or step) and the non-permeating device of the recovery device 13 are returned to the introduction side of the first concentrating device 11 (or step), the carbon dioxide and the methane gas that have permeated through the second concentrating device 12 (or step) are reintroduced to the first concentrating device 11 (or step), the methane gas that has not permeated through the recovery device 13 is reintroduced to the first concentrating device 11 (or step), and the methane gas concentration and recovery rate are improved.

[0048]

When the surface areas of the separating membranes of the first concentrating device 11 (or step) and the second concentrating device 12 (or step) are substantially equal, the substantially equal surface areas of the separating membranes of the first concentrating device 11 (or step) and the second concentrating device 12 (or step) advantageously improve efficiency because the first concentrating device 11 and the second concentrating device 12 are concentrating devices using similar separating membranes. Also, because the difference between the introduction pressure of the first concentrating device 11 (or step) and the introduction pressure of the second concentrating device 12 (or step) is small, the substantially equal surface areas of the separating membranes mean the concentration performance of the first concentrating device 11 (or step) and the concentration performance of the second concentrating device 12 (or step) are nearly identical. In this way, the methane gas concentration and recovery rate can be improved.

[0049]

When the surface area of the separating membrane of the recovery device 13 (or step) is smaller than the surface area of the separating membrane of the first concentrating device 11 (or step), methane gas permeates the separating membrane of the recovery device 13 (or step) less easily, and the methane gas concentration and recovery rate are improved.

[0050]

When the pressure difference before and after the separating membrane of the recovery device 13 (or step) is 0.1 MPa or less, methane gas permeates the separating membrane of the recovery device 13 (or step) less easily, and the methane gas concentration and recovery rate are improved.

[0051]

When the adding means adds a high-calorie gas to biogas upstream from a compressor 6 serving as a boosting means for boosting the pressure of the gas introduced to the first concentrating device 11 (or step), the high-calorie gas is added to the low-pressure biogas and liquefaction of the high-calorie gas is prevented. This prevents changes in the mixing ratio of the methane gas and the high-calorie gas after permeation of the separating membrane, and the stable production of high-quality fuel gas is easily managed.

[Examples]

[0052]

This fuel gas producing device was used to concentrate the methane gas in a mixed gas containing 55 to 60% methane gas and 5% nitrogen gas with the remainder being carbon dioxide. The methane gas concentrating device 1 described above was used to concentrate the methane gas in the example of the present invention. In a first comparative example, the methane gas was concentrated using only the first concentrating device 11, and in a second comparative example, the methane gas was concentrated using the first concentrating device 11 and the second concentrating device 12. The pressure at which the mixed gas is introduced was changed to 0.6 MPa, 0.65 MPa and 0.7 MPa, and the flow rate of the refined gas was changed to 4 m³/hr, 5 m³/hr and 6 m³/hr. The recovery rates for methane gas are shown in Table 1. The flow rate was adjusted by opening and closing a valve (not shown) in the product gas discharge passage 16, and the introduction pressure was adjusted by changing the rotational speed of the compressor 6 at each flow rate.

[0053]

[Table 1]

Examples	Pressure (MPa)	Flow Rate (m ³ /hr)		
		4	5	6
		Yield (%)	Yield (%)	Yield (%)
C. Ex. 1	0.6	64	66	69
	0.65	63	67	71
	0.7	62	68	71
C. Ex. 2	0.6	66	70	77
	0.65	66	66	72
	0.7	63	72	76
Example	0.6	99	99	99
	0.65	99	99	99
	0.7	99	99	-

[0054]

As shown in Table 1, the recovery rate of the example was always 99% or greater, which is higher than the values of both the first comparative example and the second comparative example.

[0055]

In the case of the example of the present invention, the introduction pressure for the mixed gas was changed to 0.6 MPa, 0.65 MPa and 0.7 MPa, the flow rate of the refined gas was changed to 4 m³/hr, 5 m³/hr and 6 m³/hr at each introduction pressure, and the methane gas concentration of the enriched gas was measured in each case. The results are shown in Table 2.

[0056]

[Table 2]

Pressure (MPa)	Refined Gas Flow Rate (m ³ /hr)		
	4	5	6
0.6	89.5%	86.0%	83.6%
0.65	89.9%	87.3%	84.0%
0.7	91.0%	87.4%	-

[0057]

In Table 2, gas generated by a biogas plant served as the raw material gas. The raw material gas contained air in addition to methane and carbon dioxide. Nitrogen gas was mixed with the generated gas, and the measured

value was 90% or less. The nitrogen gas derived from the air was not factored into the methane gas calculations.

