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REGENERATIVE FUEL CELL SYSTEM

Abstract

A regenerative fuel cell system includes a water electrolysis device for performing electrolysis of alkaline water, a fuel cell for performing power generation by using a generated gas that is a gas generated by the electrolysis, a storage container for storing generated water that is water generated by the power generation, and a gas flow path for guiding the generated gas to the fuel cell through the generated water stored in the storage container.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2024-021142 filed on Feb. 15, 2024, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present disclosure relates to a regenerative fuel cell system.

Description of the Related Art

[0003] In recent years, research and development have been conducted on fuel cells that contribute to energy efficiency in order to ensure that more people have access to affordable, reliable, sustainable and modern energy.

[0004] JP 2023-117525 A discloses a regenerative fuel cell system including a water electrolysis device and a fuel cell. In this regenerative fuel cell system, the water electrolysis device generates gas by electrolyzing water. The fuel cell generates electric power using gas generated by electrolysis of the water electrolysis device.

SUMMARY OF THE INVENTION

[0005] Alkaline water may be supplied to the water electrolysis device. In this case, the gas generated by the electrolysis of the water electrolysis device contains the alkaline water. When alkaline water is supplied to the fuel cell, a problem may occur in that the durability of the fuel cell is reduced.

[0006] An object of the present invention is to solve the aforementioned problem.

[0007] An aspect of the present disclosure is characterized by a regenerative fuel cell system including: a water electrolysis device configured to perform electrolysis of alkaline water; a fuel cell configured to perform power generation by using a generated gas that is a gas generated by the electrolysis; a storage container configured to store generated water that is water generated by the power generation; and a gas flow path configured to guide the generated gas to the fuel cell through the generated water stored in the storage container.

[0008] Thus, even if alkaline water is contained in the generated gas, the alkaline water can be neutralized by the generated water stored in the storage container. As a result, the durability of the fuel cell can be prevented from deteriorating.

[0009] The above and other objects, features, and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings, in which a preferred embodiment of the present invention is shown by way of illustrative example.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a schematic view of a regenerative fuel cell system according to a first embodiment;

[0011] FIG. **2** is a block diagram of a control device;

[0012] FIG. **3** is a flowchart showing a procedure of an operation stop control of a water electrolysis device;

[0013] FIG. **4** is a diagram showing a storage container;

[0014] FIG. **5** is a schematic view showing a regenerative fuel cell system according to a second embodiment; and

[0015] FIG. **6** is a flowchart showing a procedure of a concentration control.

DETAILED DESCRIPTION OF THE INVENTION

First Embodiment

[0016] FIG. **1** is a schematic view showing a regenerative fuel cell system **10** according to a first embodiment. The regenerative fuel cell system **10** includes a fuel cell **12**, a gas generation device **14**, a supply mechanism **16**, and a control device **18**.
[0017] The fuel cell **12** generates power through an electrochemical reaction between oxygen gas and hydrogen gas. The fuel cell **12** includes a plurality of electrochemical cells. Each electrochemical cell includes an electrolyte membrane and a pair of electrodes provided on both sides of the electrolyte membrane in the thickness direction. The electrolyte membrane used in the fuel cell **12** is a proton exchange membrane. One of the pair of electrodes is an anode, and the other of the pair of electrodes is a cathode. The fuel cell **12** supplies hydrogen gas to the anode of each electrochemical cell. The fuel cell **12** supplies oxygen gas to the cathode of each electrochemical cell. The fuel cell **12** collects power generated in each electrochemical cell by an electrochemical reaction between oxygen gas and hydrogen gas, and stores the power in a battery **20**.
[0018] The fuel cell **12** collects excess oxygen gas that has not undergone the electrochemical reaction, and discharges oxygen-containing exhaust gas containing that oxygen gas. Most of the oxygen-containing exhaust gas is circulated to the fuel cell **12** again and reused. The fuel cell **12** collects excess hydrogen gas that has not undergone the electrochemical reaction, and discharges hydrogen-containing exhaust gas containing that hydrogen gas. Most of the hydrogen-containing exhaust gas is circulated to the fuel cell **12** again and reused.
[0019] The gas generation device **14** is a device that generates one of oxygen gas or hydrogen gas. A water electrolysis device **22** and a hydrogen compression device **24** are provided as the gas generation device **14**.
[0020] The water electrolysis device **22** is a gas generation device **14** that generates oxygen gas and hydrogen gas by electrolyzing water. Water is supplied from a gas-liquid separator **26** via a water supply path **28**. The water supplied to the water electrolysis device **22** is alkaline water. For example, the water supplied to the water electrolysis device **22** is water containing potassium hydroxide. The water supply path **28** connects the gas-liquid separator **26** and the water electrolysis device **22**. A water supply pump **31** is provided in a portion of the water supply path **28** between the gas-liquid separator **26** and the water electrolysis device **22**. The water supply pump **31** supplies water stored in the gas-liquid separator **26** to the water electrolysis device **22**.
[0021] The gas-liquid separator **26** is supplied with supplementary water from a water tank **30** via a supplementary water path **29**. The supplementary water is water to be added to the water (alkaline water) to be supplied to the water electrolysis device **22**. A water supply pump **33** is provided in the supplementary water path **29**. The supplementary water is supplied to the gas-liquid separator **26** by the water supply pump **33**.
[0022] The water electrolysis device **22** includes a plurality of electrochemical cells. Each electrochemical cell includes an electrolyte membrane and a pair of electrodes provided on both sides of the electrolyte membrane in the thickness direction. The electrolyte membrane used in the water electrolysis device **22** is an anion exchange membrane. One of the pair of electrodes is an anode, and the other of the pair of electrodes is a cathode. A power supply device **23** is connected to the anode and the cathode. The power supply device **23** is configured to be able to change the voltage value of the voltage applied to the anode and the cathode. The power supply device **23** may obtain power for the voltage to be applied between the anode and the cathode, from the battery **20**.
[0023] The water electrolysis device **22** supplies water flowing in from the water supply path **28** to the cathode of each electrochemical cell. Each electrochemical cell electrolyzes water based on the voltage applied by the power supply device **23**. As a result, oxygen gas is generated at the anode, and hydrogen gas is generated at the cathode. The oxygen gas generated in the water electrolysis device **22** is compressed to a high pressure. For example, the oxygen gas is compressed in a range of 1 to 100 MPa.
[0024] The water electrolysis device **22** collects oxygen gas generated in each electrochemical cell and outputs exhaust gas containing that oxygen gas to the supply mechanism **16**. The exhaust gas

