

APPARATUS AND METHOD FOR SUPPLYING LIQUID FUEL GAS

5 The present invention relates to an apparatus and a method for supplying liquid fuel gas and more particularly relates, for example, to an apparatus and a method capable of supplying liquid fuel gas giving an approximately uniform amount of heat generation to comply with change in the composition of a liquefied natural gas (which may hereafter referred to as “LNG”) serving as a source material.

10 A natural gas (NG) is stored as a liquid source material in an LNG tank for facility in transportation and storage, and a fuel gas obtained by gasification of this is used for a variety of purposes such as for combustion power generation and for city gases.

 Here, it is widely known in the art that the composition of the natural gas is largely dependent on the place at which the natural gas is buried, and the composition of the natural
15 gas must be adjusted in using the natural gas.

 This applies also to what is known as a shale gas that is under development of digging out all over the world in recent years. At this time, a Wobbe index (WI) represented by the following formula 9 may be sometimes used for the adjustment.

$$WI = H / (G)^{1/2} \quad \dots \text{formula 9}$$

20 Then, the Wobbe index WI is determined by the total amount of heat generation H (kcal/m³) and the specific gravity G of the natural gas. When the Wobbe index WI is used as an index, change in the composition of the supplied natural gases does not affect the operation of combustion equipment such as a burner or a combustion furnace when the numerical values of the Wobbe index WI thereof are close to each other.

25 For this reason, in supplying a fuel gas, for example, to a gas turbine or the like (combustion equipment) of a power generation station, there is proposed a heat quantity

controlling method capable of operating the system safely and smoothly by alleviating a rapid change in the amount of heat generation of the fuel gas to be within a range that the gas turbine can follow.

Specifically, referring to Fig. 4, in supplying a fuel gas mixed with a boil off gas (BOG) from a liquefied natural gas tank 101 to a gas turbine 113 through a pipe 105, there is known a heat quantity controlling method of alleviating a discontinuous fluctuation in the heat quantity of the fuel gas passing through the pipe 105, comprising a heat quantity measurement step, a heat quantity adjustment step of supplying a heat quantity adjustment gas to the fuel gas before and after occurrence of heat quantity change in the pipe 105 when heat quantity fluctuation occurs, so as to increase or decrease by a heat quantity approximately equal to the amount of change in the heat quantity of the fuel gas, thereby to stabilize as a gas having a heat quantity equal to that before the change, and thereafter gradually decreasing the amount of the supplied heat quantity adjustment gas and stopping the supply of the heat quantity adjustment gas within a certain period of time, and a fuel gas supplying step (See, for example, Document 1: JP-A-2002-188460).

Here, the reference numeral 102 represents an evaporator; 103 represents a BOG compressor; 104 represents a BOG pipe; 106 represents a heat quantity measurement device; 107 and 108 represent flow rate adjustment valves; 109 represents a heat quantity adjustment apparatus; 110 and 112 represent holders; and 114 represents a heat quantity measurement device.

SUMMARY OF THE INVENTION

However, a heat quantity controlling method such as described above may still raise various problems such as the following.

- i. Generally, the amount of LNG supplied to the combustion equipment may fluctuate due to change in the demand for combustion power generation, city gases, and the like, so that

there is a demand for an apparatus and a method capable of efficiently using the LNG having a stable heat generation amount and the like so as not to affect the combustion state of the combustion equipment even when the amount of the supplied LNG decreases.

ii. Specifically, when the LNG tanks are exchanged and LNGs having different Wobbe indices due to difference in the place of production thereof are supplied to the point of use of the natural gas, there is a possibility of incomplete combustion or, in the worst cases, an accident caused by backfire in the combustion equipment, thereby giving a big problem.

iii. Further, since a composition fluctuation may occur in the natural gas stored in the tank depending also on the time of taking out the natural gas or on the position within the tank of taking out the natural gas, there has been a demand for development of an apparatus capable of controlling the heat generation amount with a quick responsiveness.

iv. Also, for measurement of the composition of natural gases, there is known a method of using the Wobbe index as described in Japanese Industrial Standard K2301:2011 "Method of analyzing and testing fuel gas and natural gas". However, when a heat-reducing gas such as nitrogen gas is used and mixing the heat-reducing gas into a natural gas being in a gaseous phase and having a high heat generation amount (See, for example, paragraph 0009 of Document 1), there has been a case in which a precise control of heat generation amount cannot be made because of a shift of correlation between the measured Wobbe index and the heat generation amount.

20 An object of the present invention is to provide an apparatus and a method for supplying a liquid fuel gas with little fluctuation in the heat generation amount of the fuel gas by controlling the Wobbe index of the fuel gas supplied to combustion equipment quickly and stably even when the composition of the supplied fuel gas fluctuates due to difference in the place of production thereof or in the storage tank.

25 As a result of repetitive eager researches in order to solve the aforementioned problems, the present inventors and others have found out that the aforementioned object can be achieved

by an apparatus and a method for supplying a liquid fuel gas shown below, thereby completing the present invention.

An apparatus for supplying a mixed liquid fuel gas according to the present invention comprising:

- 5 • a liquid source material supplying portion having a storage tank for storing a liquid source material, a supply amount adjusting means for adjusting a supply amount of the liquid source material, and a specific gravity measuring means for measuring a specific gravity of the liquid source material;
- an adjustment fluid supplying portion having a storage tank for storing an
10 adjustment fluid and a supply amount adjusting means for adjusting a supply amount of the adjustment fluid; and a mixing portion having a mixing tank in which the liquid source material supplied from the liquid source material supplying portion is mixed with the adjustment fluid supplied from the adjustment fluid supplying portion and a supply-out portion from which the mixed liquid fuel gas is supplied out, and
- 15 - the supply amount of the adjustment liquid corresponding to the supply amount of the liquid source material is adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material so that a Wobbe index of the mixed liquid fuel gas falls within a predetermined value range, wherein the feedforward control is
20 performed so that the Wobbe index corresponding to a desired heat generation amount range of the mixed liquid fuel gas falls within a predetermined range based on the specific gravity G_{ao} of the mixed liquid fuel gas represented by the following formula 3 while setting a relationship of a

superficial velocity in each space volume V_a , V_o of the liquid source material and the adjustment fluid to be under conditions represented by the following formula 1 and setting a time delay ΔT_a according to the following formula 2, where V_a represents a space volume from the specific gravity measuring means of the liquid source material supplying portion to the mixing tank; G_a represents the specific gravity of the liquid source material; F_a represents a supply flow rate of the liquid source material; V_o represents a space volume from the supply amount adjusting means of the adjustment fluid supplying portion to the mixing tank; G_o represents the specific gravity of the adjustment fluid; and F_o represents a supply flow rate of the adjustment fluid.

