

Description

Title of Invention: GAS TURBINE COGENERATION SYSTEM,
IMPROVEMENT METHOD FOR GAS TURBINE COGENERATION SYSTEM,
AND ADD-ON UNIT FOR GAS TURBINE COGENERATION SYSTEM

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Technical Field

[0001]

The present disclosure relates to a gas turbine cogeneration system, a
modification method for a gas turbine cogeneration system, and an add-on unit
10 for a gas turbine cogeneration system.

The present application claims priority based on JP 2023-004504 filed in
the Japan Patent Office on January 16, 2023, and is hereby incorporated by
reference.

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Background Art

[0002]

In a gas turbine cogeneration system described in Patent Document 1, a
mixed gas containing ammonia gas and steam and a fuel such as natural gas are
supplied to a combustor of a gas turbine. The ammonia gas is produced from a
20 treated liquid by using exhaust gas discharged from a heat recovery steam
generator of the gas turbine cogeneration system as a heat source. Steam
produced by the heat recovery steam generator is supplied to a steam utilization
facility.

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Citation List

Patent Literature

[0003]

Patent Document 1: JP 2022-067465 A

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Summary of Invention

Technical Problem

[0004]

The exhaust gas discharged from the heat recovery steam generator
contains moisture. If this moisture can be used as a fuel for a gas turbine
35 cogeneration system, consumption of a fossil fuel having a high carbon content
ratio can be suppressed, and contribution to realization of a carbon-neutral
society can be expected.

[0005]

An object of the present disclosure is to provide a gas turbine cogeneration system with reduced carbon dioxide emissions, a modification method for a gas turbine cogeneration system, and an add-on unit for a gas turbine cogeneration system.

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Solution to Problem

[0006]

A gas turbine cogeneration system according to at least an embodiment of the present disclosure includes:

- 10 a gas turbine including a combustor;
 a heat recovery steam generator configured to produce boiler steam by using exhaust gas discharged from the gas turbine as a heat source;
 a water recovery device configured to recover moisture from the exhaust gas discharged from the heat recovery steam generator by heat exchange
15 between the exhaust gas and refrigerant water; and
 a fuel gas production facility configured to produce gas turbine fuel gas to be supplied to the combustor by using industrial water containing recovered water recovered by the water recovery device as at least one of feedstock materials.

20 [0007]

A modification method for a cogeneration system according to an embodiment of the present disclosure is a modification method for a gas turbine cogeneration system including a gas turbine including a combustor, and a heat recovery steam generator, the modification method including:

- 25 a water recovery device addition step of adding a water recovery device configured to recover moisture from exhaust gas discharged from the heat recovery steam generator by heat exchange between the exhaust gas and refrigerant water; and
 a fuel gas production facility addition step of adding a fuel gas
30 production facility configured to produce gas turbine fuel gas to be supplied to the combustor by using industrial water containing recovered water recovered by the water recovery device as at least one of feedstock materials.

[0008]

35 An add-on unit for a gas turbine cogeneration system according to an embodiment of the present disclosure includes:

- a water recovery device configured to recover moisture from exhaust gas discharged from a heat recovery steam generator by heat exchange between the exhaust gas and refrigerant water; and

a fuel gas production facility configured to produce gas turbine fuel gas to be supplied to a combustor of a gas turbine by using industrial water containing recovered water recovered by the water recovery device as at least one of feedstock materials.

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Advantageous Effects of Invention

[0009]

According to the present disclosure, it is possible to provide a gas turbine cogeneration system with reduced carbon dioxide emissions, a
10 modification method for a gas turbine cogeneration system, and an add-on unit for a gas turbine cogeneration system.

Brief Description of Drawings

[0010]

15 FIG. 1 is a schematic diagram of a gas turbine cogeneration system according to an embodiment.

FIG. 2 is a schematic diagram of a cogeneration line according to an embodiment.

20 FIG. 3 is a schematic diagram of a combustor according to an embodiment.

FIG. 4 is a schematic diagram of a water recovery system according to an embodiment.

FIG. 5A is a schematic diagram of a fuel gas production facility according to a first embodiment.

25 FIG. 5B is a schematic diagram of a fuel gas production facility according to a second embodiment.

FIG. 5C is a schematic diagram of a fuel gas production facility according to a third embodiment.

30 FIG. 5D is a schematic diagram of a fuel gas production facility according to a fourth embodiment.

FIG. 5E is a schematic diagram of a fuel gas production facility according to a fifth embodiment.

FIG. 5F is a schematic diagram of a fuel gas production facility according to a sixth embodiment.

35 FIG. 6 is a schematic diagram of a cogeneration system before modification according to an embodiment.

FIG. 7 is a flowchart illustrating a modification method for a cogeneration system according to an embodiment.

Description of Embodiments

[0011]

Hereinafter, some embodiments of the present disclosure will be
5 described with reference to the accompanying drawings. Note that dimensions, materials, shapes, relative arrangement and the like of components described in the embodiments or illustrated in the drawings are merely illustrative examples and are not intended to limit the scope of the present disclosure.

For example, expressions indicating relative or absolute arrangement
10 such as "in a direction", "along a direction", "parallel", "orthogonal", "center", "concentric", or "coaxial" shall not be construed as indicating only such arrangement in a strict literal sense, but also construed as indicating a state of being relatively displaced by a tolerance, or by an angle or a distance to the extent that the same function can be achieved.

For example, an expression of a state where features are equal, such as
15 "same", "equal", and "uniform" shall not be construed as indicating only a state where the features are equal in a strict literal sense, but also construed as expressing a state where there is a tolerance or a difference to the extent that the same function can be achieved.

For example, expressions indicating a shape such as a rectangular shape
20 or a tube shape shall not be construed as only indicating a shape such as a rectangular shape or a tube shape in a strict geometrical sense, but also construed as indicating a shape including depressions, protrusions, and chamfered corners to the extent that the same effect can be achieved.

On the other hand, expressions such as "comprising", "including", or
25 "having" one component are not intended as exclusive expressions that exclude the presence of other components.

Note that the same reference signs may be assigned to similar components, and descriptions thereof may be omitted.

30 [0012]

1. Outline of Gas Turbine Cogeneration System 10

FIG. 1 is a schematic diagram of a gas turbine cogeneration system 10
according to an embodiment of the present disclosure. In the following description, the "gas turbine cogeneration system 10" may be simply
35 abbreviated as the "cogeneration system 10".

[0013]

The cogeneration system 10 includes a cogeneration line 1, a water recovery system 40, and a fuel gas production facility 80. The cogeneration

system 10 of the present example is realized by adding the water recovery system 40 and the fuel gas production facility 80 to the existing cogeneration line 1. That is, the water recovery system 40 and the fuel gas production facility 80 constitute an add-on unit 4 for a gas turbine cogeneration system (hereinafter, may be referred to as "add-on unit 4"). The cogeneration system 10 according to another example may be realized by newly installing the cogeneration line 1, the water recovery system 40, and the fuel gas production facility 80 at the same timing.

[0014]

The cogeneration line 1 includes a gas turbine 9 including a combustor 3. The combustor 3 is configured to be supplied with a fuel from a mixed fuel gas supply facility 79 and a start-up fuel gas supply facility 77. In addition, the cogeneration line 1 further includes a heat recovery steam generator 14 for producing boiler steam by using exhaust gas 13 discharged from the gas turbine 9 as a heat source, a makeup water tank 17 for storing boiler feedwater to be supplied to the heat recovery steam generator 14, a water supply line 19 for guiding the boiler feedwater from the makeup water tank 17 to the heat recovery steam generator 14, a steam consumer 11 configured to be driven by the boiler steam discharged from the heat recovery steam generator 14, an exhaust gas line 57 through which the exhaust gas 13 discharged from the heat recovery steam generator 14 flows, and an exhaust line 29 for guiding the exhaust gas 13 flowing through the exhaust gas line 57 to an exhaust tower 30. The exhaust line 29 is provided with an exhaust damper 31. While the exhaust damper 31 is closed, the exhaust gas 13 does not flow through the exhaust line 29 and is guided to the water recovery system 40.

[0015]

The water recovery system 40 includes an exhaust gas supply line 141 and a water recovery device 33. The exhaust gas supply line 141 is connected to the exhaust gas line 57 and the water recovery device 33, and while the exhaust damper 31 is closed, the exhaust gas 13 discharged from the heat recovery steam generator 14 is guided to the water recovery device 33 by the exhaust gas supply line 141. The water recovery device 33 is configured to recover moisture from the exhaust gas 13 by heat exchange between the exhaust gas 13 and refrigerant water described later. The water recovery system 40 further includes a water supply line 43 for supplying recovered water containing the recovered moisture to the makeup water tank 17. Therefore, the boiler feedwater guided to the heat recovery steam generator 14 by the water supply line 19 contains the recovered water.