contains water vapor vaporized by heat of the water electrolysis device **22** or the like. On the other hand, the water electrolysis device **22** collects hydrogen gas generated in each electrochemical cell and excess water (unreacted water) that has not been electrolyzed, and discharges exhaust fluid containing the hydrogen gas and the unreacted water to a hydrogen supply path **32**. The exhaust fluid also includes water vapor vaporized by heat of the water electrolysis device **22** or the like.

[0025] The hydrogen supply path **32** includes a first partial flow path **32**A, a second partial flow path **32**B, and a third partial flow path **32**C. The first partial flow path **32**A connects the water electrolysis device **22** and the gas-liquid separator **26**. The second partial flow path **32**B connects the gas-liquid separator **26** and the water tank **30**. The third partial flow path **32**C connects the water tank **30** and the hydrogen compression device **24**. A gas supply pump **34** is provided in the third partial flow path **32**C.

[0026] The exhaust fluid output from the water electrolysis device **22** flows into the gas-liquid separator **26** via the first partial flow path **32**A. The gas-liquid separator **26** separates the exhaust fluid into a liquid component (liquid water) and a gas component (hydrogen gas). The liquid water is supplied to the water electrolysis device **22** by the water supply pump **31**. The hydrogen gas is supplied to the hydrogen compression device **24** by the gas supply pump **34**.

[0027] The hydrogen compression device **24** is the gas generation device **14** that generates high-pressure hydrogen gas. The hydrogen compression device **24** pressurizes hydrogen gas flowing in from the hydrogen supply path **32**. The hydrogen gas flowing in from the hydrogen supply path **32** is hydrogen gas generated by the water electrolysis device **22**.

[0028] The hydrogen compression device **24** includes a plurality of electrochemical cells. Each electrochemical cell includes an electrolyte membrane and a pair of electrodes provided on both sides of the electrolyte membrane in the thickness direction. The electrolyte membrane used in the hydrogen compression device **24** is a proton exchange membrane. One of the pair of electrodes is an anode, and the other of the pair of electrodes is a cathode. A power supply device **25** is connected to the anode and the cathode. The power supply device **25** is configured to be able to change the voltage value of the voltage applied between the anode and the cathode. The power supply device **25** may obtain power for the voltage to be applied between the anode and the cathode, from the battery **20**.

[0029] The hydrogen compression device **24** supplies the hydrogen gas flowing in from the hydrogen supply path **32**, to the anode. The hydrogen compression device **24** ionizes the hydrogen gas based on the voltage applied by the power supply device **25**. Protons obtained by ionization of the hydrogen gas return to hydrogen gas when they reach the cathode via the electrolyte membrane (proton exchange membrane). The hydrogen compression device **24** may compress hydrogen gas by moving protons from the anode to a closed space including the cathode. For example, the hydrogen containing gas is compressed in a range of 1 to 100 MPa. In this way, the hydrogen compression device **24** is an electrochemical hydrogen compressor (EHC) configured to compress hydrogen gas electrochemically.

[0030] The hydrogen compression device **24** outputs exhaust gas containing the compressed hydrogen gas to the supply mechanism **16**. The exhaust gas contains water vapor vaporized by heat of the hydrogen compression device **24** or the like. On the other hand, the hydrogen compression device **24** discharges excess hydrogen gas that has not been ionized, to a hydrogen discharge path **35**. The hydrogen discharge path **35** connects the hydrogen compression device **24** and the gas-liquid separator **26**.

[0031] The supply mechanism **16** includes an oxygen supply mechanism **36** and a hydrogen supply mechanism **38** as the supply mechanism **16** for supplying gas to the fuel cell **12**. The oxygen supply mechanism **36** is the supply mechanism **16** for supplying the oxygen gas generated by the water electrolysis device **22** to the fuel cell **12**. The hydrogen supply mechanism **38** is the supply mechanism **16** for supplying the hydrogen gas generated by the hydrogen compression device **24** to the fuel cell **12**.