10 $(V_a/F_a) > (V_o/F_o)$... formula 1

$\Delta T_a = (V_a/F_a) - (V_o/F_o)$... formula 2

$G_{ao} = (F_a \times G_a + F_o \times G_o) / (F_a + F_o)$... formula 3.

Further, a method for supplying a liquid fuel gas according to the present invention comprises:

- 15
- mixing a liquid source material in a low-temperature liquid state, which is supplied out from a storage tank for storing the liquid source material, adjusted to have a desired supply amount, and thereafter subjected to measurement of a specific gravity thereof, with an

adjustment fluid, which is supplied out from a storage tank for storing the adjustment fluid and subjected to control and adjustment of a supply amount thereof, in a mixing tank so as to prepare a liquid fuel gas; and

- adjusting the supply amount of the adjustment fluid by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material so that a Wobbe index of the liquid fuel gas falls within a predetermined value range.

By such a construction, the Wobbe index of the fuel gas supplied to combustion equipment can be stably controlled, whereby the liquid fuel gas having little fluctuation of the heat generation amount of the fuel gas can be supplied. Specifically, in preparing a liquid fuel gas by mixing a liquid source material (for example, LNG) with an adjustment fluid (for example, nitrogen), rapid and precise control can be made by performing the feedforward control using, as an index, a measured value of the specific gravity of the liquid source material before mixing, so as to adjust the supply amount of the adjustment fluid. Also, rapid and stable control can be made by performing calculation based on the Wobbe index from the measured value of the specific gravity so that the Wobbe index corresponding to a desired heat generation amount falls within a predetermined value range. Furthermore, a uniform and highly stable liquid fuel gas can be prepared by mixing the adjustment fluid into a dissolved state with the liquid source material that is in a low-temperature liquid state or in a supercooled liquid state.

In the above-described apparatus for supplying the liquid fuel gas according to the present invention, the feedforward control is performed so that the Wobbe index corresponding to a desired heat generation amount range of the liquid fuel gas falls within a predetermined range based on the specific gravity G_{ao} of the prepared liquid fuel gas represented by the following formula 3, while setting a relationship of a superficial velocity in each space volume V_a , V_o of the liquid source material and the adjustment fluid to be under conditions represented by the following formula 1 and setting a time delay ΔT_a according to the following

formula 2, where V_a represents a space volume from the specific gravity measuring means of the liquid source material supplying portion to the mixing tank; G_a represents the specific gravity of the liquid source material; F_a represents a supply flow rate of the liquid source material; V_o represents a space volume from the supply amount adjusting means of the adjustment fluid supplying portion to the mixing tank; G_o represents the specific gravity of the adjustment fluid; and F_o represents a supply flow rate of the adjustment fluid.

$$(V_a/F_a) > (V_o/F_o) \quad \dots \text{formula 1}$$

$$\Delta T_a = (V_a/F_a) - (V_o/F_o) \quad \dots \text{formula 2}$$

$$G_{ao} = (F_a \times G_a + F_o \times G_o) / (F_a + F_o) \quad \dots \text{formula 3}$$

In mixing the adjustment fluid into the liquid source material, when there is a difference between the period of time from the time at which the specific gravity of the liquid source material is measured until the time at which the liquid source material is mixed in the mixing tank and the period of time from the time at which the adjustment fluid is controlled until the time at which the adjustment fluid is actually mixed in the mixing tank, the difference may affect the uniformity of the mixed fluid.

For example, when the adjustment fluid controlled to increase the supply amount reaches the mixing tank earlier than the liquid source material supplied at the time of specific gravity measurement that forms the basis of the control, a mixed fluid containing the adjustment fluid having a higher concentration than a controlled value is formed in the mixing tank.

In other words, there is a possibility that, by such a time shift of the control elements, a liquid fuel gas with a spike noise relative to the heat generation amount may be supplied. Also, a shift of the rise characteristics (for example, 90% rise time T_{90}) of the control elements generated by the difference of the flow rates of the two increases the influence of such a time shift.

The present invention has made it possible to prevent generation of the spike noise by restricting the space volume pertaining to the liquid source material and the adjustment fluid

that affects these control elements and setting a control standard of the supply amount of the adjustment fluid to be at the time of start of mixing in the mixing tank to correct the shift from the time of specific gravity measurement of the liquid source material that is actually measured.

The apparatus for supplying the liquid fuel gas according to the present invention further
5 comprises an off gas supplying portion having a supply amount adjusting means for adjusting a supply amount of an off gas generated by evaporation of the liquid source material in the storage tank or an off gas supplied out from another storage tank and a specific gravity measuring means for measuring a specific gravity of the off gas, wherein:

- the liquid source material in a low-temperature liquid state is mixed with the
10 adjustment fluid and the off gas in the mixing tank, and
- the supply amounts of the adjustment liquid and the off gas corresponding to the supply amount of the liquid source material are adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material and a measured value of the specific gravity of the off gas so that a Wobbe index of the mixed liquid fuel gas
15 falls within a predetermined value range.

The method for supplying the liquid fuel gas according to the present invention comprises:

- mixing the liquid source material with the adjustment fluid and an off gas, which is supplied out from the storage tank for storing the liquid source material or from another storage
20 tank, subjected to control and adjustment of a supply amount thereof, and thereafter subjected to measurement of a specific gravity thereof, in a mixing tank so as to prepare a liquid fuel gas; and
- adjusting the supply amounts of the adjustment fluid and the off gas by feedforward control using, as an index, the measured value of the specific gravity of the liquid source
25 material and a measured value of the specific gravity of the off gas so that a Wobbe index of the liquid fuel gas falls within a predetermined value range.