[0016]

The fuel gas production facility 80 includes a water extraction line 49 for extracting the boiler feedwater from the water supply line 19, and a fuel gas production unit 81 configured to receive industrial water, which is the boiler feedwater extracted by the water extraction line 49. The fuel gas production unit 81 is configured to produce gas turbine fuel gas to be supplied to the combustor 3 by using the industrial water as at least one of feedstock materials.

[0017]

In some embodiments, the gas turbine fuel gas produced by the fuel gas production unit 81 is supplied to the above-described mixed fuel gas supply facility 79 via a fuel gas supply line 88. More specifically, the fuel gas production facility 80 further includes a gas mixing device 8, and the gas turbine fuel gas supplied by the fuel gas supply line 88 flows into the gas mixing device 8. Further, fossil fuel gas flows into the gas mixing device 8, and the gas mixing device 8 is configured to produce mixed fuel gas obtained by mixing the gas turbine fuel gas and the fossil fuel gas. Further, the fuel gas production facility 80 further includes a mixed fuel gas supply line 86 for supplying the mixed fuel gas to the mixed fuel gas supply facility 79. The mixed fuel gas supplied by the mixed fuel gas supply line 86 is supplied to the combustor 3 via the mixed fuel gas supply facility 79 and a mixed supply line 78 in this order. Therefore, it is understood that the mixed fuel gas supply line 86 is configured to supply the mixed fuel gas to the combustor 3.

[0018]

According to the above configuration, the moisture contained in the exhaust gas 13 is recovered by the water recovery device 33, and the industrial water containing the recovered water is utilized as at least one of feedstock materials of the gas turbine fuel gas. Since the gas turbine fuel gas is supplied to the combustor 3, a supply amount of another fuel gas such as fossil fuel gas can be reduced. Therefore, the gas turbine cogeneration system 10 can reduce carbon dioxide emissions. In addition, the moisture contained in the exhaust gas 13 is recovered by the water recovery device 33 and then used as the gas turbine fuel gas, and moisture generated by combustion of the gas turbine fuel gas is recovered again by the water recovery device 33. In this way, the gas turbine cogeneration system 10 in which a material constituting moisture (more specifically, hydrogen as described below) circulates is realized, allowing the supply amount of fossil fuel gas existing outside the system to be reduced and contributing to carbon neutrality. Similar advantages are also achieved by the addition of the add-on unit 4 to the existing cogeneration line 1.

[0019]

Note that the present disclosure is not limited to the embodiment described above. Instead of the fossil fuel gas, off-gas may flow into the gas mixing device 8. In this case, the gas mixing device 8 mixes the gas turbine fuel gas and the off-gas to produce mixed fuel gas. Alternatively, the fuel gas production facility 80 may not include the gas mixing device 8 and the mixed fuel gas supply line 86. In this case, the fuel gas supply line 88 is configured to directly supply the gas turbine fuel gas to the combustor 3. In either embodiment, the above advantages are obtained.

[0020]

In addition, according to the configuration in which the fuel gas production facility 80 includes the gas mixing device 8 that mixes the gas turbine fuel gas and the fossil fuel gas, since the fossil fuel gas is contained in the mixed fuel gas to be supplied to the combustor 3, the calorific value generated with the combustion in the combustor 3 can be sufficiently ensured.

[0021]

Hereinafter, detailed configurations of the cogeneration line 1, the water recovery system 40, and the fuel gas production facility 80 will be exemplified in order.

[0022]

2. Cogeneration Line 1

FIG. 2 is a schematic diagram of the cogeneration line 1 according to an embodiment of the present disclosure. The gas turbine 9 of the cogeneration line 1 includes a compressor 16 for producing compressed air 7 from compressor inlet air 6, the combustor 3 for combusting supplied fuel and raising a temperature of the compressed air 7 to produce combustion gas 12, a turbine 2 for rotating using the combustion gas 12 discharged from the combustor 3 as a drive source, and a generator 5 connected to the turbine 2. The combustor 3 is, for example, a diffusion type combustor. The generator 5 is configured to generate electric power by driving the turbine 2.

[0023]

The fuel that is supplied by the combustor 3 is start-up fuel gas that is supplied by the start-up fuel gas supply facility 77 and mixed fuel gas that is supplied by the mixed fuel gas supply facility 79. The cogeneration line 1 includes a start-up supply line 76 for guiding the start-up fuel gas from the start-up fuel gas supply facility 77 to the combustor 3, and the mixed supply line 78 for guiding the mixed fuel gas from the mixed fuel gas supply facility 79 to the combustor 3.

[0024]

The start-up supply line 76 and the mixed supply line 78 are provided with on-off valves 76A and 78A, respectively. By controlling opening and closing of the on-off valves, the fuel that is supplied to the combustor 3 is selectively switched to the start-up fuel gas or the mixed fuel gas. More specifically, when the gas turbine 9 is started up, the on-off valve 76A is opened and the on-off valve 78A is closed. As a result, the start-up supply line 76 exclusively supplies the start-up fuel gas to the combustor 3, and the single-fuel combustion of the start-up fuel gas occurs in the combustor 3. After the startup of the gas turbine 9 is completed, the on-off valve 76A is closed and the on-off valve 78A is opened. Thereby, the supply of the start-up fuel gas is terminated, and the mixed supply line 78 supplies the mixed fuel gas to the combustor 3. Hereinafter, the start-up fuel gas and the mixed fuel gas may be collectively referred to as "fuel gas".

[0025]

FIG. 3 is a schematic diagram illustrating the combustor 3 according to an embodiment of the present disclosure. The combustor 3 includes a combustor casing 23 formed in a cylindrical shape, a head end 24 provided at one end portion of the combustor casing 23, a fuel nozzle 25 provided at the head end 24, a cylindrical combustor liner 26 separating un-combusted air from combusted combustion gas 12, and a combustor transition piece 27 connected to a downstream portion of the combustor liner 26. The fuel nozzle 25 is configured to inject the fuel gas supplied by the start-up supply line 76 or the mixed supply line 78 into the combustor liner 26. The compressed air 7 is supplied to the combustor casing 23. In the combustor casing 23, the compressed air 7 flows toward the head end 24 side through an annular space formed on an outer side of the combustor liner 26. The compressed air 7 flowing through the annular space flows into the combustor liner 26 and is mixed with the fuel gas injected by the fuel nozzle 25. The fuel gas is combusted inside the combustor liner 26 and a flame 28 is generated inside the combustor liner 26. The combustion gas 12 generated inside the combustor liner 26 is discharged from the combustor transition piece 27 and flows into the turbine 2.

[0026]

Referring back to FIG. 2, the heat recovery steam generator 14 is configured to produce boiler steam from boiler feedwater guided by the water supply line 19 by using the exhaust gas 13, which is the combustion gas 12 discharged from the turbine 2, as a heat source. The cogeneration line 1

includes a steam supply pipe 21 for supplying the boiler steam discharged from the heat recovery steam generator 14 to the steam consumer 11. The steam consumer 11 of the present example is a steam turbine. The steam consumer 11 according to another example may be a steam turbine of a combined cycle power plant, an industrial process device, or the like.

[0027]

Although not an essential component of the present disclosure, the cogeneration system 10 includes a steam extraction pipe 130 for supplying the boiler steam extracted from the steam supply pipe 21 to the combustor 3. The steam extraction pipe 130 exemplified in the drawing includes an upstream steam pipe 131 for supplying steam extracted from the steam supply pipe 21 to the head end 24 side in the combustor 3, and a downstream steam pipe 132 for supplying the extracted steam to the turbine 2 side in the combustor 3.

[0028]

More specifically, as illustrated in FIG. 3, the upstream steam pipe 131 is configured to supply the extracted steam between the head end 24 and the combustor liner 26. By changing an opening degree of an upstream steam flow control valve 131A provided in the upstream steam pipe 131, an upstream steam supply amount, which is a flow rate of the boiler steam flowing through the upstream steam pipe 131, is adjusted. As the upstream steam supply amount increases, the effect of lowering a temperature of a flame zone increases, and thus an amount of nitrogen oxides generated in the combustor 3 decreases. For example, when a proportion of the fossil fuel gas in the gas turbine fuel gas is high, or when ammonia gas described below is adopted as the gas turbine fuel gas supplied to the combustor 3, the amount of nitrogen oxides generated in the combustor 3 is high. In this regard, according to the above-described configuration, the generation of nitrogen oxides can be suppressed by the boiler steam supplied by the upstream steam pipe 131. In addition, the boiler steam supplied to the combustor 3 is mixed into the exhaust gas 13 and then recovered by the water recovery device 33 as moisture contained in the exhaust gas 13. As a result, a sufficient amount of recovered water can be recovered, so the fuel gas production facility 80 (see FIG. 1) can produce a sufficient amount of gas turbine fuel gas.