[0032] The oxygen supply mechanism **36** and the hydrogen supply mechanism **38** have basically the same configuration. Accordingly, unless otherwise specified, the oxygen supply mechanism **36** and the hydrogen supply mechanism **38** will both be described as the supply mechanism **16**.
[0033] In the following description, the "supply mechanism **16**" refers to either one of the oxygen supply mechanism **36** or the hydrogen supply mechanism **38**. Similarly, "gas" refers to either one of oxygen gas or hydrogen gas. Similarly, the term "gas generation device **14**" refers to either the water electrolysis device **22** or the hydrogen compression device **24**.
[0034] It should be noted that, when the "supply mechanism **16**" is referring to the oxygen supply mechanism **36**, the "gas" refers to oxygen gas, not hydrogen gas. Furthermore, it should be noted that, when the "supply mechanism **16**" is referring to the oxygen supply mechanism **36**, the "gas generation device **14**" refers to the water electrolysis device **22**, not the hydrogen compression device **24**. Similarly, it should be noted that, when the "supply mechanism **16**" is referring to the hydrogen supply mechanism **38**, the "gas" refers to hydrogen gas, not oxygen gas. It should be noted that when the "supply mechanism **16**" is referring to the hydrogen supply mechanism **38**, the "gas generation device **14**" refers to the hydrogen compression device **24**, not the water electrolysis device **22**.
[0035] The supply mechanism **16** includes a gas supply path **40**, a pressure container **42**, a bypass path **44**, a first on-off valve **46**, a second on-off valve **48**, a first pressure regulating valve **50**, a second pressure regulating valve **52**, a first check valve **54**, a second check valve **56**, a pressure control valve **58**, a flow regulating valve **60**, a pressure sensor **62**, and a gas-liquid separator **64**.
[0036] The gas supply path **40** is a path for supplying gas from the gas generation device **14** to the fuel cell **12**. The gas supply path **40** includes a first supply path **40**A and a second supply path **40**B. The first supply path **40**A is a flow path that guides gas from the gas generation device **14** to the pressure container **42**. The first supply path **40**A includes a flow path portion **40**A**1** connecting the gas generation device **14** and the gas-liquid separator **64**, and a flow path portion **40**A**2** connecting the gas-liquid separator **64** and the pressure container **42**. The second supply path **40**B is a flow path that guides gas from the pressure container **42** to the fuel cell **12**.
[0037] The pressure container **42** is provided on the gas supply path **40**. The pressure container **42** stores the gas generated by the gas generation device **14**. The gas stored in the pressure container **42** is compressed.
[0038] The bypass path **44** is a path for supplying the gas generated by the gas generation device **14** to the fuel cell **12** without passing through the pressure container **42**. The bypass path **44** of the oxygen supply mechanism **36** and the bypass path **44** of the hydrogen supply mechanism **38** are different from each other. The bypass path **44** of the oxygen supply mechanism **36** connects the flow path portion **40**A**1** of the first supply path **40**A and a gas-liquid separator **68**. The bypass path **44** of the hydrogen supply mechanism **38** connects the flow path portion **40**A**1** of the first supply path **40**A and the second supply path **40**B.
[0039] The first on-off valve **46** is provided in the bypass path **44**. The first on-off valve **46** is configured to be openable and closable. The first on-off valve **46** opens and closes in accordance with the control of the control device **18**. The first on-off valve **46** may be a shutoff valve. When an abnormality is detected, the shutoff valve shuts off the bypass path **44** without depending on the control of the control device **18**.
[0040] The second on-off valve **48** is provided in the second supply path **40**B. The second on-off valve **48** is configured to be openable and closable. The second on-off valve **48** opens and closes in accordance with the control of the control device **18**. The second on-off valve **48** may be a shutoff valve.
[0041] The first pressure regulating valve **50** is provided in the bypass path **44** of the oxygen supply mechanism **36**. The first pressure regulating valve **50** is not provided in the bypass path **44** of the hydrogen supply mechanism **38**. The first pressure regulating valve **50** is positioned between the branching portion BP and the first on-off valve **46** in the bypass path **44** of the oxygen supply

mechanism **36**. The branch portion BP is a portion where the bypass path **44** branches from the first supply path **40**A.
[0042] The second pressure regulating valve **52** is provided in the second supply path **40**B at a position between the second on-off valve **48** and the fuel cell **12**. The second pressure regulating valve **52** reduces the pressure of gas.
[0043] The first check valve **54** is provided in a portion of the first supply path **40**A between the branch portion BP and the gas-liquid separator **64**. The second check valve **56** is provided in a portion of the bypass path **44** positioned downstream of the first on-off valve **46**.
[0044] The pressure control valve **58** is provided in the flow path portion **40**A**2** of the first supply path **40**A. The pressure control valve **58** narrows the flow path portion **40**A**2**. Thus, when the gas generation device **14** is the water electrolysis device **22**, the pressure of the oxygen gas generated at the anode of each electrochemical cell increases to a pressure higher than the pressure of the hydrogen gas generated at the cathode of each electrochemical cell. The pressure control valve **58** may be a solenoid valve whose opening degree is adjustable. Alternatively, the pressure control valve **58** may be a back pressure valve.
[0045] That is, in the water electrolysis device **22**, the pressure on the anode side of the electrolyte membrane is higher than the pressure on the cathode side of the electrolyte membrane. Therefore, it is possible to suppress crossover in which hydrogen gas generated at the cathode permeates through the electrolyte membrane toward the anode. As a result, it is possible to suppress a decrease in the amount of hydrogen gas supplied from the water electrolysis device **22** to the hydrogen compression device **24**.
[0046] The flow regulating valve **60** is provided in the second supply path **40**B. The flow regulating valve **60** is configured to be able to adjust the flow rate of the gas flowing through the fuel cell **12**. The flow regulating valve **60** adjusts the flow rate in accordance with the control of the control device **18**.
[0047] The pressure sensor **62** detects the pressure of the gas supplied to the gas supply path **40**. The pressure sensor **62** outputs a signal indicating the detected pressure to the control device **18**. The pressure sensor **62** is preferably provided in the gas supply path **40** near the gas generation device **14**. For example, the pressure sensor **62** is provided in a portion of the first supply path **40**A between the gas generation device **14** and the branch portion BP.
[0048] The gas-liquid separator **64** is provided on the gas supply path **40** between the pressure control valve **58** and the first check valve **54**. As described above, the exhaust gas discharged from the gas generation device **14** to the gas supply path **40** contains water vapor in addition to the gas. The gas-liquid separator **64** separates the exhaust gas into a liquid component (liquid water) and a gas component (gas). The gas separated by the gas-liquid separator **64** is supplied to the pressure container **42**. Therefore, it is possible to suppress the pressure container **42** from becoming humid. As a result, the durability of the pressure container **42** can be improved without making the pressure container **42** excessively rust-resistant.
[0049] On the other hand, the liquid water separated by the gas-liquid separator **64** is supplied to the gas-liquid separator **26** via a liquid water supply path **65**. The liquid water supply path **65** connects the gas-liquid separator **64** and the gas-liquid separator **26**. Liquid water obtained from water vapor in the exhaust gas discharged from the water electrolysis device **22** is supplied to the gas-liquid separator **26** that stores water to be supplied to the water electrolysis device **22**, via the liquid water supply path **65**. Therefore, the water used in the water electrolysis device **22** can be saved.
[0050] The oxygen supply mechanism **36** includes an oxygen exhaust gas flow path **66**, the gas-liquid separator **68**, and a circulation pump **70**, in addition to the configuration of the supply mechanism **16** described above. The oxygen exhaust gas flow path **66** is a path for returning, back to the fuel cell **12**, the oxygen-containing exhaust gas discharged from the fuel cell **12**. The oxygen exhaust gas flow path **66** has an upstream partial flow path **66**A and a downstream partial flow path

66B. The upstream partial flow path **66**A connects the fuel cell **12** and the gas-liquid separator **68**. The downstream partial flow path **66**B connects a portion of the second supply path **40**B between the flow regulating valve **60** and the fuel cell **12**, to the gas-liquid separator **68**.