In the storage tank of the liquid source material such as LNG, a gas phase (boil off gas BOG, hereafter referred to as "off gas") having a composition different from that of a liquid phase is generated during the supply.

Such an off gas gradually increases in amount in accordance with decrease of the liquid phase, whereby the composition thereof changes. For example, in the case of LNG, the methane (CH_4) component increases in amount, so that the off gas has a smaller heat generation amount than that of LNG, as shown in Table 1 described later.

Also, in the case of LPG, in the case of an off gas in which the propane (C_3H_8) component is large in amount, the off gas has a smaller heat generation amount than that of LPG, whereas in the case of an off gas in which the butane (C_4H_{10}) component is large in amount, the off gas has a larger heat generation amount than that of LPG.

The present invention has made it possible to adjust a desired heat generation amount in a wide range by being separately provided with an adjustment fluid that is mixed with the liquid source material and using an off gas as a part of the adjustment fluid in preparing the liquid fuel gas.

As will be described later, when LNG is used as a liquid source material, by using an off gas containing methane as a major component and using nitrogen as an adjustment fluid, the two function in a direction of decreasing the heat generation amount against a large fluctuation of increasing the heat generation amount of LNG, whereby efficient adjustment can be made.

Also, when LPG is used as a liquid source material, by using an off gas containing butane as a major component for increasing the heat generation amount and using nitrogen as an adjustment fluid for decreasing the heat generation amount, adjustment can be made in both directions of increasing and decreasing the heat generation amount against a large fluctuation of the heat generation amount of LPG.

In the above-described apparatus for supplying the liquid fuel gas according to the present invention, the feedforward control is performed so that the Wobbe index corresponding

to a desired heat generation amount range of the liquid fuel gas falls within a predetermined range based on the specific gravity G_{abo} of the prepared liquid fuel gas represented by the following formula 6, while setting a relationship of a superficial velocity in each space volume V_a , V_b , V_o of the liquid source material, the off gas, and the adjustment fluid to be under

5 conditions represented by the following formulas 1 and 4 and setting time delays ΔT_a , ΔT_b according to the following formulas 2 and 5, where V_a represents a space volume from the specific gravity measuring means of the liquid source material supplying portion to the mixing tank; G_a represents the specific gravity of the liquid source material; F_a represents a supply flow rate of the liquid source material; V_b represents a space volume from the specific gravity

10 measuring means of the off gas supplying portion to the mixing tank; G_b represents the specific gravity of the off gas; F_b represents a supply flow rate of the off gas; V_o represents a space volume from the supply amount adjusting means of the adjustment fluid supplying portion to the mixing tank; G_o represents the specific gravity of the adjustment fluid; and F_o represents a supply flow rate of the adjustment fluid.

15 $(V_a/F_a) > (V_o/F_o)$... formula 1

$(V_b/F_b) > (V_o/F_o)$... formula 4

$\Delta T_a = (V_a/F_a) - (V_o/F_o)$... formula 2

$\Delta T_b = (V_b/F_b) - (V_o/F_o)$... formula 5

$G_{abo} = (F_{ab} \times G_{ab} + F_o \times G_o) / (F_{ab} + F_o)$... formula 6

20 Here, F_{ab} and G_{ab} are defined as represented in the following formulas 7 and 8.

$F_{ab} = F_a + F_b$... formula 7

$G_{ab} = (F_a \times G_a + F_b \times G_b) / (F_a + F_b)$... formula 8

As described above, in preparing the liquid fuel gas, an off gas can be used as part of the adjustment fluid that is mixed with the liquid source material. At this time, the conditions of

25 mixing the off gas into the liquid source material and the adjustment fluid must be set so as not to affect the control elements as described above.

The present invention has made it possible to prevent generation of the spike noise by employing the conditions of mixing the adjustment fluid into the liquid source material as a basis, further restricting the space volume pertaining to mixing of the off gas and the adjustment fluid, and setting a control standard of the supply amounts of the adjustment fluid and the off gas to be at the time of start of mixing in the mixing tank to correct the shift from the time of specific gravity measurement of the liquid source material that is actually measured.

In the above-described apparatus for supplying the liquid fuel gas according to the present invention, a space capable of being set to have a predetermined volume is provided in a flow passageway for supplying the liquid source material that is linked from the specific gravity measuring means to the mixing tank, and adjustment of the supply amount of the adjustment fluid or the supply amounts of the adjustment fluid and the off gas is carried out on the basis of the space volume and the measured value of the specific gravity.

The conditions of mixing the adjustment fluid or the adjustment fluid and the off gas into the liquid source material must be set so as not to affect the control elements as described above.

The present invention has made it possible to prevent generation of the spike noise by determining the basic conditions of mixing the adjustment fluid into the liquid source material, restricting the space volume pertaining to mixing of the adjustment fluid or the adjustment fluid and the off gas, providing the space capable of being set to have a predetermined volume in the flow passageway for supplying the liquid source material that is linked from the specific gravity measuring means to the mixing tank, and setting a control standard of the supply amounts of the adjustment fluid and the off gas to be at the time of start of mixing in the mixing tank to correct the shift in time and space from the time of specific gravity measurement of the liquid source material that is actually measured.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view illustrating a basic exemplary structure of an apparatus for supplying a liquefied gas according to the present invention;

Fig. 2 is a schematic view illustrating the second exemplary structure of an apparatus for supplying a liquefied gas according to the present invention;

Fig. 3 is a schematic view illustrating the third exemplary structure of an apparatus for supplying a liquefied gas according to the present invention; and

Fig. 4 is a schematic view illustrating an exemplary structure of a heat quantity controlling system according to a conventional art.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Construction of apparatus for supplying a liquid fuel gas

An apparatus for supplying a liquid fuel gas according to the present invention (hereafter referred to as “present apparatus”) comprises a liquid source material supplying portion having a storage tank for storing a liquid source material, a supply amount adjusting means for adjusting a supply amount of the liquid source material, and a specific gravity measuring means for measuring a specific gravity of the liquid source material; an adjustment fluid supplying portion having a storage tank for storing an adjustment fluid and a supply amount adjusting means for adjusting a supply amount of the adjustment fluid; and a mixing portion having a mixing tank in which the liquid source material supplied from the liquid source material supplying portion is mixed with the adjustment fluid supplied from the adjustment fluid supplying portion and a supply-out portion from which the mixed liquid fuel gas is supplied out, wherein the liquid source material in a low-temperature liquid state is mixed with the adjustment fluid in the mixing tank, and the supply amount of the adjustment liquid corresponding to the supply amount of the liquid source material is adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material

so that a Wobbe index of the mixed liquid fuel gas falls within a predetermined value range. Hereafter, embodiments of the present invention will be described with reference to the attached drawings. Here, conditions such as the temperature, the pressure, and the flow rate of each portion can be appropriately changed in accordance with other conditions such as the kind
5 and the flow rate of the gas.