[0029]

In addition, the downstream steam pipe 132 is configured to supply the extracted boiler steam to the downstream side of the combustor liner 26. By changing an opening degree of a downstream steam flow control valve 132A provided in the downstream steam pipe 132, a downstream steam supply

amount, which is a flow rate of the boiler steam flowing through the downstream steam pipe 132, is adjusted. As a total amount of the upstream steam supply amount and the downstream steam supply amount increases, the flow rate of the steam flowing into the turbine 2 and performing work increases, and the power generation capacity of the generator 5, which is an output of the gas turbine 9, increases. Note that the boiler steam supplied through the downstream steam pipe 132 is also mixed into the exhaust gas 13 and then recovered by the water recovery device 33.

[0030]

Referring back to FIG. 2, although not an essential component of the present disclosure, the steam extraction pipe 130 further includes a desuperheater 22 for lowering a temperature of the steam extracted from the steam supply pipe 21. The desuperheater 22 arranged upstream with respect to the upstream steam pipe 131 and the downstream steam pipe 132 in a direction in which the boiler steam flows is configured such that, for example, part of the boiler feedwater supplied to the heat recovery steam generator 14 flows in as cold water (see arrow B), and the cold water is injected inside the desuperheater 22 to cool the boiler steam. The cooled steam flows through the upstream steam pipe 131 and the downstream steam pipe 132.

[0031]

Although not essential components of the present disclosure, the cogeneration line 1 includes the makeup water tank 17 that stores recovered water containing moisture recovered from the water recovery system 40 as boiler feedwater, a water supply line 15 for supplying makeup water to the makeup water tank 17, the water supply line 19 connected to the makeup water tank 17 and the heat recovery steam generator 14, and a water supply pump 18 provided in the water supply line 19. When the water supply pump 18 is driven, the boiler feedwater stored in the makeup water tank 17 flows through the water supply line 19 and is supplied to the heat recovery steam generator 14. The temperature of the boiler feedwater supplied to the heat recovery steam generator 14 is preferably high. This is because the amount of heat required for the heat recovery steam generator 14 to produce boiler steam is reduced and the efficiency of the cogeneration system 10 is improved.

[0032]

3. Water Recovery System 40

FIG. 4 is a schematic diagram of the water recovery system 40 according to an embodiment of the present disclosure. The above-described water recovery device 33, which is a component of the water recovery system 40, is

configured to recover moisture in the exhaust gas 13 as recovered water by bringing the exhaust gas 13 guided by the exhaust gas supply line 141 and the refrigerant water into gas-liquid contact with each other. As a more detailed example, the water recovery device 33 includes a heat exchange vessel 135 into which the exhaust gas 13 and the refrigerant water flow, water spraying equipment 34 for spraying the refrigerant water inside the heat exchange vessel 135, and a filler 35 positioned below the water spraying equipment 34 inside the heat exchange vessel 135. When a water recovery damper 59 provided in the exhaust gas supply line 141 is opened, the exhaust gas 13 flows into the heat exchange vessel 135 from the exhaust gas supply line 141. The refrigerant water sprayed by the water spraying equipment 34 adheres to the filler 35 and exchanges heat with the exhaust gas 13 flowing into the heat exchange vessel 135. Thereby, moisture in the exhaust gas 13 is condensed. The recovered water containing the condensed moisture and the heat-exchanged refrigerant water falls and is stored in a water storage tank 136 constituting a lower portion of the heat exchange vessel 135. Note that the exhaust gas 13 from which moisture has been recovered is discharged from an exhaust gas outlet provided in an upper portion of the water recovery device 33.

[0033]

The water recovery system 40 further includes a recovered water cooling device 36 for cooling the recovered water discharged from the water storage tank 136 of the water recovery device 33, a recovered water discharge line 39 for guiding the recovered water discharged from the water storage tank 136 of the water recovery device 33 to the recovered water cooling device 36, and a recovered water supply line 42 for guiding the cooled recovered water discharged from the recovered water cooling device 36 to the heat exchange vessel 135 as refrigerant water. The recovered water cooling device 36 of the present example is configured to cool the recovered water with cooling water, which may be, for example, seawater. A cooling water supply pump 55 is provided in a cooling water supply line 41 for supplying cooling water to the recovered water cooling device 36.

[0034]

The water recovery system 40 further includes the water supply line 43 for guiding the recovered water to the makeup water tank 17, and the water supply line 43 includes a high-temperature water supply line 44 and a low-temperature water supply line 47. The high-temperature water supply line 44 is connected to the recovered water discharge line 39 and is configured to guide the recovered water taken out from the recovered water discharge line 39 to the

makeup water tank 17. The recovered water taken out from the recovered water discharge line 39 has a relatively high temperature because the recovered water has heat recovered from the exhaust gas 13. The low-temperature water supply line 47 is connected to the recovered water supply line 42 and is configured to guide the recovered water taken out from the recovered water supply line 42 to the makeup water tank 17. The recovered water taken out from the recovered water supply line 42 has a relatively low temperature because it has been subjected to cooling treatment by the recovered water cooling device 36.

[0035]

The low-temperature water supply line 47 is provided with a water treatment device 46, which is a component of the water recovery system 40. The water treatment device 46 is configured to perform treatment for removing impurities such as sulfur on the recovered water flowing through the low-temperature water supply line 47. The impurities are generated along with combustion in the combustor 3 (see FIG. 3) and may be mixed into the exhaust gas 13. At least part of the impurities is dissolved in the recovered water by heat exchange between the exhaust gas 13 and the refrigerant water in the water recovery device 33. The water treatment device 46 removes the impurities contained in the recovered water, so that the impurities are suppressed from being contained in the boiler feedwater stored in the makeup water tank 17. In general, the lower the temperature of the water to be treated, the higher the treatment capacity for removing impurities in the water treatment device 46. When the temperature of the recovered water is high, an ion exchange resin constituting the water treatment device 46 may be damaged, and there is a concern of a reduction in the treatment capacity for removing impurities.

[0036]

The high-temperature water supply line 44 is provided with a high-temperature water supply on-off valve 48, and the low-temperature water supply line 47 is provided with a low-temperature water supply on-off valve 45. When the fuel gas, which may be LPG classified as clean energy, is supplied to the combustor 3 as the start-up fuel gas of the gas turbine 9, an amount of the impurities mixed into the exhaust gas 13 is less than a tolerance. In this case, the high-temperature water supply on-off valve 48 is opened, and the high-temperature recovered water that does not require the impurity removing treatment flows into the makeup water tank 17 via the high-temperature water supply line 44 (at this time, the low-temperature water supply on-off valve 45 is closed). Since the temperature of the boiler feedwater

supplied from the makeup water tank 17 to the heat recovery steam generator 14 can be raised, the efficiency of the cogeneration system 10 is improved.

[0037]

On the other hand, when the mixed fuel gas is supplied to the combustor 3 after the startup of the gas turbine 9, the amount of impurities mixed into the exhaust gas 13 may be equal to or greater than the tolerance and less than an allowable upper limit value, depending on the type of the gas turbine fuel gas or the proportion of the fossil fuel gas contained in the mixed fuel gas. In this case, the high-temperature water supply on-off valve 48 is closed, the low-temperature water supply on-off valve 45 is opened, and the low-temperature recovered water requiring the impurity removing treatment flows into the makeup water tank 17 via the water treatment device 46 provided in the low-temperature water supply line 47. Therefore, it is possible to avoid a situation in which impurities adhere to devices constituting the cogeneration system 10, such as the water supply line 19 and the heat recovery steam generator 14, and to suppress deterioration of the cogeneration system 10.

[0038]

As described above, in the water recovery system 40 of the present example, the water supply line 43 for the recovered water to be sent to the makeup water tank 17 can be switched in accordance with the amount of impurities contained in the fuel gas supplied to the combustor 3. Note that when the amount of impurities contained in the exhaust gas 13 becomes equal to or greater than the allowable upper limit value, the water recovery damper 59 is closed and the exhaust damper 31 (see FIG. 2) is opened. As a result, the exhaust gas 13 is discharged from the exhaust tower 30 without being supplied to the water recovery system 40.

[0039]

4. Fuel Gas Production Facility 80

FIGS. 5A to 5F are schematic diagrams of fuel gas production facilities 80A (80) to 80F (80) according to a first embodiment to a sixth embodiment, respectively. The gas turbine fuel gas in the first embodiment is methane gas. The gas turbine fuel gas in the second embodiment and the fourth embodiment is ammonia gas. The gas turbine fuel gas in the third embodiment, the fifth embodiment, and the sixth embodiment is hydrogen gas. In FIGS. 5A to 5F, the cogeneration system 10 is illustrated as cogeneration systems 10A (10) to 10F (10).