[0051] The gas-liquid separator **68** and the circulation pump **70** are provided on the oxygen exhaust gas flow path **66**. The gas-liquid separator **68** separates the oxygen-containing exhaust gas discharged from the fuel cell **12** to the oxygen exhaust gas flow path **66**, into a gas component (oxygen gas and water vapor) and a liquid component (liquid water). The gas component is supplied back to the fuel cell **12** by the circulation pump **70**. On the other hand, the liquid component is supplied to the water tank **30** via a water supply path **71**. The water supply path **71** connects the gas-liquid separator **68** and the water tank **30**.

[0052] The hydrogen supply mechanism **38** includes, in addition to the configuration of the supply mechanism **16** described above, a hydrogen exhaust gas flow path **72**, a gas-liquid separator **74**, and a circulation pump **76**. The hydrogen exhaust gas flow path **72** is a path for returning, back to the fuel cell **12**, the hydrogen-containing exhaust gas discharged from the fuel cell **12**. The hydrogen exhaust gas flow path **72** has an upstream partial flow path **72**A and a downstream partial flow path **72**B. The upstream partial flow path **72**A connects the fuel cell **12** and the gas-liquid separator **74**. The downstream partial flow path **72**B connects a portion of the second supply path **40**B between the flow regulating valve **60** and the fuel cell **12**, to the gas-liquid separator **74**.

[0053] The gas-liquid separator **74** and the circulation pump **76** are provided on the hydrogen exhaust gas flow path **72**. The gas-liquid separator **74** separates the hydrogen-containing exhaust gas discharged from the fuel cell **12** to the hydrogen exhaust gas flow path **72**, into a gas component (hydrogen gas and water vapor) and a liquid component (liquid water). The gas component is supplied back to the fuel cell **12** by the circulation pump **76**. On the other hand, the liquid component is supplied to the water tank **30** via a water supply path **77**. The water supply path **77** connects the gas-liquid separator **74** and the water tank **30**.

[0054] FIG. **2** is a block diagram of the control device **18**. The control device **18** includes one or more processors **100** and one or more storage media **102**. The storage medium **102** may be constituted by a volatile memory and a non-volatile memory. The processor **100** may be a CPU, a GPU, or the like. As examples of the volatile memory, there may be cited a RAM or the like. As examples of the non-volatile memory, there may be cited a ROM, a flash memory, or the like.

[0055] The processor **100** includes a water electrolysis control unit **110**, a hydrogen compression control unit **112**, and a power generation control unit **114**. When the processor **100** executes a program stored in the storage medium **102**, the processor **100** operates as the water electrolysis control unit **110**, the hydrogen compression control unit **112**, and the power generation control unit **114**. At least one of the water electrolysis control unit **110**, the hydrogen compression control unit **112**, and the power generation control unit **114** may be realized by an integrated circuit such as an ASIC, an FPGA, or the like. At least one of the water electrolysis control unit **110**, the hydrogen compression control unit **112**, and the power generation control unit **114** may be configured by an electronic circuit including a discrete device.

[0056] The water electrolysis control unit **110** can execute operation control of the water electrolysis device **22** and operation stop control of the water electrolysis device **22**. For example, when the processor **100** receives an operation start instruction of the regenerative fuel cell system **10**, the water electrolysis control unit **110** starts operation control of the water electrolysis device **22**.

[0057] In the operation control of the water electrolysis device **22**, the water electrolysis control unit **110** drives the water supply pump **31** to supply water to the water electrolysis device **22**. In the operation control of the water electrolysis device **22**, the water electrolysis control unit **110** controls the power supply device **23** such that an electric current of a predetermined value flows between the cathode and the anode of the water electrolysis device **22**.

[0058] When the operation control of the water electrolysis device **22** is executed, oxygen gas