Basic construction of present apparatus

The basic construction of the present apparatus will be schematically exemplified in Fig. 1. The present apparatus comprises a liquid source material supplying portion 10 having a
10 storage tank 11 for storing a liquid source material, a supply amount adjusting means 12 for adjusting a supply amount of the liquid source material, and a specific gravity measuring means 13 for measuring a specific gravity of the liquid source material; an adjustment fluid supplying portion 20 having a storage tank 21 for storing an adjustment fluid and a supply amount adjusting means 22 for adjusting a supply amount of the adjustment fluid; and a mixing
15 portion 30 having a mixing tank 31 in which the liquid source material supplied from the liquid source material supplying portion 10 is mixed with the adjustment fluid supplied from the adjustment fluid supplying portion 20 and a supply-out portion 32 from which the mixed liquid fuel gas is supplied out. The liquid source material (for example, LNG) supplied out from the storage tank 11 undergoes adjustment by the supply amount adjusting means 12 to have a
20 desired supply amount, undergoes measurement of a specific gravity thereof by the specific gravity measuring means 13, and is in a low-temperature liquid state guided into the mixing tank 31. The adjustment fluid (for example, nitrogen) supplied out from the storage tank 21 undergoes adjustment by the supply amount adjusting means 22 to have a supply amount corresponding to the supply amount of the liquid source material and is guided into the mixing
25 tank 31.

In the mixing tank 31, the adjustment fluid is mixed into the liquid source material while maintaining the low-temperature liquid state, and the mixture is supplied out from the supply-out portion 32 as a liquid fuel gas having a desired heat generation amount.

By mixing of the adjustment fluid in a dissolved state into the liquid source material that
5 is in a low-temperature liquid state or in a supercooled liquid state, a uniform and highly stable liquid fuel gas can be prepared.

Here, in Fig. 1, a construction has been exemplified in which a valve 14 and a valve 24 are provided downstream of the specific gravity measuring means 13 of the liquid source material supplying portion 10 and downstream of the supply amount adjusting means 22 of the
10 adjustment fluid supplying portion 20, respectively, from the viewpoints of preventing backflow and the like; however, it is possible to adopt a construction in which these are omitted.

Also, in the present apparatus, the supply amount of the adjustment liquid corresponding to the supply amount of the liquid source material is adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material so that the
15 Wobbe index WI of the mixed liquid fuel gas falls within a predetermined value range.

As exemplified in Fig. 1, it is preferable to adopt a construction in which the input and the output needed for control of the present apparatus are managed in a concentrated manner in a control portion 40. The control portion 40 receives the input of supply amount signals from the supply amount adjusting means 12, 22 and the specific gravity measurement value signal
20 from the specific gravity measuring means 13 and outputs supply amount control signals to the supply amount adjusting means 12, 22.

Also, in the control method that is applied to the present apparatus, it is preferable to perform feedforward control using, as an index, the specific gravity measurement value of the liquid source material before mixing that forms a basis of the mixing. By quickly grasping a
25 change in the composition of the liquid source material and immediately performing an adjustment, the influence on the change at the downstream stage can be greatly reduced.

Also, by using the specific gravity measurement value as an index, the Wobbe index WI corresponding to a desired range of heat generation amount of the liquid fuel gas can be adjusted to fall within a predetermined range.

In the present embodiment, cases will be exemplified in which the liquid source material is mainly LNG; however, the present invention can also be in a similar manner applied to other liquid source materials such as liquefied petroleum gas (LPG) and liquefied butane gas. The adjustment fluid is a fluid having a lower heat generation amount or a higher heat generation amount than the liquid source material and having a property of being uniformly mixed with the liquid source material in order to prepare a liquid fuel gas having a desired heat generation amount, and it is preferable that the liquid source material is mixed in a low-temperature liquid state.

By being dissolved and mixed into a liquid source material that is in a supercooled state, a stable liquid fuel gas having an extremely high uniformity can be prepared.

For example, when the liquid source material is LNG, it is possible to use nitrogen, hydrogen, methane, carbon dioxide, air, argon, or the like as a fluid having a lower heat generation amount, and it is possible to use propane, LPG, or the like as a fluid having a higher heat generation amount.

When the liquid source material is LPG, it is possible to use nitrogen, hydrogen, or the like as a fluid having a lower heat generation amount, and it is possible to use butane or the like as a fluid having a higher heat generation amount.

Also, not only a single substance but also a mixture of some of these can be used as well. The following Table 1 shows thermal characteristics (high heat generation amount, Wobbe index) and the gas specific gravity of typical fuel components. The fuel components are stored in the storage tanks 11, 21 under conditions with a low temperature and a high pressure.

Table 1

Component	Formula	Gas specific gravity (Air: 1.0)	High heat generation amount (kcal/Nm ³)	Wobbe index (MJ/Nm ³)
Hydrogen	H ₂	0.07	3,015	48.00
Methane	CH ₄	0.43	9,428	53.20
Ethane	C ₂ H ₆	1.04	16,533	68.15
Propane	C ₃ H ₈	1.52	23,540	80.13
iso-Butane	i-C ₄ H ₁₀	2.01	30,454	90.29
Liquefied natural gas (LNG)		0.58	9,783	54.04
Liquefied petroleum gas (LPG)		1.77	26,977	85.21
Nitrogen	N ₂	0.80	0	0.00

Regarding Wobbe index

In the present apparatus, the supply amount of the adjustment liquid corresponding to the
5 supply amount of the liquid source material is adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material so that a Wobbe index of the mixed liquid fuel gas falls within a predetermined value range.