[0040]

4-1. Fuel Gas Production Facility 80A (80) According to First Embodiment

As illustrated in FIG. 5A, a fuel gas production unit 81A (81) of the fuel gas production facility 80A includes a water-splitting device 61 for producing hydrogen gas by performing a water-splitting treatment on industrial water, a carbon dioxide recovery device 62 for recovering carbon dioxide gas from the exhaust gas 13 discharged from the water recovery device 33, a methane production device 63 for producing methane gas from hydrogen gas produced by the water-splitting device 61 and carbon dioxide gas recovered by the carbon dioxide recovery device 62, and a methane fuel gas supply line 88A for supplying methane gas to the gas mixing device 8 as the gas turbine fuel gas. The carbon dioxide recovery device 62 uses boiler steam discharged from the steam consumer 11 as a heat source in the recovery of carbon dioxide gas. The methane fuel gas supply line 88A is an example of the fuel gas supply line 88 (see FIG. 1).

[0041]

The water-splitting device 61 is connected to the water extraction line 49, and the industrial water flowing through the water extraction line 49 flows into the water-splitting device 61. The water-splitting treatment performed by the water-splitting device 61 is, for example, a water electrolysis treatment. The hydrogen gas produced by the above treatment is guided to the methane production device 63 by a hydrogen gas supply line 91, which is a component of the fuel gas production facility 80A (80).

[0042]

The carbon dioxide recovery device 62 is connected to the steam consumer 11 by a boiler steam supply line 101, which is a component of the fuel gas production facility 80A. The boiler steam discharged from the steam consumer 11 flows into the carbon dioxide recovery device 62 via the boiler steam supply line 101. In addition, the carbon dioxide recovery device 62 is connected to an exhaust gas outlet of the water recovery device 33 by an exhaust gas supply line 109, which is a component of the fuel gas production facility 80A. The heat-exchanged exhaust gas 13 discharged from the water recovery device 33 flows into the carbon dioxide recovery device 62 via the exhaust gas supply line 109. The exhaust gas 13 that has passed through the carbon dioxide recovery device 62 is discharged to the atmosphere from an exhaust tower 38.

[0043]

In the carbon dioxide recovery device 62 of the present example, a chemical absorption method is employed. More specifically, the exhaust gas 13 discharged from the water recovery device 33 is mixed with an absorption liquid

such as an amine liquid to dissolve carbon dioxide contained in the exhaust gas 13 in the absorption liquid. Thereafter, the carbon dioxide gas is recovered from the absorption liquid by heating the absorption liquid using the boiler steam as a heat source. The temperature of the exhaust gas 13 before being mixed with the absorption liquid is preferably relatively low. In this regard, the exhaust gas 13 discharged from the water recovery device 33 is subjected to a certain degree of cooling treatment by heat exchange with the refrigerant water in the water recovery device 33. That is, the water recovery device 33 has both a function of recovering moisture from the exhaust gas 13 and a function of cooling the exhaust gas 13 for recovery of carbon dioxide. Accordingly, the moisture recovery treatment and the cooling treatment are performed without waste, which contributes to energy saving of the cogeneration system 10A. Note that in the carbon dioxide recovery device 62, a physical absorption method, a membrane separation method, or a cryogenic separation method may be employed instead of the chemical absorption method.

[0044]

The carbon dioxide gas produced in the carbon dioxide recovery device 62 flows into the methane production device 63 via a carbon dioxide supply line 162. The methane production device 63 is configured to produce methane gas by causing oxygen gas and carbon dioxide gas to react with each other on a surface of a catalyst at high temperature and high pressure. Here, the catalyst may be a Ni-based catalyst such as LaNi_5 or a Ru-based catalyst such as $\text{Ru-Al}_2\text{O}_3$.

[0045]

In some embodiments, the methane gas produced in the methane production device 63 is supplied to the gas mixing device 8 by the methane fuel gas supply line 88A. In another embodiment, the methane fuel gas supply line 88A may directly supply the methane gas as the gas turbine fuel gas to the combustor 3. In either embodiment, hydrogen contained in the methane gas is combined with oxygen in the combustor 3 to generate moisture. This moisture is recovered by the water recovery device 33 and then reused for the production of methane gas. In addition, after the carbon dioxide gas generated by the combustion of the methane gas is also absorbed by the carbon dioxide recovery device 62, at least part thereof is reused for the production of methane gas. That is, in the cogeneration system 10A, hydrogen and carbon circulate.

[0046]

According to the configuration in which the fuel gas production facility 80A includes the water-splitting device 61, methane gas can be produced as the gas turbine fuel gas derived from hydrogen gas, and the cogeneration system

10A can reduce carbon dioxide emissions. In addition, since moisture generated by combustion of the gas turbine fuel gas derived from hydrogen gas in the combustor 3 is recovered by the water recovery device 33, the amount of recovered water increases, and the amount of produced gas turbine fuel gas also increases. Therefore, it is possible to reduce dependence on other fuel gas such as fossil fuel gas existing outside the system. In addition, hydrogen and carbon can be circulated within the system of the cogeneration system 10A. In addition, since heat of the boiler steam discharged from the steam consumer 11 is used in the production of carbon dioxide in the carbon dioxide recovery device 62, the cogeneration system 10A can achieve energy saving.

[0047]

Note that, although not an essential component of the first embodiment, the fuel gas production unit 81A may further include an oxygen gas supply line 64 for supplying oxygen gas, which is generated in the process of producing the hydrogen gas by the water-splitting device 61, to the combustor 3. The oxygen gas flowing through the oxygen gas supply line 64 is mixed with the compressed air 7 in the combustor casing 23 (see FIG. 3) and then flows into the combustor liner 26 (see FIG. 3).

[0048]

According to the configuration in which the oxygen gas supply line 64 is provided, the industrial water to be subjected to the water-splitting treatment can be utilized without waste by using the oxygen gas generated in the water-splitting device 61 as an oxidizing agent of the combustor 3.

[0049]

4-2. Fuel Gas Production Facility 80B (80) According to Second Embodiment

Referring to FIG. 5B, the configuration of the fuel gas production facility 80B (80) is exemplified. In FIG. 5B, components that are the same as those described with reference to FIG. 5A are denoted with the same reference signs, and a description of these components may be omitted below.

[0050]

A fuel gas production unit 81B (81) of the fuel gas production facility 80B includes the water-splitting device 61 described above. In addition, the fuel gas production unit 81B further includes a nitrogen gas extraction device 66 for extracting nitrogen gas from the atmosphere, a first ammonia production device 71 for producing ammonia from hydrogen gas produced by the water-splitting device 61 and nitrogen gas extracted by nitrogen gas extraction device 66, and a first ammonia fuel gas supply line 88B for supplying ammonia gas discharged from the first ammonia production device 71 to the gas mixing

device 8 as the gas turbine fuel gas. The first ammonia fuel gas supply line 88B is an example of the fuel gas supply line 88 (see FIG. 1). The hydrogen gas discharged from the water-splitting device 61 flows into the first ammonia production device 71 via a hydrogen gas supply pipe 173.

5 [0051]

The nitrogen gas extraction device 66 is configured to take out nitrogen gas from the atmosphere by pressure swing adsorption (PSA). The nitrogen gas produced by the nitrogen gas extraction device 66 flows into the first ammonia production device 71 via a nitrogen gas supply pipe 174.

10 [0052]

The first ammonia production device 71 is configured to produce ammonia by synthesis using a catalyst from hydrogen gas and nitrogen gas, and ammonia catalyst synthesis by the Haber Bosch process is employed. Electric power required in the synthesis using the catalyst is supplied by electric power
15 generated by the generator 5 (see FIG. 2). In addition to electric power generated by cogeneration, electric power may be supplied by using a renewable energy power source (photovoltaic power generation, wind power generation, or the like). The ammonia produced in the first ammonia production device 71 is in a supercritical fluid state. The ammonia discharged from the
20 first ammonia production device 71 is in a gaseous state, and this ammonia gas is supplied to the gas mixing device 8 via the first ammonia fuel gas supply line 88B. Note that the first ammonia fuel gas supply line 88B may be configured to directly supply the ammonia gas as the gas turbine fuel gas to the combustor 3. In either embodiment, hydrogen contained in the ammonia gas is combined
25 with oxygen in the combustor 3 to generate moisture. This moisture is recovered by the water recovery device 33 and then reused for the production of ammonia gas. That is, hydrogen circulates in the cogeneration system 10B.
[0053]

According to the configuration in which the fuel gas production facility
30 80B includes the water-splitting device 61, the ammonia gas derived from hydrogen gas can be supplied to the combustor 3 as the gas turbine fuel gas, and the cogeneration system 10B can reduce carbon dioxide emissions. In addition, since moisture generated by combustion of the ammonia gas derived from hydrogen gas in the combustor 3 is recovered by the water recovery
35 device 33, the amount of recovered water increases, and the amount of produced gas turbine fuel gas also increases. Therefore, it is possible to reduce dependence on other fuel gas such as fossil fuel gas existing outside the system. In addition, hydrogen can be circulated within the system of the

cogeneration system 10B. Further, according to the configuration in which the fuel gas production facility 80B includes the nitrogen gas extraction device 66 and the first ammonia production device 71, ammonia is produced from the hydrogen gas, so that the supply system of the gas turbine fuel gas can be further simplified. Specifically, since the boiling point of ammonia is higher than the boiling points of other liquid fuels such as hydrogen, facilities for storing ammonia in a liquid phase state can be simplified. A storage tank as such a storage facility may be arranged in the first ammonia fuel gas supply line 88B. Alternatively, a large-sized vehicle or a tanker, which transports ammonia produced by the first ammonia production device 71 while storing the ammonia in a liquid phase state, may be used.