[0058]

First, the composition of the refined gas at a mixed gas introduction pressure of 0.6 MPa and at refined gas flow rates of 1 m³/hr and 6 m³/hr was measured. The results are shown in Table 3. The results of measuring the composition of the raw material gas are shown in Table 3.

[0059]

[Table 3]

Refining Pressure (MPa)	Refined Gas Flow Rate (m ³ /hr)	Refined Gas Composition				
		CH ₄ (%)	CO ₂ (%)	N ₂ (%)	O ₂ (%)	Total (%)
0.6	1	95.29	0.00	4.71	0.00	100
0.6	6	82.72	5.63	11.65	0.00	100
Raw Gas Composition		58.37	34.73	5.52	1.38	100

[0060]

As shown in Table 3, the methane concentration was 95.29% and the nitrogen concentration was 4.71% at a refined gas flow rate of 1 m³/hr, and the methane concentration was 82.72% and the nitrogen concentration was 11.65% at a refined gas flow rate of 6 m³/hr. The mixed gas introduction rate was 0.6 MPa in both cases.

[0061]

These results were used to plot the relationship between methane concentration and residual nitrogen concentration in FIG. 2 as an indicator of the separation performance of the separating membrane. The relationship between the methane concentration and the residual nitrogen concentration expressed by Equation (1) is clearly established by the straight line.

$$y \text{ (residual nitrogen concentration)} = -0.5521x \text{ (methane concentration)} + 57.32 \dots (1)$$

[0062]

The residual nitrogen concentration and the residual carbon dioxide concentration in the refined gas were calculated in accordance with Equation

(1) from the measurements in Table 2. The calculated results are shown in Table 4. Because of the permeation rate for permeable gas components expressed by Equation (2), the separation performance changes if the partial pressure difference of the permeable gas components changes. However, because the permeation coefficient of the gases in the separating membrane is an eigenvalue corresponding to the gas components, the effect on the separation performance of the separating member is very small even when the mixed gas introduction pressure changes as long as the methane concentration in the refined gas is the same. Therefore, Equation (1) applies to the measurements for the introduction pressures of 0.65 MPa and 0.7 MPa as well.

$$F = \{P \cdot (P_1 - P_2)\} / L \dots (2)$$

F: Permeation rate of gas components

P: Permeation coefficient of gas components

P1-P2: Partial pressure difference of permeable gas components

L: Thickness of separating membrane

[0063]

[Table 4]

Flow Rate (m ³ /hr)	4			5			6		
Pressure (Mpa)	CH ₄ (%)	CO ₂ (%)	N ₂ (%)	CH ₄ (%)	CO ₂ (%)	N ₂ (%)	CH ₄ (%)	CO ₂ (%)	N ₂ (%)
0.6	89.5	2.6	7.9	86.0	4.2	9.8	83.9	5.2	11.2
0.65	89.9	2.4	7.7	87.3	3.6	9.1	84.0	5.1	10.9
0.7	91.0	1.9	7.1	87.4	3.5	9.1	-	-	-

[0064]

Methane gas concentrations not factoring in the residual nitrogen levels were calculated using the results shown in Table 4. The calculated results are shown in Table 5.

[0065]

[Table 5]

Flow Rate (m ³ /hr)	4		5		6	
Pressure (Mpa)	CH ₄ (%)	CO ₂ (%)	CH ₄ (%)	CO ₂ (%)	CH ₄ (%)	CO ₂ (%)
0.6	97.2	2.8	95.4	4.6	94.1	5.9
0.65	97.4	2.6	96.1	3.9	94.3	5.7
0.7	97.9	2.1	96.1	3.9	-	-

[0066]

It is clear from the results in Table 5 that methane can be concentrated to a methane gas concentration of 94% or greater if the raw material gas does not contain nitrogen. These results represent the methane gas refining performance of the example of the present invention. Therefore, the fuel gas producing device in the example can recover methane gas at a recovery rate of 99% or greater while maintaining sufficient methane gas separation performance.

[Brief Explanation of the Drawings]

[0067]

[FIG. 1]

FIG. 1 is a diagram showing the methane gas concentration device and fuel gas producing device in an embodiment of the present invention.

[FIG. 2]

FIG. 2 is a graph plotting the relationship between methane concentration and residual nitrogen concentration as an indicator of the separation performance of the separating membrane.