At this time, when LNG, for example, is used as the liquid source material, a controlling
method that meets a large difference in composition of LNG produced in each country is
10 needed in applying Japanese Industrial Standard K2301:2011 "Method of analyzing and testing fuel gas and natural gas". The present apparatus can prepare a liquid fuel gas having little fluctuation in heat generation amount and can be quickly and stably controlled.

Specifically, the specific gravity G_{ao} of the prepared liquid fuel gas is determined by the
calculation formula represented by the following formula 3 on the basis of the supply amount
15 F_o of the adjustment fluid (specific gravity of G_o), the supply amount F_a of the liquid source

material from the supply amount adjusting means 12, and the specific gravity measurement value G_a from the specific gravity measuring means 13.

$$G_{ao} = (F_a \times G_a + F_o \times G_o) / (F_a + F_o) \quad \dots \text{formula 3}$$

At this time, the Wobbe index W_a of the liquid fuel gas is determined by the calculation
5 formula represented by the following formula 3a on the basis of the desired heat generation amount H_a and the above specific gravity G_{ao} .

$$W_a = H_a / (G_{ao})^{1/2} \rightarrow H_a^2 = W_a^2 \times G_{ao} \quad \dots \text{formula 3a}$$

Therefore, the relationship between the desired heat generation amount H_a of the liquid fuel gas and the supply amount F_o of the adjustment fluid with respect to the Wobbe index W_a
10 corresponding thereto is determined by the calculation formula represented by the following formula 3b.

$$H_a^2 = W_a^2 \times (F_a \times G_a + F_o \times G_o) / (F_a + F_o) \quad \dots \text{formula 3b}$$

From the above, the Wobbe index corresponding to the desired range of heat generation amount of the liquid fuel gas can be adjusted to fall within a predetermined range by
15 controlling the supply amount F_o of the adjustment fluid on the basis of the following formula 3c using the specific gravity G_a of the liquid source material as an index.

$$F_o = (H_a^2 \times F_a - W_a^2 \times F_a \times G_a) / (W_a^2 \times G_o - H_a^2) \quad \dots \text{formula 3c}$$

Regarding mixing conditions

20 In the present apparatus, it is extremely important to ensure the uniformity of the liquid fuel gas (mixed fluid). For that purpose, correction must be made on the shift of control accompanying the difference between the period of time from the time at which the specific gravity of the liquid source material is measured until the time at which the liquid source material is mixed in the mixing tank and the period of time from the time at which the
25 adjustment fluid is controlled until the time at which the adjustment fluid is actually mixed in the mixing tank.

For example, when the adjustment fluid controlled to increase the supply amount reaches the mixing tank earlier than the liquid source material supplied at the time of specific gravity measurement that forms the basis of the control, a mixed fluid containing the adjustment fluid having a higher concentration than a controlled value is formed in the mixing tank.

5 Also, a shift of the rise characteristics (for example, 90% rise time T90) of the control elements generated by the difference of the flow rates of the two increases the influence of such a time shift. Such a shift may be generated by switching to a liquid source material having a different composition, change in the composition within the storage tank accompanying the use, and the like, so that, by correcting the influence thereof, it is possible to prevent formation
10 of a mixed fluid having a spike noise generated by the time shift of the control elements.

Specifically, the feedforward control is performed while setting a relationship of a superficial velocity in each space volume V_a , V_o of the liquid source material and the adjustment fluid to be under conditions represented by the following formula 1 and setting a time delay ΔT_a according to the following formula 2, where V_a represents a space volume
15 from the specific gravity measuring means 13 of the liquid source material supplying portion 10 to the mixing tank 31; G_a represents the specific gravity of the liquid source material; F_a represents a supply flow rate of the liquid source material; V_o represents a space volume from the supply amount adjusting means 22 of the adjustment fluid supplying portion 20 to the mixing tank 31; G_o represents the specific gravity of the adjustment fluid; and F_o represents a
20 supply flow rate of the adjustment fluid.

$$(V_a/F_a) > (V_o/F_o) \quad \dots \text{formula 1}$$

$$\Delta T_a = (V_a/F_a) - (V_o/F_o) \quad \dots \text{formula 2}$$

By restricting the space volume V_a , V_o pertaining to the liquid source material and the adjustment fluid that affects the control elements as in the formula 1, generation of the spike
25 noise can be prevented.

Also, by setting a control standard of the supply amount of the adjustment fluid to be at the time of start of mixing in the mixing tank 31 to correct the shift from the time of specific gravity measurement of the liquid source material that is actually measured, generation of the spike noise can be prevented.

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Regarding simulation pertaining to mixing conditions

The influence accompanying the difference of the space volume V_o , V_a pertaining to the liquid source material and the adjustment fluid and the difference of time by which the liquid source material and the adjustment fluid pass through the spaces was simulated as a fluctuation of the Wobbe index of the mixed liquid fuel gas.

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(i) Validation conditions

LNG was supplied as a liquid source material at about 7,326 L/min (pressure of about 0.7 MPa) in the space volume V_o , while nitrogen was supplied as an adjustment fluid at about 5,830 L/min (pressure of about 0.7 MPa) in the space volume V_a . Simulation was made on the fluctuation of the Wobbe index after mixing with presence or absence of the conditions of the above formulas 1 and 2.

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(ii) Validation result

When the two were compared, reduction by about 50% could be made as a fluctuation of the Wobbe index.

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Method of supplying a liquid fuel gas using the present apparatus

The method of supplying a liquid fuel gas using the present apparatus comprises the following steps.

(1) The liquid source material is supplied out from the storage tank 11, adjusted to have a desired supply amount, subjected to measurement of the specific gravity thereof, and guided into the mixing tank 31.

25

(2) The adjustment fluid is supplied out from the storage tank 21 and guided into the mixing tank 31.

(3) At this time, the supply amount thereof is adjusted by feedforward control using, as an index, the specific gravity measured in the above (1). Specifically, adjustment is made so
5 that the Wobbe index falls within a predetermined value range relative to the demanded heat generation amount of the liquid fuel gas.

(4) In the mixing tank 31, the guided liquid source material in a low-temperature liquid state or in a supercooled liquid state is mixed with the guided adjustment fluid that has been subjected to control and adjustment of the supply amount.