generated in the water electrolysis device **22** is supplied to the pressure container **42** of the oxygen supply mechanism **36** via the gas supply path **40** of the oxygen supply mechanism **36**. On the other hand, the hydrogen gas generated in the water electrolysis device **22** is supplied to the hydrogen compression device **24** via the hydrogen supply path **32**.
[0059] For example, when the amount of gas supplied to the pressure container **42** of the oxygen supply mechanism **36** exceeds a predetermined amount of gas, the water electrolysis control unit **110** shifts from the operation control of the water electrolysis device **22** to the operation stop control of the water electrolysis device **22**. The operation stop control of the water electrolysis device **22** will be described later.
[0060] The hydrogen compression control unit **112** can execute operation control of the hydrogen compression device **24** and operation stop control of the hydrogen compression device **24**. For example, when supply of hydrogen gas to the third partial flow path **32**C of the hydrogen supply path **32** is confirmed, the hydrogen compression control unit **112** performs operation control of the hydrogen compression device **24**. The supply of hydrogen gas to the third partial flow path **32**C is confirmed based on, for example, a flow sensor or the like provided in the third partial flow path **32**C near the hydrogen compression device **24**.
[0061] In the operation control of the hydrogen compression device **24**, the hydrogen compression control unit **112** drives the gas supply pump **34** to supply hydrogen gas to the hydrogen compression device **24**. In the operation control of the hydrogen compression device **24**, the hydrogen compression control unit **112** controls the power supply device **25** such that an electric current of a predetermined value flows between the cathode and the anode of the hydrogen compression device **24**.
[0062] When the operation control of the hydrogen compression device **24** is executed, hydrogen gas generated in the hydrogen compression device **24** is supplied to the pressure container **42** of the hydrogen supply mechanism **38** via the gas supply path **40** of the hydrogen supply mechanism **38**.
[0063] For example, when the supply of hydrogen gas to the third partial flow path **32**C is not confirmed, the hydrogen compression control unit **112** shifts from the operation control of the hydrogen compression device **24** to the operation stop control of the hydrogen compression device **24**. The operation stop control of the hydrogen compression device **24** will be described later.
[0064] The power generation control unit **114** can execute operation control of the fuel cell **12** and operation stop control of the fuel cell **12**. For example, when the amount of electric power stored in the battery **20** falls below a lower limit value, the power generation control unit **114** starts the operation control of the fuel cell **12**.
[0065] In the operation control of the fuel cell **12**, the power generation control unit **114** opens the second on-off valve **48** of the oxygen supply mechanism **36** and drives the circulation pump **70** of the oxygen supply mechanism **36**. The power generation control unit **114** opens the second on-off valve **48** of the hydrogen supply mechanism **38** and drives the circulation pump **76** of the hydrogen supply mechanism **38**. The power generation control unit **114** controls at least one of the second pressure regulating valve **52** and the flow regulating valve **60** based on a target power generation amount and the like.
[0066] When the operation control of the fuel cell **12** is executed, the oxygen gas stored in the pressure container **42** of the oxygen supply mechanism **36** is supplied to the fuel cell **12** through the second supply path **40**B of the oxygen supply mechanism **36**. The oxygen gas that has not undergone the electrochemical reaction in the fuel cell **12** flows into the second supply path **40**B of the oxygen supply mechanism **36** through the oxygen exhaust gas flow path **66**, and is supplied to the fuel cell **12** again.
[0067] The hydrogen gas stored in the pressure container **42** of the hydrogen supply mechanism **38** is supplied to the fuel cell **12** through the second supply path **40**B of the hydrogen supply mechanism **38**. The hydrogen gas that has not undergone the electrochemical reaction in the fuel cell **12** flows into the second supply path **40**B of the hydrogen supply mechanism **38** through the

hydrogen exhaust gas flow path **72**, and is supplied to the fuel cell **12** again.
[0068] For example, when the amount of electric power stored in the battery **20** exceeds an upper limit value, the power generation control unit **114** shifts from the operation control of the fuel cell **12** to the operation stop control of the fuel cell **12**.
[0069] In the operation stop control of the fuel cell **12**, the power generation control unit **114** closes the second on-off valve **48** of the oxygen supply mechanism **36** and stops the circulation pump **70** of the oxygen supply mechanism **36**. The power generation control unit **114** closes the second on-off valve **48** of the hydrogen supply mechanism **38** and stops the circulation pump **76** of the hydrogen supply mechanism **38**. The power generation control unit **114** stops the control of the second pressure regulating valve **52** and the flow regulating valve **60**.
[0070] Next, the operation stop control of the gas generation device **14** will be described. The operation stop control of the water electrolysis device **22** and the operation stop control of the hydrogen compression device **24** are basically the same. Therefore, only the operation stop control of the water electrolysis device **22** will be described here unless otherwise specified. FIG. **3** is a flowchart showing a procedure of the operation stop control of the water electrolysis device **22**.
[0071] In step S**1**, the water electrolysis control unit **110** opens the first on-off valve **46** of the oxygen supply mechanism **36**. When the first on-off valve **46** is opened, the operation stop control of the water electrolysis device **22** is shifted to step S**2**.
[0072] In step S**2**, the water electrolysis control unit **110** starts a depressurizing process. In the depressurizing process, the water electrolysis control unit **110** controls the power supply device **23** such that the current flowing between the electrodes of each electrochemical cell of the water electrolysis device **22** gradually decreases.
[0073] In addition, in the depressurizing process, the water electrolysis control unit **110** adjusts the opening degree of the first pressure regulating valve **50** so as to achieve a target depressurization rate, based on the pressure detected by the pressure sensor **62**. This can suppress a rapid decrease in gas pressure, and as a result, it is possible to suppress the occurrence of blisters and the like in the electrolyte membrane of the water electrolysis device **22**.
[0074] The opening degree of the first pressure regulating valve **50** is adjusted, for example, as follows. That is, the water electrolysis control unit **110** measures a depressurization rate, which is the pressure reduction per unit time, based on the pressure detected by the pressure sensor **62**, and calculates the difference between the depressurization rate and the target depressurization rate. The target depressurization rate is a target value of the depressurization rate for suppressing the occurrence of blisters and the like, and is stored in the storage medium **102**. The water electrolysis control unit **110** sets the opening degree of the first pressure regulating valve **50** such that the difference from the target depressurization rate is reduced. The opening degree of the first pressure regulating valve **50** is set to be smaller as the difference from the target depressurization rate is larger.
[0075] In the depressurizing process of the operation stop control of the hydrogen compression device **24**, the hydrogen compression control unit **112** adjusts the opening degree of the second pressure regulating valve **52**. When the depressurizing process is started, the operation stop control of the water electrolysis device **22** proceeds to step S**3**.
[0076] In step S**3**, the water electrolysis control unit **110** compares the pressure detected by the pressure sensor **62** with a predetermined pressure. When the pressure detected by the pressure sensor **62** is equal to or higher than the predetermined pressure, the water electrolysis control unit **110** continues to compare the pressure detected by the pressure sensor **62** with the predetermined pressure. On the other hand, when the pressure detected by the pressure sensor **62** is less than the predetermined pressure, the operation stop control of the water electrolysis device **22** proceeds to step S**4**.
[0077] In step S**4**, the water electrolysis control unit **110** ends the depressurizing process. That is, the water electrolysis control unit **110** stops the control of the power supply device **23** and stops the

electrochemical reaction (water electrolytic reactions) in the water electrolysis device **22**. The water electrolysis control unit **110** sets the opening degree of the flow regulating valve **60** to a predetermined opening degree. When the depressurizing process is completed, the operation stop control of the water electrolysis device **22** proceeds to step S**5**.