[0054]

In addition, according to the configuration in which the fuel gas production facility 80B includes the first ammonia fuel gas supply line 88B, carbon-free ammonia gas can be used as the gas turbine fuel gas, so the cogeneration system 10B can reduce carbon dioxide emissions.

[0055]

Note that, although not an essential component of the second embodiment, the fuel gas production unit 81B may further include the oxygen gas supply line 64 described in the first embodiment. The advantages obtained by providing the oxygen gas supply line 64 are as described in the first embodiment.

[0056]

4-3. Fuel Gas Production Facility 80C (80) According to Third Embodiment

Referring to FIG. 5C, the configuration of the fuel gas production facility 80C (80) is exemplified. In FIG. 5C, components that are the same as those described with reference to FIG. 5B are denoted with the same reference signs, and a description of these components may be omitted below.

[0057]

A fuel gas production unit 81C (81) of the fuel gas production facility 80C includes the water-splitting device 61, the nitrogen gas extraction device 66, the nitrogen gas supply pipe 174, and the first ammonia production device 71. The details of these components are as described in the second embodiment.

[0058]

The fuel gas production unit 81C includes an ammonia gas discharge line 175, a first hydrogen gas production device 51, and a first hydrogen fuel gas supply line 88C, in place of the first ammonia fuel gas supply line 88B. The ammonia gas discharge line 175 is connected to the first hydrogen gas production device 51 and the gas mixing device 8. The first hydrogen fuel gas

supply line 88C is connected to the first hydrogen gas production device 51 and the gas mixing device 8. The first hydrogen fuel gas supply line 88C is an example of the fuel gas supply line 88 (see FIG. 1).

[0059]

5 The first hydrogen gas production device 51 is connected to the steam consumer 11 via a boiler steam supply line 102. That is, the boiler steam discharged from the steam consumer 11 flows into the first hydrogen gas production device 51. The first hydrogen gas production device 51 is configured to produce hydrogen gas from the ammonia gas discharged from the
10 first ammonia production device 71 by using boiler steam discharged from the heat recovery steam generator 14 as a heat source. The first hydrogen gas production device 51 of the present example is configured to produce hydrogen gas by thermally decomposing ammonia gas utilizing a catalytic decomposition reaction (cracking reaction) using a catalyst. In this thermal decomposition, the
15 boiler steam is used as a heat source. In addition, the catalyst used in the cracking reaction is a Ru-based catalyst.

[0060]

 The first hydrogen fuel gas supply line 88C illustrated in FIG. 5C is configured to supply hydrogen gas produced by the first hydrogen gas
20 production device 51 to the gas mixing device 8 as the gas turbine fuel gas. The first hydrogen fuel gas supply line 88C according to another example may directly supply the hydrogen gas as the gas turbine fuel gas to the combustor 3. In either embodiment, hydrogen constituting the hydrogen gas is combined with oxygen in the combustor 3 to generate moisture. This moisture is
25 recovered by the water recovery device 33 and then reused for the production of ammonia gas (i.e., production of hydrogen gas). That is, hydrogen circulates in the cogeneration system 10C.

[0061]

 According to the above configuration, since the carbon-free hydrogen
30 gas is used as the gas turbine fuel gas, the cogeneration system 10C can reduce carbon dioxide emissions. The cogeneration system 10C can produce the gas turbine fuel gas as hydrogen gas and reduce carbon dioxide emissions. In addition, since moisture generated by combustion of hydrogen gas as the gas turbine fuel gas in the combustor 3 is recovered by the water recovery device
35 33, the amount of recovered water increases, and the amount of produced gas turbine fuel gas also increases. Therefore, it is possible to reduce the dependence on other fuel gas such as fossil fuel gas existing outside the system. In addition, hydrogen can be circulated within the system of the

cogeneration system 10C. Further, since the hydrogen gas having a relatively high calorific value per unit weight can be used as the gas turbine fuel gas, it is possible to reduce a supply amount of other fuel gas such as fossil fuel gas existing outside the cogeneration system 10C.

5 [0062]

Note that like the cogeneration system 10B, the cogeneration system 10C includes the nitrogen gas extraction device 66, the first ammonia production device 71, and the oxygen gas supply line 64. The advantages obtained by providing these configurations are as described in the second
10 embodiment, and a detailed description thereof will be omitted to avoid redundant description.

[0063]

4-4. Fuel Gas Production Facility 80D (80) According to Fourth Embodiment

Referring to FIG. 5D, the configuration of the fuel gas production
15 facility 80D (80) is exemplified. In FIG. 5D, components that are the same as those described with reference to FIG. 5B are denoted with the same reference signs, and a description of these components may be omitted below.

[0064]

A fuel gas production unit 81D (81) of the fuel gas production facility
20 80D includes the nitrogen gas extraction device 66 and the nitrogen gas supply pipe 174. The details of these components are as described in the second embodiment.

[0065]

The fuel gas production unit 81D further includes a second ammonia
25 production device 72 connected to the water extraction line 49 and the nitrogen gas supply pipe 174, and a second ammonia fuel gas supply line 88D connected to the second ammonia production device 72 and the gas mixing device 8. The second ammonia fuel gas supply line 88D is an example of the fuel gas supply line 88 (see FIG. 1).

30 [0066]

The second ammonia production device 72 is configured to produce ammonia through electrolytic synthesis from the industrial water supplied by the water extraction line 49 and the nitrogen gas supplied by the nitrogen gas supply pipe 174. In the electrolytic synthesis of this example, a solid electrolyte is used
35 to separate water and nitrogen from each other when a voltage is applied to them. Hydrogen ions generated by applying a voltage to water pass through the solid electrolyte and migrate to the nitrogen side. As a result, hydrogen and nitrogen combine to produce ammonia. The ammonia at the time of production is in a

gaseous state. Note that the electric power required for the electrolytic synthesis is supplied by the electric power generated by the generator 5 (see FIG. 2). In addition to the above-described power source, electric power may be supplied by using a renewable energy power source (photovoltaic power generation, wind power generation, or the like).

[0067]

The second ammonia fuel gas supply line 88D is configured to supply ammonia gas discharged from the second ammonia production device 72 to the gas mixing device 8 as the gas turbine fuel gas. The second ammonia fuel gas supply line 88D according to another example may directly supply the ammonia gas as the gas turbine fuel gas to the combustor 3. In either embodiment, hydrogen contained in the ammonia gas is combined with oxygen in the combustor 3 to generate moisture. This moisture is recovered by the water recovery device 33 and then reused for the production of ammonia. That is, hydrogen circulates in the cogeneration system 10D.

[0068]

According to the above configuration, since ammonia is produced through electrolytic synthesis, the number of steps required for the production can be reduced as compared with the case where the Haber Bosch process is employed. Therefore, the second ammonia production device 72 can produce ammonia through a simple process. In addition, by using ammonia as the gas turbine fuel gas, the supply system of the gas turbine fuel gas can further be simplified (details are as described in the second embodiment). Further, since the carbon-free ammonia gas is used as the gas turbine fuel gas, the cogeneration system 10D can reduce carbon dioxide emissions.

[0069]

In some embodiments, the fuel gas production facility 80D (80) may further include an oxygen gas supply line 65 for supplying oxygen gas generated in the process of producing ammonia in the second ammonia production device 72 to the combustor 3. The oxygen gas flowing through the oxygen gas supply line 65 is mixed with the compressed air 7 in the combustor casing 23 (see FIG. 3) and then flows into the combustor liner 26 (see FIG. 3). According to the above configuration, the industrial water to be subjected to the water-splitting treatment can be utilized without waste by using the oxygen gas generated in the second ammonia production device 72 as an oxidizing agent of the combustor 3.

[0070]

4-5. Fuel Gas Production Facility 80E (80) According to Fifth Embodiment

Referring to FIG. 5E, the configuration of the fuel gas production facility 80E (80) is exemplified. In FIG. 5E, components that are the same as those described with reference to FIG. 5D are denoted with the same reference signs, and a description of these components may be omitted below.

5 [0071]

A fuel gas production unit 81E (81) of the fuel gas production facility 80E includes the nitrogen gas extraction device 66, the nitrogen gas supply pipe 174, and the second ammonia production device 72. The details of these components are as described in the fourth embodiment. In addition, the fuel gas production facility 80E (80) further includes the oxygen gas supply line 65. The component is also as described in the fourth embodiment.