10 (5) The liquid fuel gas prepared by mixing in the mixing tank 31 is supplied out from the supply-out portion 32.

Another construction example (second construction example) of the present apparatus

Another construction example (second construction example) of the present apparatus
15 will be schematically shown in Fig. 2. The second construction example is characterized in that, in addition to the construction of the basic construction example, the apparatus for supplying the liquid fuel gas further comprises an off gas supplying portion 50 having a storage tank 51 for storing an off gas generated by evaporation of the liquid source material in the storage tank 11 or an off gas supplied out from another storage tank, a supply amount adjusting means 52
20 for adjusting a supply amount of the off gas, a specific gravity measuring means 53 for measuring a specific gravity of the off gas, and a valve 54 (which can be omitted in the same manner as in the basic construction example), wherein the liquid source material in a low-temperature liquid state is mixed with the adjustment fluid and the off gas in the mixing tank 31, so as to prepare a liquid fuel gas. The prepared liquid fuel gas is supplied out via the
25 supply-out portion 32.

By using the off gas as part of the adjustment fluid that is mixed into the liquid source material in preparing the liquid fuel gas, a desired heat generation amount can be adjusted in a wide range.

Here, the off gas refers to a gas-phase component that is generated in the storage tank for
5 storing the liquid source material such as LNG, has a composition different from that of the liquid phase, and is referred to as boil off gas (BOG). Such an off gas forms a composition different from that of the liquid phase in accordance with the supply of the liquid source material. The off gas gradually increases in amount according as the liquid phase decreases in amount and, in accordance therewith, the composition thereof further changes. For example, in
10 the case in which the liquid source material is LNG, the off gas contains a large amount of the methane (CH_4) component having a smaller heat generation amount than that of LNG.

Therefore, for example, in the case of using LNG as the liquid source material, using the off gas containing methane as a major component, and using nitrogen as the adjustment fluid, the heat generation amount can be quickly increased by decreasing the amount of mixing
15 nitrogen in order to meet the decrease in the heat generation amount accompanying the fluctuation of the LNG composition by which the off gas increases in amount, whereby a highly precise adjustment of the heat generation amount can be made.

On the other hand, in the case in which the liquid source material is LPG, the off gas contains a large amount of propane having a larger heat generation amount than that of LPG
20 containing propane (C_3H_8) or butane (C_4H_{10}) as a major component.

Therefore, by using this as an off gas, the heat generation amount can be quickly decreased by increasing the amount of mixing nitrogen in order to meet the increase in the heat generation amount accompanying the fluctuation of the LPG composition by which the off gas increases in amount, whereby a highly precise adjustment of the heat generation amount can be
25 made.

Also, a highly precise adjustment of the heat generation amount can be made by adjusting the amount of mixing the off gas and nitrogen in order to meet the fluctuation of the heat generation amount of LNG or LPG itself.

In other words, the heat generation amount can be quickly decreased by increasing the amount of mixing the off gas and/or nitrogen in order to meet the fluctuation that goes in the direction of increasing the heat generation amount of LNG, while the heat generation amount can be quickly increased by decreasing the amount of mixing the off gas and/or nitrogen in order to meet the fluctuation that goes in the direction of decreasing the heat generation amount of LNG.

Also, the heat generation amount can be quickly decreased by decreasing the amount of mixing the off gas and/or increasing the amount of mixing nitrogen in order to meet the fluctuation that goes in the direction of increasing the heat generation amount of LPG, while the heat generation amount can be quickly increased by increasing the amount of mixing the off gas and/or decreasing the amount of mixing nitrogen in order to meet the fluctuation that goes in the direction of decreasing the heat generation amount of LPG.

Specifically, a case will be exemplified in the following Table 2 in which a liquid fuel gas having a Wobbe index of 54.0 (MJ/Nm³) is desired and LNG having a Wobbe index of 55.0 (MJ/Nm³) is used at a flow rate of 200 t/h.

When an off gas (BOG) containing methane as a major component and having a Wobbe index of 53.2 (MJ/Nm³) is mixed at a flow rate of 100 t/h (Case-1), the desired liquid fuel gas can be realized by mixing nitrogen at a flow rate of 2.45 t/h.

Under similar conditions, when the off gas is not mixed (Case-2), the required flow rate of nitrogen is 4.45 t/h.

Table 2

	Wobbe index (MJ/Nm ³)	Case-1: Flow (t/h)	Case-2: Flow (t/h)
LNG	55.0	200	200
BOG	53.2	100	0
GAN	0	2.45	4.45
Required	54.0	-	-

Also, the off gas in LNG has a composition close to that of methane alone as a hydrocarbon.

5 Therefore, by specific gravity measurement, the heat generation amount of the off gas can be estimated, and this will be needed as a basis of calculation in setting the flow rate of the adjustment fluid. However, in the validation process of the present invention, a knowledge has been obtained such that there may be cases in which nitrogen is mingled in the off gas.

Therefore, in order to control the Wobbe index to stabilize the heat generation amount of
10 the supplied liquid fuel gas, adjustment of the amount of mixing the adjustment fluid corresponding to the nitrogen component contained in the off gas will be needed.

Specifically, the following relationship holds, so that, in the case of mixing an off gas into LNG, the influence of nitrogen mingled in the off gas must be taken into consideration. When the amount of nitrogen mingled in the off gas is large, there is a fear that decrease in the
15 desired heat generation amount may be invited by excessive mixing of nitrogen which is substantially the adjustment fluid.