[0078] In step S**5**, the water electrolysis control unit **110** closes the first on-off valve **46** of the oxygen supply mechanism **36** and stops the water supply pump **31**. Thus, the operation stop control of the water electrolysis device **22** is ended.

[0079] As shown in FIG. **1**, when the first on-off valve **46** is opened in the operation stop control, oxygen gas generated in the water electrolysis device **22** flows into the bypass path **44** from the branch portion BP of the gas supply path **40**. The oxygen gas that has flowed into the bypass path **44** is supplied to the fuel cell **12**. The oxygen gas generated in the water electrolysis device **22** contains water vapor obtained by vaporizing alkaline water which has been supplied to the water electrolysis device **22** and has moved from the cathode to the anode together with hydroxide ions, as described above. When the depressurizing process of the operation stop control is started, the differential pressure between the cathode and the anode decreases, and the amount of water pushed back from the anode to the cathode by the differential pressure decreases. Therefore, a larger amount of water vapor generated by alkaline water being vaporized occurs at the anode than during the operation control. That is, the present invention can be more effective for the operation stop control of differential pressure water electrolysis devices in which the amount of water vapor is not large during the operation control and a large amount of water vapor is generated during the operation stop control.

[0080] The regenerative fuel cell system **10** is provided with a gas flow path **200** for suppressing supply of alkaline water to the fuel cell **12**. The gas flow path **200** includes a gas flow path **200**A for guiding oxygen gas and a gas flow path **200**B for guiding hydrogen gas.

[0081] The gas flow path **200**A includes a first flow path portion (bypass path **44**), a second flow path portion (downstream partial flow path **66**B), and the inside of a storage container **202** provided in the gas-liquid separator **68**.

[0082] FIG. **4** is a view showing the storage container **202**. The storage container **202** has an internal space **216** surrounded by an upper wall **210**, a lower wall **212**, and side walls **214**. Generated water is stored in the internal space **216**. The generated water is liquid water generated by power generation of the fuel cell **12** and separated by the gas-liquid separator **68**. The liquid water generated by the power generation of the fuel cell **12** is acidic.

[0083] The water level of the generated water may be maintained within a predetermined range. For example, when the water level detected by a water level sensor provided in the storage container **202** falls below a lower limit water level, the power generation control unit **114** executes the operation control of the fuel cell **12**. When the water level detected by the water level sensor reaches an upper limit water level, the power generation control unit **114** shifts from the operation control of the fuel cell **12** to the operation stop control of the fuel cell **12**. A part of the generated water stored in the storage container **202** is supplied to the water tank **30** at an optional timing. In this case, the control device **18** opens an on-off valve (not shown) provided in the water supply path **71** to supply the generated water to the water tank **30**.

[0084] The upstream partial flow path **66**A of the oxygen exhaust gas flow path **66** penetrates the upper portion of one of the sidewalls **214**. The downstream end of the upstream partial flow path **66**A is located above the generated water that is stored in the internal space **216**. As shown in FIG. **1**, the upstream end of the upstream partial flow path **66**A is connected to the fuel cell **12**.

[0085] The downstream partial flow path **66**B of the oxygen exhaust gas flow path **66** penetrates the upper wall **210**. The upstream end of the downstream partial flow path **66**B is located above the water surface of the generated water stored in the internal space **216**. As shown in FIG. **1**, the downstream end of the downstream partial flow path **66**B is connected to the second supply path **40**B.

[0086] The storage container **202** is provided with a tubular member **218**. The tubular member **218** extends through the upper wall **210** and under the water surface of the generated water. The tubular member **218** may be the downstream end of the bypass path **44**. Alternatively, the tubular member **218** may be a member separate from the bypass path **44**. In this case, the upper end of the tubular member **218** and the downstream end of the bypass path **44** are joined to each other. The lower end of the tubular member **218** is positioned below the water surface of the generated water stored in the internal space **216**. The lower end of the tubular member **218** is spaced apart from the lower wall **212**.
[0087] The oxygen gas that has flowed into the bypass path **44** when the first on-off valve **46** is opened in the operation stop control reaches the tubular member **218**. The oxygen gas that has reached the tubular member **218** is released into the generated water from the lower end of the tubular member **218**. The oxygen gas released into the generated water becomes bubbles and moves upward and beyond the water surface of the generated water. In this case, the water (alkaline water vapor) containing oxygen gas is neutralized by the generated water. The oxygen gas that has moved upward and beyond the water surface of the generated water flows into the downstream partial flow path **66**B of the oxygen exhaust gas flow path **66**, and is supplied to the fuel cell **12** through the second supply path **40**B.
[0088] In this way, the gas flow path **200** guides the oxygen gas generated at the anode of the water electrolysis device **22** to the fuel cell **12** through the generated water stored in the storage container **202**. Thus, even if alkaline water is contained in the oxygen gas, the water can be neutralized by the generated water stored in the storage container **202**. In particular, a more remarkable advantageous effect can be exhibited by supplying the gas in the operation stop control, which may generate the water vapor obtained by a larger amount of alkaline water being vaporized, to the storage container **202**. Therefore, alkaline water does not reach the fuel cell **12**, and it is possible to suppress deterioration of the seal member, the electrolyte membrane, and the like provided in the fuel cell **12** due to the alkaline water. As a result, it is possible to suppress a decrease in the durability of the fuel cell **12**.
[0089] The gas flow path **200**B is a hydrogen supply path **32** for guiding the hydrogen gas generated in the electrolytic device **22**, to the hydrogen compression device **24** through the supplementary water stored in the water tank **30**. The gas flow path **200**B includes a first partial flow path **32**A, a second partial flow path **32**B, a part of the water tank **30**, and a third partial flow path **32**C.
[0090] Although not shown, the downstream end of the second partial flow path **32**B of the hydrogen supply path **32** is provided in the water tank **30** as a member corresponding to the tubular member **218**. The downstream end of the second partial flow path **32**B penetrates the upper wall of the water tank **30** and extends under the water surface of the supplementary water stored in the water tank **30**. The supplementary water is liquid water (generated water) stored in the storage container **202**, and therefore is acidic.
[0091] As described above, the hydrogen gas separated by the gas-liquid separator **26** is the hydrogen gas generated by the water electrolysis device **22**. Therefore, the hydrogen gas flowing from the gas-liquid separator **26** into the second partial flow path **32**B contains water vapor obtained by alkaline water being vaporized. The hydrogen gas that has flowed into the second partial flow path **32**B is discharged into the supplementary water from the lower end of the second partial flow path **32**B. The hydrogen gas released into the supplementary water becomes bubbles and moves upward and beyond the water surface of the supplementary water. In this case, the water (alkaline water vapor) containing hydrogen gas is neutralized by the supplementary water. The hydrogen gas that has moved upward and beyond the water surface of the supplementary water flows into the third partial flow path **32**C and is supplied to the hydrogen compression device **24**.
[0092] In this way, the hydrogen supply path **32** guides the hydrogen gas generated by the water electrolysis device **22** to the hydrogen compression device **24** through the supplementary water