[0072]

The fuel gas production unit 81E includes an ammonia gas discharge line 176, a second hydrogen gas production device 52, and a second hydrogen fuel gas supply line 88E (88). The ammonia gas discharge line 176 is connected to the second ammonia production device 72 and the second hydrogen gas production device 52. The ammonia gas discharge line 176 supplies ammonia gas discharged from the second ammonia production device 72 to the second hydrogen gas production device 52. The second hydrogen fuel gas supply line 88E (88) is connected to the second hydrogen gas production device 52 and the gas mixing device 8. The second hydrogen fuel gas supply line 88E is an example of the fuel gas supply line 88 (see FIG. 1).

[0073]

The second hydrogen gas production device 52 has the same or similar configuration as or to that of the first hydrogen gas production device 51. The second hydrogen gas production device 52 is connected to the steam consumer 11 via the boiler steam supply line 102. The second hydrogen gas production device 52 is configured to produce hydrogen gas from ammonia gas discharged from the second ammonia production device 72 by using boiler steam discharged from the heat recovery steam generator 14 as a heat source. Since the hydrogen gas producing method is the same as or similar to that of the first hydrogen gas production device 51 (see FIG. 5C), a detailed description thereof will be omitted.

[0074]

35 The second hydrogen fuel gas supply line 88E supplies the hydrogen gas produced by the second hydrogen gas production device 52 to the gas mixing device 8 as the gas turbine fuel gas. Note that the second hydrogen fuel gas supply line 88E may be configured to directly supply the hydrogen gas as the

gas turbine fuel gas to the combustor 3. In either embodiment, hydrogen constituting the hydrogen gas is combined with oxygen in the combustor 3 to generate moisture. This moisture is recovered by the water recovery device 33 and then reused for the production of ammonia (i.e., production of hydrogen gas). That is, hydrogen circulates in the cogeneration system 10E.
[0075]

According to the above configuration, since the hydrogen gas having a relatively high calorific value per unit weight can be used as the gas turbine fuel gas, it is possible to reduce a supply amount of other fuel gas existing outside the cogeneration system 10E. Further, since the advantages obtained by providing the fuel gas production facility 80E with the second ammonia production device 72 are as described in the fourth embodiment, a description thereof will be omitted. The advantages obtained by providing the fuel gas production facility 80E with the oxygen gas supply line 65 are also as described in the fourth embodiment, so a detailed description thereof will be omitted.
[0076]

4-6. Fuel Gas Production Facility 80F (80) According to Sixth Embodiment

Referring to FIG. 5F, the configuration of the fuel gas production facility 80F (80) is exemplified. A fuel gas production unit 81F (81) of the fuel gas production facility 80F includes the water-splitting device 61 described above. Further, the fuel gas production unit 81F includes a hydrogen fuel gas supply line 88F (88) connected to the water-splitting device 61 and the gas mixing device 8. The hydrogen fuel gas supply line 88F is configured to supply hydrogen gas produced by the water-splitting device 61 to the gas mixing device 8 as the gas turbine fuel gas. The hydrogen fuel gas supply line 88F is an example of the fuel gas supply line 88 (see FIG. 1). Note that the hydrogen fuel gas supply line 88F may directly supply the hydrogen gas to the combustor 3. In either embodiment, hydrogen constituting the hydrogen gas is combined with oxygen in the combustor 3 to generate moisture. This moisture is recovered by the water recovery device 33 and then reused for the production of hydrogen gas. That is, hydrogen circulates in the cogeneration system 10F.
[0077]

According to the above configuration, since the hydrogen gas having a relatively high calorific value per unit weight can be used as the gas turbine fuel gas, it is possible to reduce a supply amount of other fuel gas such as fossil fuel gas existing outside the cogeneration system 10F.
[0078]

4-7. Others

Each of the fuel gas production facilities 80A to 80F (80) according to the first embodiment to the sixth embodiment may be installed alone, or at least two or more of the fuel gas production facilities 80A to 80F may be installed in combination. In addition, in the fuel gas production facilities 80B and 80D in which ammonia gas is employed as the gas turbine fuel gas, the above-described upstream steam pipe 131 (see FIG. 2 and FIG. 3) is preferably provided. When efficiently operating the large gas turbine 9, a temperature of a combustion chamber formed on an inner side of the combustor liner 26 is high, and thus nitrogen oxides are likely to be produced during combustion of ammonia gas. In this regard, the upstream steam pipe 131 supplies the boiler steam to the head end 24 side of the combustor 3, thereby significantly achieving an advantage of suppressing the generation of nitrogen oxides.

[0079]

5. Modification Method for Cogeneration System 10G

Referring to FIGS. 1, 6, and 7, a method of modifying a cogeneration system 10G, which is the cogeneration system 10 before modification, into the cogeneration system 10 will be described. FIG. 6 is a schematic diagram of the cogeneration system 10G according to an embodiment of the present disclosure. FIG. 7 is a flow chart illustrating a modification method for the cogeneration system 10G.

[0080]

The cogeneration system 10G (10) will be first described before describing the modification method. The cogeneration system 10G does not include the add-on unit 4 illustrated in FIG. 1 (that is, the water recovery system 40 and the fuel gas production facility 80). In addition, the exhaust line 29 of the cogeneration system 10G is not provided with the exhaust damper 31 (see FIG. 1). The cogeneration system 10 is realized by adding the add-on unit 4 and the exhaust damper 31 to the cogeneration system 10G. A detailed modification method is as follows.

[0081]

First, a water recovery system addition step (S11) of adding the water recovery system 40 including the water recovery device 33 is performed. Specifically (see also FIG. 4), the water recovery system 40 is installed, and the inlet of the exhaust gas supply line 141 is connected to the connection between the exhaust gas line 57 and the exhaust line 29. Further, the water supply line 43 is connected to the makeup water tank 17. That is, the outlet of the high-temperature water supply line 44 and the outlet of the low-temperature water supply line 47 are connected to the makeup water tank 17.

[0082]

Next, an exhaust damper addition step (S13) of adding the exhaust damper 31 to the exhaust line 29 is performed. Note that when the exhaust damper 31 is provided in the exhaust line 29 before the modification, S13 may be omitted.

[0083]

Next, a fuel gas production facility addition step (S15) of adding the fuel gas production facility 80 is performed. Specifically, the inlet of the water extraction line 49 is connected to the water supply line 19, and the outlet of the mixed fuel gas supply line 86 (see FIG. 1) is connected to the mixed fuel gas supply facility 79. Thereby, the cogeneration system 10 is completed.

[0084]

Note that when adding the fuel gas production facility 80A (see FIG. 5A), a step of connecting the exhaust gas outlet of the water recovery device 33 and the carbon dioxide recovery device 62 using the exhaust gas supply line 109 is additionally performed in S15.

In addition, when adding the fuel gas production facility 80C (see FIG. 5C), a step of connecting the first hydrogen gas production device 51 and the steam consumer 11 using the boiler steam supply line 102 is additionally performed in S15.

Similarly, when adding the fuel gas production facility 80E (see FIG. 5E), a step of connecting the second hydrogen gas production device 52 and the steam consumer 11 using the boiler steam supply line 102 is additionally performed in S15.

Further, when adding the fuel gas production facilities 80A, 80B, 80C, and 80F (FIG. 5A, FIG. 5B, FIG. 5C, and FIG. 5F) including the water-splitting device 61, a step of connecting the water-splitting device 61 and the combustor 3 by the oxygen gas supply line 64 may be additionally performed in S15.

[0085]

The modification method for the cogeneration system 10G described above is performed by an operator, a robot arm operated by the operator, or a combination thereof.

6. Summary

The contents of some embodiments described above can be understood as follows, for example.

[0086]

1) A gas turbine cogeneration system (10) according to at least one embodiment of the present disclosure includes:

a gas turbine (9) including a combustor (3);
a heat recovery steam generator (14) configured to produce boiler steam by using exhaust gas (13) discharged from the gas turbine as a heat source;
a water recovery device (33) configured to recover moisture from the exhaust gas discharged from the heat recovery steam generator by heat exchange between the exhaust gas and refrigerant water; and
a fuel gas production facility (80) configured to produce gas turbine fuel gas to be supplied to the combustor by using industrial water containing recovered water recovered by the water recovery device as at least one of feedstock materials.

[0087]

According to the configuration of 1) above, the moisture contained in the exhaust gas is recovered by the water recovery device, and the industrial water containing the recovered water is utilized as at least one of feedstock materials of the gas turbine fuel gas. Since the gas turbine fuel gas is supplied to the combustor, a supply amount of another fuel gas such as fossil fuel gas can be reduced. Therefore, the gas turbine cogeneration system can reduce carbon dioxide emissions. In addition, the moisture contained in the exhaust gas is recovered by the water recovery device and then used as the gas turbine fuel gas, and the moisture generated by combustion of the gas turbine fuel gas is recovered again by the water recovery device. In this way, the gas turbine cogeneration system in which a material constituting moisture circulates is realized, allowing the supply amount of fossil fuel gas existing outside the system to be reduced and contributing to carbon neutrality.