In order to prevent this, the amount of nitrogen mingled in the off gas is specified by using the specific gravity measurement value G_f of the off gas. The heat generation amount H_f [KJ/Nm³] of the off gas will be as represented in the following formulas 9a to 9c, where
20 Y_m represents the molar ratio of methane in the off gas; G_n represents the specific gravity of nitrogen (assuming that the specific gravity of air is 1); G_m represents the specific gravity of methane; and H_m [KJ/Nm³] represents the heat generation amount of methane.

$$G_f = G_n \times (1 - Y_m) + G_m \times Y_m \quad \dots \text{formula 9a}$$

$$Y_m = (G_n - G_f) / (G_n - G_m) \quad \dots \text{formula 9b}$$

$$H_f = H_m \times Y_m \quad \dots \text{formula 9c}$$

5 Regarding Wobbe index

In the second construction example, the supply amount of the adjustment liquid and the supply amount of the off gas corresponding to the supply amount of the liquid source material are adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material and a measured value of the specific gravity of the off gas so that a

10 Wobbe index of the mixed liquid fuel gas falls within a predetermined value range.

Specifically, when G_b represents the specific gravity of the off gas and F_b represents the supply flow rate of the off gas, the specific gravity G_{abo} of the prepared liquid fuel gas is determined by the calculation formula represented by the following formula 6 on the basis of the supply amount F_o of the adjustment fluid (specific gravity of G_o), the supply amount F_a

15 and the specific gravity measurement value G_a of the liquid source material, and the supply amount F_b and the specific gravity measurement value G_b of the off gas.

$$G_{abo} = (F_b \times G_b + F_o \times G_o) / (F_b + F_o) \quad \dots \text{formula 6}$$

Here, F_b and G_b are defined as represented in the following formulas 7 and 8.

$$F_b = F_a + F_b \quad \dots \text{formula 7}$$

20 $G_b = (F_a \times G_a + F_b \times G_b) / (F_a + F_b) \quad \dots \text{formula 8}$

At this time, the Wobbe index W_b of the liquid fuel gas is determined by the calculation formula represented by the following formula 6a on the basis of the desired heat generation amount H_b and the above specific gravity G_{abo} .

$$W_b = H_b / (G_{abo})^{1/2} \rightarrow H_b^2 = W_b^2 \times G_{abo} \quad \dots \text{formula 6a}$$

25 Therefore, the relationship between the desired heat generation amount H_b of the liquid fuel gas and the supply amount F_o of the adjustment fluid with respect to the Wobbe index W_b

corresponding thereto is determined by the calculation formula represented by the following formula 6b.

$$Hb^2 = Wb^2 \times (Fab \times Gab + Fo \times Go) / (Fab + Fo) \quad \dots \text{formula 6b}$$

From the above, the Wobbe index corresponding to the desired range of heat generation
5 amount of the liquid fuel gas can be adjusted to fall within a predetermined range by
controlling the supply amount Fo of the adjustment fluid on the basis of the following formula
6c using the specific gravity Ga of the liquid source material as an index.

$$Fo = (Hb^2 \times Fab - Wb^2 \times Fab \times Gab) / (Wb^2 \times Go - Hb^2) \quad \dots \text{formula 6c}$$

Here, Fab and Gab are defined as represented in the following formulas 7 and 8.

10

Regarding mixing conditions

In the second construction example, the feedforward control is performed while
setting a relationship of a superficial velocity in each space volume Va , Vb , Vo of the
liquid source material, the off gas, and the adjustment fluid to be under conditions
15 represented by the following formulas 1 and 4 and setting time delays ΔTa , ΔTb according
to the following formulas 2 and 5, where Va represents a space volume from the specific
gravity measuring means 13 of the liquid source material supplying portion 10 to the
mixing tank 31; Ga represents the specific gravity of the liquid source material; Fa
represents a supply flow rate of the liquid source material; Vb represents a space volume
20 from the specific gravity measuring means 53 of the off gas supplying portion 50 to the
mixing tank 31; Gb represents the specific gravity of the off gas; Fb represents a supply
flow rate of the off gas; Vo represents a space volume from the supply amount adjusting
means 22 of the adjustment fluid supplying portion 20 to the mixing tank 31; Go represents
the specific gravity of the adjustment fluid; and Fo represents a supply flow rate of the
25 adjustment fluid.

$$(V_a/F_a) > (V_o/F_o) \quad \dots \text{formula 1}$$

$$(V_b/F_b) > (V_o/F_o) \quad \dots \text{formula 4}$$

$$\Delta T_a = (V_a/F_a) - (V_o/F_o) \quad \dots \text{formula 2}$$

$$\Delta T_b = (V_b/F_b) - (V_o/F_o) \quad \dots \text{formula 5}$$

5 By restricting the space volume V_a , V_o , V_b pertaining to the liquid source material, the adjustment fluid, and the off gas that affects the control elements as in the formulas 1 and 4, generation of the spike noise can be prevented.

Also, by setting a control standard of the supply amount of the adjustment fluid to be at the time of start of mixing in the mixing tank 31 to correct the shift from the time of specific gravity measurement of the liquid source material and from the time of specific gravity measurement of the off gas that are actually measured, generation of the spike noise can be prevented.

Method of supplying a liquid fuel gas according to the second construction example

15 The method of supplying a liquid fuel gas according to the second construction example comprises the following steps.

(1) The liquid source material is supplied out from the storage tank 11, adjusted to have a desired supply amount, subjected to measurement of the specific gravity thereof, and guided into the mixing tank 31.

20 (2) The off gas is supplied out from the storage tank 51, adjusted to have a desired supply amount, subjected to measurement of the specific gravity thereof, and guided into the mixing tank 31.

(3) The adjustment fluid is supplied out from the storage tank 21 and guided into the mixing tank 31.

25 (4) At this time, the supply amount thereof is adjusted by feedforward control using, as an index, the specific gravities measured in the above (1) and (2). Specifically, adjustment is

made so that the Wobbe index falls within a predetermined value range relative to the demanded heat generation amount of the liquid fuel gas.

(5) In the mixing tank 31, the guided liquid source material in a low-temperature liquid state or in a supercooled liquid state is mixed with the guided adjustment fluid that has been
5 subjected to control and adjustment of the supply amount.

(6) The liquid fuel gas prepared by mixing in the mixing tank 31 is supplied out from the supply-out portion 32.

Third construction example of the present apparatus

10 The third construction example of the present apparatus will be schematically shown in Fig. 3. The third construction example is characterized in that, in addition to the construction of the basic construction example, a space 15 capable of being set to have a predetermined volume is provided in a flow passageway for supplying the liquid source material that is linked from the specific gravity measuring means 13 to the mixing tank 31.

15 This allows that adjustment of the supply amount of the adjustment fluid can be carried out on the basis of the measured value of the specific gravity while adjusting the volume of the space 15. Here, although not illustrated in the drawings, when the present construction is applied to the second construction example, adjustment of the supply amount of the off gas can also be carried out in addition to adjustment of the supply amount of the adjustment fluid.