stored in the water tank **30**. Thus, even if alkaline water is contained in the hydrogen gas, the water can be neutralized by the supplementary water stored in the water tank **30**. Therefore, alkaline water does not reach the fuel cell **12**, and it is possible to suppress deterioration of the seal member, the electrolyte membrane, and the like provided in the fuel cell **12** due to the alkaline water. As a result, it is possible to suppress a decrease in the durability of the fuel cell **12**.

Second Embodiment

[0093] FIG. **5** is a schematic view showing the regenerative fuel cell system **10** according to a second embodiment. In FIG. **5**, the same components as those described in the first embodiment are denoted by the same reference numerals. In the second embodiment, descriptions that overlap or are duplicative of those stated in the first embodiment are omitted.

[0094] In the second embodiment, a concentration measurement device **220**, a water supply path **222**, a water supply pump **224**, a check valve **226**, and a concentration control unit **228** are further provided.

[0095] The concentration measurement device **220** is provided in the storage container **202**. The concentration measurement device **220** measures the hydrogen ion concentration of the generated water stored in the storage container **202**. The concentration measurement device **220** may be a pH meter.

[0096] The water supply path **222** connects the gas-liquid separator **64** and the storage container **202**. The water supply path **222** is provided with the water supply pump **224** and the check valve **226**. The water supply pump **224** supplies the water stored in the gas-liquid separator **64** to the storage container **202**. The water stored in the gas-liquid separator **64** is alkaline. The water supply pump **224** is driven by the concentration control unit **228**.

[0097] The concentration control unit **228** operates when the processor **100** (FIG. **2**) executes a program. The concentration control unit **228** may be realized by an integrated circuit such as an ASIC, an FPGA, or the like. The concentration control unit **228** may be configured by an electronic circuit including a discrete device. The concentration control unit **228** can execute concentration control for adjusting the concentration of the generated water stored in the storage container **202** based on the hydrogen ion concentration measured by the concentration measurement device **220**.

[0098] FIG. **6** is a flowchart showing a procedure of the concentration control. The concentration control is performed, for example, during the operation period of the regenerative fuel cell system **10**.

[0099] In step S**11**, the concentration control unit **228** compares the hydrogen ion concentration measured by the concentration measurement device **220** with a threshold value. The threshold value is set to, for example, a hydrogen ion concentration corresponding to a hydrogen ion concentration index selected from the range of pH6 to pH7. When the hydrogen ion concentration measured by the concentration measurement device **220** is on the neutral side relative to the threshold value, the concentration control unit **228** continues to compare the hydrogen ion concentration measured by the concentration measurement device **220** with the threshold value. On the other hand, when the hydrogen ion concentration measured by the concentration measurement device **220** is on the acidic side relative to the threshold value, the concentration control proceeds to step S**12**.

[0100] In step S**12**, the concentration control unit **228** determines whether the water electrolysis device **22** is stopped. When the water electrolysis control unit **110** (FIG. **2**) is executing the operation control or the operation stop control, the concentration control unit **228** determines that the water electrolysis device **22** is not stopped. In this case, the concentration control does not proceed to step S**13**. On the other hand, when the water electrolysis control unit **110** (FIG. **2**) is executing neither the operation control nor the operation stop control, the concentration control unit **228** determines that the water electrolysis device **22** is stopped. In this case, the concentration control proceeds to step S**13**.

[0101] In step S**13**, the concentration control unit **228** drives the water supply pump **224**. When the