[0088]

2) In some embodiments, in the gas turbine cogeneration system according to 1) above, the fuel gas production facility further includes a water-splitting device (61) configured to produce hydrogen gas by performing a water-splitting treatment on the industrial water.

[0089]

According to the configuration of 2) above, it is possible to produce the gas turbine fuel gas as the hydrogen gas or the gas turbine fuel gas derived from the hydrogen gas, and to reduce carbon dioxide emissions. In addition, since moisture generated by combustion of the gas turbine fuel gas as the hydrogen gas or the gas turbine fuel gas derived from the hydrogen gas in the combustor is recovered by the water recovery device, the amount of recovered water increases, and the amount of produced gas turbine fuel gas also increases. Therefore, it is possible to reduce the dependence on other fuel gas existing

outside the system. In addition, hydrogen can be circulated within the system of the cogeneration system.

[0090]

3) In some embodiments, in the gas turbine cogeneration system
5 according to 2) above, the fuel gas production facility further includes:

a carbon dioxide recovery device (62) configured to recover carbon dioxide from the exhaust gas discharged from the water recovery device by using the boiler steam discharged from the heat recovery steam generator;

a methane production device (63) configured to produce methane gas
10 from the hydrogen gas produced by the water-splitting device and the carbon dioxide recovered by the carbon dioxide recovery device; and

a methane fuel gas supply line (88A) configured to supply the methane gas to the combustor as the gas turbine fuel gas.

[0091]

15 According to the configuration of 3) above, the methane gas derived from the hydrogen gas can be supplied to the combustor as the gas turbine fuel gas. In addition, since carbon dioxide contained in the exhaust gas is used for the production of the methane gas, the carbon dioxide emissions can be reduced. Further, since the heat of the boiler steam is utilized when the carbon
20 dioxide is produced, energy saving is realized.

[0092]

4) In some embodiments, in the gas turbine cogeneration system according to 2) or 3) above, the fuel gas production facility further includes a hydrogen fuel gas supply line (88F) configured to supply the hydrogen gas
25 produced by the water-splitting device to the combustor as the gas turbine fuel gas.

[0093]

According to the configuration of 4) above, since the hydrogen gas having a relatively high calorific value per unit weight can be used as the gas
30 turbine fuel gas, it is possible to reduce a supply amount of other fuel gas existing outside the gas turbine cogeneration system.

[0094]

5) In some embodiments, in the gas turbine cogeneration system according to any one of 2) to 4) above, the fuel gas production facility further
35 includes:

a nitrogen gas extraction device (66) configured to extract nitrogen gas from an atmosphere; and

a first ammonia production device (71) configured to produce ammonia from the hydrogen gas produced by the water-splitting device and the nitrogen gas extracted by the nitrogen gas extraction device.

[0095]

5 According to the configuration of 5) above, ammonia is produced from the hydrogen gas, so that the supply system of the gas turbine fuel gas can be further simplified. More specifically, since the boiling point of ammonia is higher than the boiling points of other liquid fuels such as hydrogen, facilities for storing a fuel of the gas turbine in a liquid phase state can be simplified.

10 [0096]

6) In some embodiments, in the gas turbine cogeneration system according to 5) above, the fuel gas production facility further includes a first ammonia fuel gas supply line (88B) configured to supply ammonia gas discharged from the first ammonia production device to the combustor as the gas turbine fuel gas.

[0097]

According to the configuration of 6) above, since the carbon-free ammonia gas is used as the gas turbine fuel gas, carbon dioxide emissions can be reduced.

20 [0098]

7) In some embodiments, in the gas turbine cogeneration system according to 5) above, the fuel gas production facility further includes:

25 a first hydrogen gas production device (51) configured to produce hydrogen gas from ammonia gas discharged from the first ammonia production device by using the boiler steam discharged from the heat recovery steam generator as a heat source; and

 a first hydrogen fuel gas supply line (88C) configured to supply the hydrogen gas produced by the first hydrogen gas production device to the combustor as the gas turbine fuel gas.

30 [0099]

According to the configuration of 7) above, since the hydrogen gas having a relatively high calorific value per unit weight can be used as the gas turbine fuel gas, it is possible to reduce a supply amount of other fuel gas existing outside the gas turbine cogeneration system.

35 [0100]

8) In some embodiments, the gas turbine cogeneration system according to any one of 2) to 7) further includes an oxygen gas supply line (64)

configured to supply oxygen gas generated in a process of producing the hydrogen gas in the water-splitting device to the combustor.

[0101]

5 According to the configuration of 8) above, the industrial water to be subjected to the water-splitting treatment can be utilized without waste by using the oxygen gas generated in the water-splitting device as an oxidizing agent of the combustor.

[0102]

10 9) In some embodiments, in the gas turbine cogeneration system according to 1) above, the fuel gas production facility further includes:

a nitrogen gas extraction device (66) configured to extract nitrogen gas from an atmosphere; and

15 a second ammonia production device (72) configured to produce ammonia through electrolytic synthesis from the industrial water and the nitrogen gas extracted by the nitrogen gas extraction device.

[0103]

20 According to the configuration of 9) above, since ammonia is produced through electrolytic synthesis, the second ammonia production device can produce ammonia through a simple process. By using ammonia as the gas turbine fuel gas, the supply system of the gas turbine fuel gas can further be simplified. More specifically, since the boiling point of ammonia is higher than the boiling points of other liquid fuels such as hydrogen, facilities for storing a fuel of the gas turbine in a liquid phase state can be simplified.

[0104]

25 10) In some embodiments, the gas turbine cogeneration system according to 9) above further includes an oxygen gas supply line (65) configured to supply oxygen gas generated in a process of producing the ammonia in the second ammonia production device to the combustor.

[0105]

30 According to the configuration of 10) above, the industrial water to be subjected to the water-splitting treatment can be utilized without waste by using the oxygen gas generated in the second ammonia production device as an oxidizing agent of the combustor.

[0106]

35 11) In some embodiments, in the gas turbine cogeneration system according to 9) or 10) above, the fuel gas production facility further includes a second ammonia fuel gas supply line (88D) configured to supply ammonia gas

discharged from the second ammonia production device to the combustor as the gas turbine fuel gas.

[0107]

According to the configuration of 11) above, the operational effects that
5 are the same as or similar to those described in 6) above can be achieved.

[0108]

12) In some embodiments, in the gas turbine cogeneration system according to any one of 9) to 11) above, the fuel gas production facility further includes:

10 a second hydrogen gas production device (52) configured to produce hydrogen gas from ammonia gas discharged from the second ammonia production device by using the boiler steam discharged from the heat recovery steam generator as a heat source; and

a second hydrogen fuel gas supply line (88E) configured to supply the
15 hydrogen gas produced by the second hydrogen gas production device to the combustor as the gas turbine fuel gas.

[0109]

According to the configuration of 12) above, the operational effects that are the same as or similar to those described in 7) above can be achieved.

20 [0110]

13) In some embodiments, in the gas turbine cogeneration system according to any one of 1) to 12) above, the fuel gas production facility includes:

a gas mixing device (8) configured to mix the gas turbine fuel gas and fossil fuel gas to produce mixed fuel gas; and

25 a mixed fuel gas supply line (86) configured to supply the mixed fuel gas to the combustor.

[0111]

According to the configuration of 13) above, since the fossil fuel gas is contained in the mixed fuel gas to be supplied to the combustor, the calorific
30 value generated with the combustion in the combustor can be sufficiently ensured.

[0112]

14) In some embodiments, the gas turbine cogeneration system according to any one of 1) to 13) above further includes a head end-side steam
35 supply pipe (upstream steam pipe 131) configured to supply the boiler steam discharged from the heat recovery steam generator to a head end side of the combustor.

[0113]

According to the configuration of 14) above, since the boiler steam is injected in the combustor, generation of nitrogen oxides in the combustor can be suppressed. Further, the injected boiler steam is mixed into the exhaust gas and then recovered by the water recovery device as moisture contained in the exhaust gas. As a result, a sufficient amount of recovered water can be recovered, so the fuel gas production facility can produce a sufficient amount of gas turbine fuel gas.

[0114]

15) A modification method for a gas turbine cogeneration system (10) according to at least one embodiment of the present disclosure is a modification method for a gas turbine cogeneration system (10) including a gas turbine (9) including a combustor (3), and a heat recovery steam generator (14), the modification method including:

a water recovery device addition step (S11) of adding a water recovery device (33) configured to recover moisture from exhaust gas (13) discharged from the heat recovery steam generator by heat exchange between the exhaust gas and refrigerant water; and

a fuel gas production facility addition step (S15) of adding a fuel gas production facility (80) configured to produce gas turbine fuel gas to be supplied to the combustor by using industrial water containing recovered water recovered by the water recovery device as at least one of feedstock materials.