20 As shown in the above (Regarding mixing conditions) portion, the conditions of mixing the adjustment fluid or the adjustment fluid and the off gas into the liquid source material must be set so as not to affect the control elements as described above.

In particular, in mixing the adjustment fluid and the off gas into the liquid source material, the conditions for mixing the three fluids must be adjusted.

25 Therefore, by only restricting the fixed space volume, there is a limit in adjustment when composition transformation of the liquid source material is large.

By providing the space 15 capable of being set to have a predetermined volume in the flow passageway for supplying the liquid source material having the largest supply amount, generation of the spike noise can be more effectively prevented by correcting the shift in time and space at the time of actual measurement.

- 5 As shown above, each construction example has been described with reference to each explanatory view; however, the present apparatus or the present liquefaction apparatus is not limited to these and is constructed in a wide concept comprising a combination of the constituent elements thereof or a combination with related known constituent elements.

CLAIMS

1. An apparatus for supplying a mixed liquid fuel gas according to the present invention comprising:
 - a liquid source material supplying portion having a storage tank for storing a liquid source material, a supply amount adjusting means for adjusting a supply amount of the liquid source material, and a specific gravity measuring means for measuring a specific gravity of the liquid source material;
 - an adjustment fluid supplying portion having a storage tank for storing an adjustment fluid and a supply amount adjusting means for adjusting a supply amount of the adjustment fluid; and a mixing portion having a mixing tank in which the liquid source material supplied from the liquid source material supplying portion is mixed with the adjustment fluid supplied from the adjustment fluid supplying portion and a supply-out portion from which the mixed liquid fuel gas is supplied out, and
 - the supply amount of the adjustment liquid corresponding to the supply amount of the liquid source material is adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material so that a Wobbe index of the mixed liquid fuel gas falls within a predetermined value range, wherein the feedforward control is performed so that the Wobbe index corresponding to a desired heat

generation amount range of the mixed liquid fuel gas falls within a predetermined range based on the specific gravity G_{ao} of the mixed liquid fuel gas represented by the following formula 3 while setting a relationship of a superficial velocity in each space volume V_a , V_o of the liquid source material and the adjustment fluid to be under conditions represented by the following formula 1 and setting a time delay ΔT_a according to the following formula 2, where V_a represents a space volume from the specific gravity measuring means of the liquid source material supplying portion to the mixing tank; G_a represents the specific gravity of the liquid source material; F_a represents a supply flow rate of the liquid source material; V_o represents a space volume from the supply amount adjusting means of the adjustment fluid supplying portion to the mixing tank; G_o represents the specific gravity of the adjustment fluid; and F_o represents a supply flow rate of the adjustment fluid.

$$(V_a/F_a) > (V_o/F_o) \quad \dots \text{formula 1}$$

$$\Delta T_a = (V_a/F_a) - (V_o/F_o) \quad \dots \text{formula 2}$$

$$G_{ao} = (F_a \times G_a + F_o \times G_o) / (F_a + F_o) \quad \dots \text{formula 3.}$$

2. The apparatus according to claim 1, comprising

- an off gas supplying portion having a supply amount adjusting means for adjusting a supply amount of an off gas generated by evaporation of the liquid source material in the storage tank or an off gas supplied out from another storage tank and a specific gravity measuring means for measuring a specific gravity of the off gas, wherein
 - the liquid source material in a low-temperature liquid state is mixed with the adjustment fluid and the off gas in the mixing tank, and
 - the supply amounts of the adjustment liquid and the off gas corresponding to the supply amount of the liquid source material are adjusted by feedforward control using, as an index, a measured value of the specific gravity of the liquid source material and a measured value of the specific gravity of the off gas so that a Wobbe index of the mixed liquid

fuel gas falls within a predetermined value range.

3. The apparatus according to claim 2, wherein the feedforward control is performed so that the Wobbe index corresponding to a desired heat generation amount range of the mixed liquid fuel gas falls within a predetermined range based on the specific gravity G_{abo} of the mixed liquid fuel gas represented by the following formula 6 while setting a relationship of a superficial velocity in each space volume V_a , V_b , V_o of the liquid source material, the off gas, and the adjustment fluid to be under conditions represented by the following formulas 1 and 4 and setting time delays ΔT_a , ΔT_b according to the following formulas 2 and 5, where V_a represents a space volume from the specific gravity measuring means of the liquid source material supplying portion to the mixing tank; G_a represents the specific gravity of the liquid source material; F_a represents a supply flow rate of the liquid source material; V_b represents a space volume from the specific gravity measuring means of the off gas supplying portion to the mixing tank; G_b represents the specific gravity of the off gas; F_b represents a supply flow rate of the off gas; V_o represents a space volume from the supply amount adjusting means of the adjustment fluid supplying portion to the mixing tank; G_o represents the specific gravity of the adjustment fluid; and F_o represents a supply flow rate of the adjustment fluid.

$$(V_a/F_a) > (V_o/F_o) \quad \dots \text{formula 1}$$

$$(V_b/F_b) > (V_o/F_o) \quad \dots \text{formula 4}$$

$$\Delta T_a = (V_a/F_a) - (V_o/F_o) \quad \dots \text{formula 2}$$

$$\Delta T_b = (V_b/F_b) - (V_o/F_o) \quad \dots \text{formula 5}$$

$$G_{abo} = (F_{ab} \times G_{ab} + F_o \times G_o) / (F_{ab} + F_o) \quad \dots \text{formula 6}$$

Here, F_{ab} and G_{ab} are defined as represented in the following formulas 7 and 8.

$$F_{ab} = F_a + F_b \quad \dots \text{formula 7}$$

$$G_{ab} = (F_a \times G_a + F_b \times G_b) / (F_a + F_b) \quad \dots \text{formula 8.}$$

4. The apparatus according to any one of claims 1 to 3, wherein a space capable of being set to have a predetermined volume is provided in a flow passageway for supplying the liquid source material that is linked from the specific gravity measuring means to the mixing tank, and adjustment of the supply amount of the adjustment fluid or the supply amounts of the adjustment fluid and the off gas is carried out on the basis of the space volume and the measured value of the specific gravity.