water supply pump **224** is driven, the concentration control shifts to step S**14**.
[0102] In step S**14**, the concentration control unit **228** compares the hydrogen ion concentration measured by the concentration measurement device **220** with the threshold value. When the hydrogen ion concentration measured by the concentration measurement device **220** is on the acidic side relative to the threshold value, the concentration control unit **228** continues to drive the water supply pump **224**. On the other hand, when the hydrogen ion concentration measured by the concentration measurement device **220** is on the neutral side relative to the threshold value, the concentration control proceeds to step S**15**.
[0103] In step S**15**, the concentration control unit **228** stops the water supply pump **224**. When the water supply pump **224** is stopped, the concentration control shifts to step S**11**.
[0104] The amount of water (acidic water) generated by the power generation of the fuel cell **12** and then supplied to the storage container **202** is larger than the amount of water (alkaline water) supplied to the storage container **202** during the operation stop control of the water electrolysis device **22**. Therefore, the acidity of the generated water stored in the storage container **202** tends to become high (the acidity becomes stronger).
[0105] In the present embodiment, when the hydrogen ion concentration measured by the concentration measurement device **220** is on the acidic side relative to the threshold value, the concentration control unit **228** drives the water supply pump **224**. Thus, the acidity of the generated water stored in the storage container **202** can be prevented from becoming high (becoming stronger).
[0106] In the present embodiment, the concentration control unit **228** drives the water supply pump **224** when the water electrolysis device **22** is stopped. This can prevent the alkalinity of the generated water stored in the storage container **202** from becoming high (strengthening).
[0107] The following Supplementary Notes are further disclosed in relation to the above embodiments.
(Supplementary Note 1)
[0108] The regenerative fuel cell system (**10**) of the present disclosure includes the water electrolysis device (**22**) that performs electrolysis of alkaline water, the fuel cell (**12**) that performs power generation by using a generated gas that is a gas generated by the electrolysis, the storage container (**202**) that stores generated water that is water generated by the power generation, and the gas flow path (**200**) that guides the generated gas to the fuel cell through the generated water stored in the storage container.
(Supplementary Note 2)
[0109] The regenerative fuel cell system according to Supplementary Note 1 may further include the pressure container (**42**) configured to store the generated gas of high pressure, and the pressure control valve (**58**) provided in the first supply path (**40**A) that is configured to guide the generated gas from the water electrolysis device to the pressure container, wherein the gas flow path may include the first flow path portion (**44**) that connects the first supply path and the storage container, and the second flow path portion (**66**B) that connects the storage container and the second supply path (**40**B) that is configured to guide the generated gas from the pressure container to the fuel cell.
(Supplementary Note 3)
[0110] In the regenerative fuel cell system according to Supplementary Note 2, the first flow path portion may include the tubular member (**218**) that penetrates the upper wall (**210**) of the storage container and extends under a water surface of the generated water.
(Supplementary Note 4)
[0111] The regenerative fuel cell system according to Supplementary Note 2 may further include the on-off valve (**46**) provided in the first flow path portion, and the water electrolysis control unit (**110**) configured to control the water electrolysis device. The water electrolysis control unit may close the on-off valve during operation control of the water electrolysis device, and open the on-off valve when operation stop control of the water electrolysis device is started.

(Supplementary Note 5)
[0112] The regenerative fuel cell system according to Supplementary Note 1 may further include the concentration measurement device (**220**) configured to measure the hydrogen ion concentration of the generated water stored in the storage container, the water supply pump (**224**) configured to supply the alkaline water to the storage container, and the concentration control unit (**228**) that adjusts the hydrogen ion concentration of the generated water. When the hydrogen ion concentration measured by the concentration measurement device is on the acidic side relative to the threshold value, the concentration control unit may drive the water supply pump.
(Supplementary Note 6)
[0113] In the regenerative fuel cell system according to Supplementary Note 5, the concentration control unit may drive the water supply pump when the water electrolysis device is stopped.
(Supplementary Note 7)
[0114] The regenerative fuel cell system according to Supplementary Note 1 may further include the water tank (**30**) configured to store supplementary water that is water to be added to the alkaline water, the hydrogen compression device (**24**) configured to pressurize hydrogen gas, and the hydrogen supply path (**32**) configured to guide the hydrogen gas generated by the water electrolysis device to the hydrogen compression device through the supplementary water stored in the water tank. The gas flow path may guide oxygen gas generated in the water electrolysis device to the fuel cell through the generated water.
[0115] Although the present disclosure has been described in detail, the present disclosure is not limited to the above-described embodiments. In these embodiments, various addition, replacement, changing, partial deletion, and the like can be made without departing from the essence and gist of the present disclosure or without departing from the essence and gist of the present disclosure derived from the contents described in the claims and equivalents thereof. These embodiments may also be implemented in combination. For example, in the above- described embodiments, the order of operations and the order of processes are shown as examples, and the present invention is not limited to them. The same applies to a case where numerical values or mathematical equations are used in the description of the above-described embodiments.

Claims

1. A regenerative fuel cell system comprising: a water electrolysis device configured to perform electrolysis of alkaline water; a fuel cell configured to perform power generation by using a generated gas that is a gas generated by the electrolysis; a storage container configured to store generated water that is water generated by the power generation; and a gas flow path configured to guide the generated gas to the fuel cell through the generated water stored in the storage container.
2. The regenerative fuel cell system according to claim 1, further comprising: a pressure container configured to store the generated gas of high pressure; and a pressure control valve provided in a first supply path that is configured to guide the generated gas from the water electrolysis device to the pressure container, wherein the gas flow path includes: a first flow path portion that connects the first supply path and the storage container; and a second flow path portion that connects the storage container and a second supply path that is configured to guide the generated gas from the pressure container to the fuel cell.
3. The regenerative fuel cell system according to claim 2, wherein the first flow path portion includes a tubular member that penetrates an upper wall of the storage container and extends under a water surface of the generated water.
4. The regenerative fuel cell system according to claim 2, further comprising: an on-off valve provided in the first flow path portion; and a control device comprising one or more processors that execute computer-executable instructions stored in a memory, wherein the one or more processors execute the computer-executable instructions to cause the control device to close the on-off valve

during operation control of the water electrolysis device, and open the on-off valve when operation stop control of the water electrolysis device is started.
5. The regenerative fuel cell system according to claim 1, further comprising: a concentration measurement device configured to measure a hydrogen ion concentration of the generated water stored in the storage container; a water supply pump configured to supply the alkaline water to the storage container; and a control device comprising one or more processors that execute computer-executable instructions stored in a memory, wherein when the hydrogen ion concentration measured by the concentration measurement device is on an acidic side relative to a threshold value, the one or more processors execute the computer-executable instructions to cause the control device to drive the water supply pump.
6. The regenerative fuel cell system according to claim 5, wherein the one or more processors cause the control device to drive the water supply pump when the water electrolysis device is stopped.
7. The regenerative fuel cell system according to claim 1, further comprising: a water tank configured to store supplementary water that is water to be added to the alkaline water; a hydrogen compression device configured to pressurize hydrogen gas; and a hydrogen supply path configured to guide the hydrogen gas generated by the water electrolysis device to the hydrogen compression device through the supplementary water stored in the water tank, wherein the gas flow path guides oxygen gas generated in the water electrolysis device to the fuel cell through the generated water.