[0115]

According to the configuration of 15) above, the operational effects that are the same as or similar to those described in 1) above can be achieved.

[0116]

16) An add-on unit (4) for a gas turbine cogeneration system according to at least one embodiment of the present disclosure includes:

a water recovery device (33) configured to recover moisture from exhaust gas (13) discharged from a heat recovery steam generator (14) by heat exchange between the exhaust gas and refrigerant water; and

a fuel gas production facility (80) configured to produce gas turbine fuel gas to be supplied to a combustor (3) of a gas turbine (9) by using industrial water containing recovered water recovered by the water recovery device as at least one of feedstock materials.

[0117]

According to the configuration of 16) above, the operational effects that are the same as or similar to those described in 1) above can be achieved.

Reference Signs List

- [0118]
- 1: Cogeneration line
 - 2: Turbine
 - 5 3: Combustor
 - 4: Add-on unit for gas turbine cogeneration system
 - 4: Add-on unit
 - 5: Generator
 - 6: Compressor inlet air
 - 10 7: Compressed air
 - 8: Gas mixing device
 - 9: Gas Turbine
 - 10: Gas turbine cogeneration system (cogeneration system)
 - 11: Steam consumer
 - 15 12: Combustion gas
 - 13: Exhaust gas
 - 14: Heat recovery steam generator
 - 21: Steam supply pipe
 - 24: Head end
 - 20 25: Fuel nozzle
 - 26: Combustor liner
 - 27: Combustor transition piece
 - 28: Flame
 - 29: Exhaust line
 - 25 30: Exhaust tower
 - 31: Exhaust damper
 - 33: Water recovery device
 - 49: Water extraction line
 - 51: First hydrogen gas production device
 - 30 52: Second hydrogen gas production device
 - 55: Cooling water supply pump
 - 57: Exhaust gas line
 - 59: Water recovery damper
 - 61: Water-splitting device
 - 35 62: Carbon dioxide recovery device
 - 63: Methane production device
 - 64, 65: Oxygen gas supply line
 - 66: Nitrogen gas extraction device

- 71: First ammonia production device
- 72: Second ammonia production device
- 80: Fuel gas production facility
- 81: Fuel gas production unit
- 5 86: Mixed fuel gas supply line
- 88: Fuel gas supply line
- 88A: Methane fuel gas supply line
- 88B: First ammonia fuel gas supply line
- 88C: First hydrogen fuel gas supply line
- 10 88D: Second ammonia fuel gas supply line
- 88E: Second hydrogen fuel gas supply line
- 88F: Hydrogen fuel gas supply line
- 91: Hydrogen gas supply line
- 101: Boiler steam supply line
- 15 102: Boiler steam supply line
- 109: Exhaust gas supply line
- 130: Steam extraction pipe
- 131: Upstream steam pipe
- 131A: Upstream steam flow control valve
- 20 132: Downstream steam pipe
- 132A: Downstream steam flow control valve
- 135: Heat exchange vessel
- 162: Carbon dioxide supply line
- 173: Hydrogen gas supply pipe
- 25 174: Nitrogen gas supply pipe
- 175, 176: Ammonia gas discharge line

Claims

[Claim 1]

A gas turbine cogeneration system comprising:

- 5 a gas turbine comprising a combustor;
 a heat recovery steam generator configured to produce boiler steam by
using exhaust gas discharged from the gas turbine as a heat source;
 a water recovery device configured to recover moisture from the exhaust
gas discharged from the heat recovery steam generator by heat exchange
10 between the exhaust gas and refrigerant water; and
 a fuel gas production facility configured to produce gas turbine fuel gas
to be supplied to the combustor by using industrial water containing recovered
water recovered by the water recovery device as at least one of feedstock
materials.

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[Claim 2]

The gas turbine cogeneration system according to claim 1, wherein the
fuel gas production facility further comprises a water-splitting device
configured to produce hydrogen gas by performing a water-splitting treatment
20 on the industrial water.

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[Claim 3]

The gas turbine cogeneration system according to claim 2, wherein the
fuel gas production facility further comprises:

- 25 a carbon dioxide recovery device configured to recover carbon dioxide
from the exhaust gas discharged from the water recovery device by using the
boiler steam discharged from the heat recovery steam generator;
 a methane production device configured to produce methane gas from
the hydrogen gas produced by the water-splitting device and the carbon dioxide
30 recovered by the carbon dioxide recovery device; and
 a methane fuel gas supply line configured to supply the methane gas to
the combustor as the gas turbine fuel gas.

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[Claim 4]

35 The gas turbine cogeneration system according to claim 2 or 3, wherein
the fuel gas production facility further comprises a hydrogen fuel gas supply
line configured to supply the hydrogen gas produced by the water-splitting
device to the combustor as the gas turbine fuel gas.

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[Claim 5]

The gas turbine cogeneration system according to claim 2 or 3, wherein the fuel gas production facility further comprises:

5 a nitrogen gas extraction device configured to extract nitrogen gas from an atmosphere; and

 a first ammonia production device configured to produce ammonia from the hydrogen gas produced by the water-splitting device and the nitrogen gas extracted by the nitrogen gas extraction device.

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[Claim 6]

The gas turbine cogeneration system according to claim 5, wherein the fuel gas production facility further comprises a first ammonia fuel gas supply line configured to supply ammonia gas discharged from the first ammonia
15 production device to the combustor as the gas turbine fuel gas.

[Claim 7]

The gas turbine cogeneration system according to claim 5, wherein the fuel gas production facility further comprises:

20 a first hydrogen gas production device configured to produce hydrogen gas from ammonia gas discharged from the first ammonia production device by using the boiler steam discharged from the heat recovery steam generator as a heat source; and

 a first hydrogen fuel gas supply line configured to supply the hydrogen
25 gas produced by the first hydrogen gas production device to the combustor as the gas turbine fuel gas.

[Claim 8]

30 The gas turbine cogeneration system according to claim 2 or 3, further comprising an oxygen gas supply line configured to supply oxygen gas generated in a process of producing the hydrogen gas in the water-splitting device to the combustor.

[Claim 9]

35 The gas turbine cogeneration system according to claim 1, wherein the fuel gas production facility further comprises:

 a nitrogen gas extraction device configured to extract nitrogen gas from an atmosphere; and

a second ammonia production device configured to produce ammonia through electrolytic synthesis from the industrial water and the nitrogen gas extracted by the nitrogen gas extraction device.

5 [Claim 10]

The gas turbine cogeneration system according to claim 9, further comprising an oxygen gas supply line configured to supply oxygen gas generated in a process of producing the ammonia in the second ammonia production device to the combustor.

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[Claim 11]

The gas turbine cogeneration system according to claim 9 or 10, wherein the fuel gas production facility further comprises a second ammonia fuel gas supply line configured to supply ammonia gas discharged from the second ammonia production device to the combustor as the gas turbine fuel gas.

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[Claim 12]

The gas turbine cogeneration system according to claim 9 or 10, wherein the fuel gas production facility further comprises:

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a second hydrogen gas production device configured to produce hydrogen gas from ammonia gas discharged from the second ammonia production device by using the boiler steam discharged from the heat recovery steam generator as a heat source; and

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a second hydrogen fuel gas supply line configured to supply the hydrogen gas produced by the second hydrogen gas production device to the combustor as the gas turbine fuel gas.

[Claim 13]

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The gas turbine cogeneration system according to any one of claims 1 to 3, wherein the fuel gas production facility comprises:

a gas mixing device configured to mix the gas turbine fuel gas and fossil fuel gas to produce mixed fuel gas; and

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a mixed fuel gas supply line configured to supply the mixed fuel gas to the combustor.

[Claim 14]

The gas turbine cogeneration system according to any one of claims 1 to 3, further comprising a head end-side steam supply pipe configured to supply

the boiler steam discharged from the heat recovery steam generator to a head end side of the combustor.

[Claim 15]

5 A modification method for a gas turbine cogeneration system comprising a gas turbine comprising a combustor, and a heat recovery steam generator, the modification method comprising:

 a water recovery device addition step of adding a water recovery device configured to recover moisture from exhaust gas discharged from the heat
10 recovery steam generator by heat exchange between the exhaust gas and refrigerant water; and

 a fuel gas production facility addition step of adding a fuel gas production facility configured to produce gas turbine fuel gas to be supplied to the combustor by using industrial water containing recovered water recovered
15 by the water recovery device as at least one of feedstock materials.

[Claim 16]

 An add-on unit for a gas turbine cogeneration system, comprising:

 a water recovery device configured to recover moisture from exhaust gas
20 discharged from a heat recovery steam generator by heat exchange between the exhaust gas and refrigerant water; and

 a fuel gas production facility configured to produce gas turbine fuel gas to be supplied to a combustor of a gas turbine by using industrial water containing recovered water recovered by the water recovery device as at least
25 one of feedstock materials.