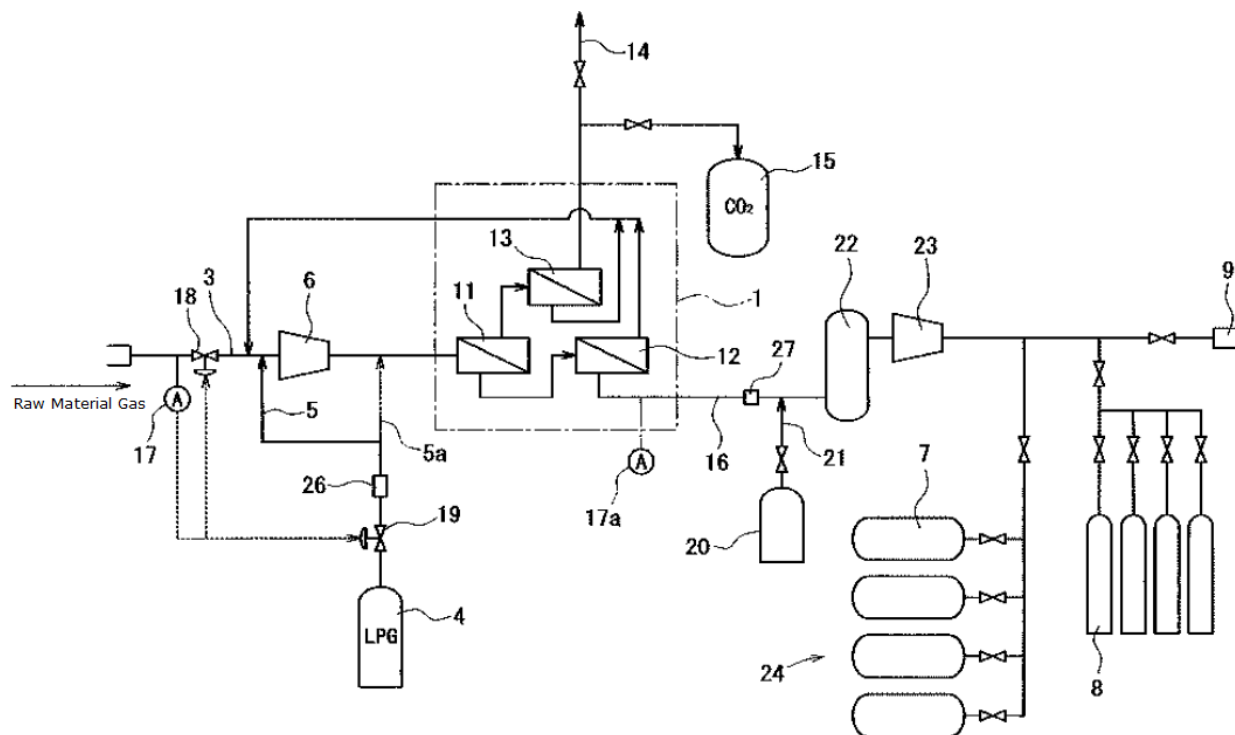
[Key to the Drawings]

[0068]

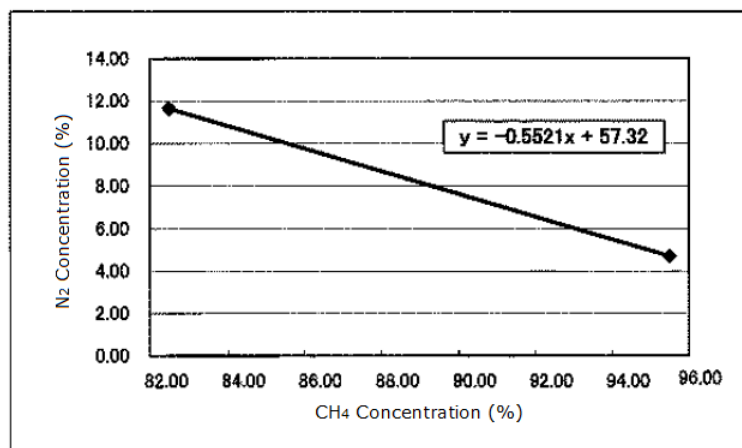
- 1: Methane gas concentrating device
- 3: Raw material gas introduction passage
- 4: Compressed LPG cylinder
- 5: Propane gas addition passage
- 5a: Propane gas addition passage
- 6: Compressor

- 7: High-pressure tank
- 8: Compressed fuel gas cylinder
- 9: Supply nozzle
- 11: 1st concentrating device
- 12: 2nd concentrating device
- 13: Recovery device
- 14: Exhaust passage
- 15: Carbon dioxide tank
- 16: Product gas discharge passage
- 17: Concentration detector
- 17a: Concentration detector
- 18: Raw material valve
- 19: Propane valve
- 20: Compressed odorant gas cylinder
- 21: Odorant gas addition passage
- 22: Buffer tank
- 23: Compressor
- 24: High-pressure gas tank unit
- 26: Flow regulator
- 27: Flow regulator

[FIG. 1]



[FIG. 2]



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[F Terms (Reference)]

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