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FUKUMA

(54) WATER ELECTROLYSIS SYSTEM

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(57) ABSTRACT

A water electrolysis system includes: a water electrolysis stack that generates oxygen gas and hydrogen gas by electrolyzing water; a gas-liquid separator that separates the hydrogen gas from water; a hydrogen compression stack that compresses the hydrogen gas; a gas tank that stores an inert gas and is connected to a hydrogen flow path that connects the water electrolysis stack and the hydrogen compression stack; a supply valve that, when opened, supplies the inert gas to the hydrogen flow path; and a supply control unit that opens the supply valve in a case where the concentration of the oxygen gas that has flowed into the hydrogen flow path exceeds an oxygen concentration threshold determined in advance.

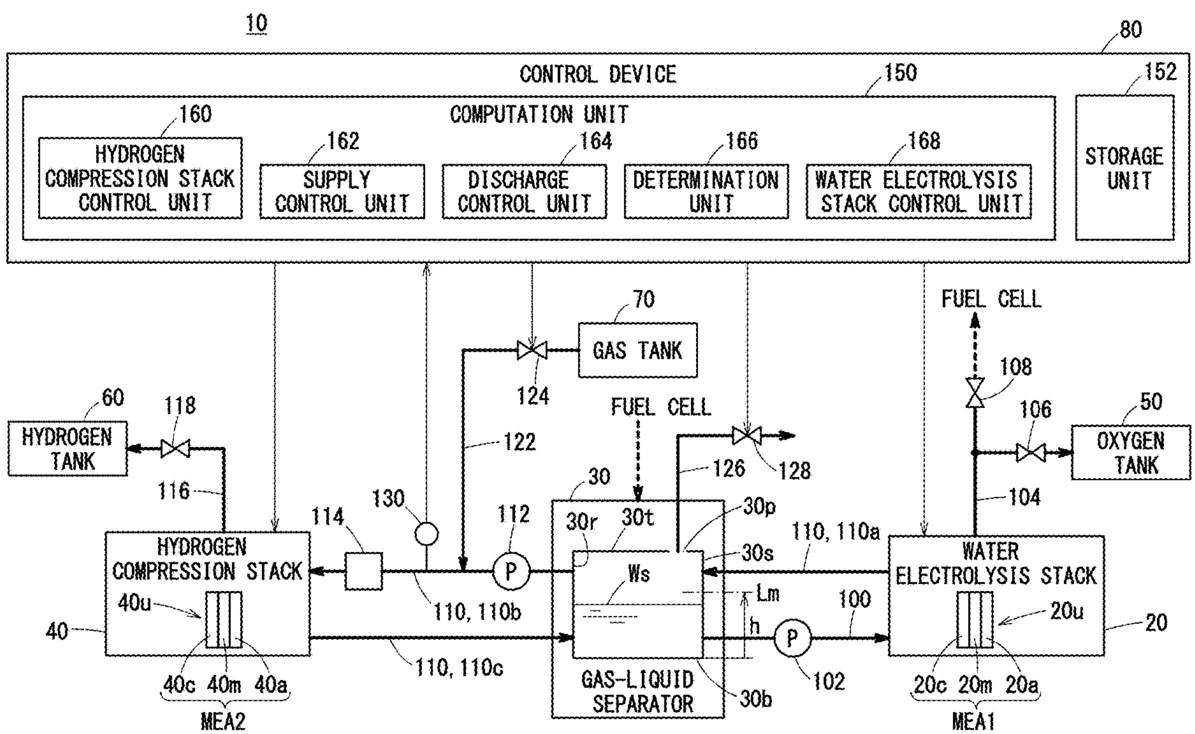
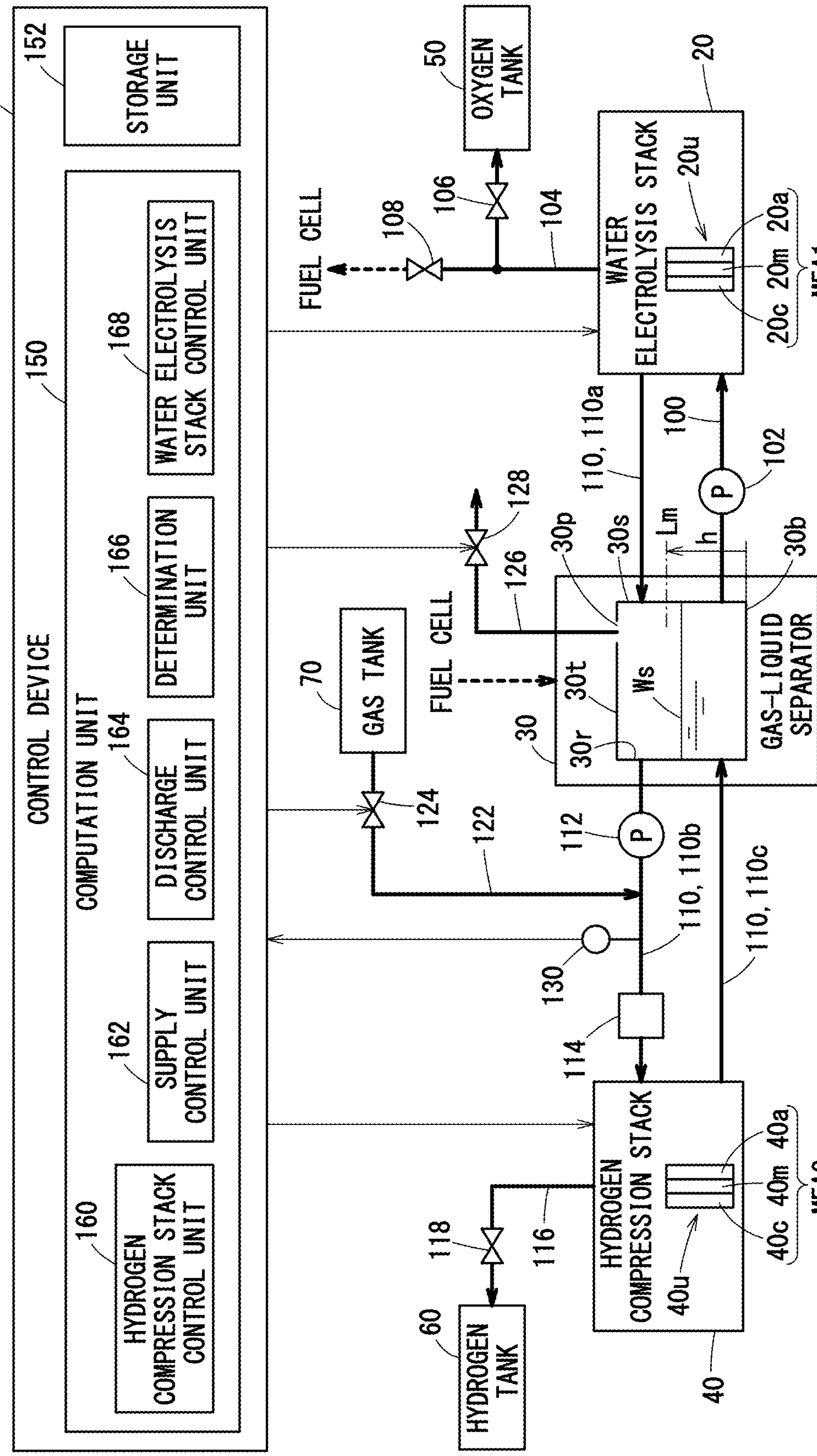


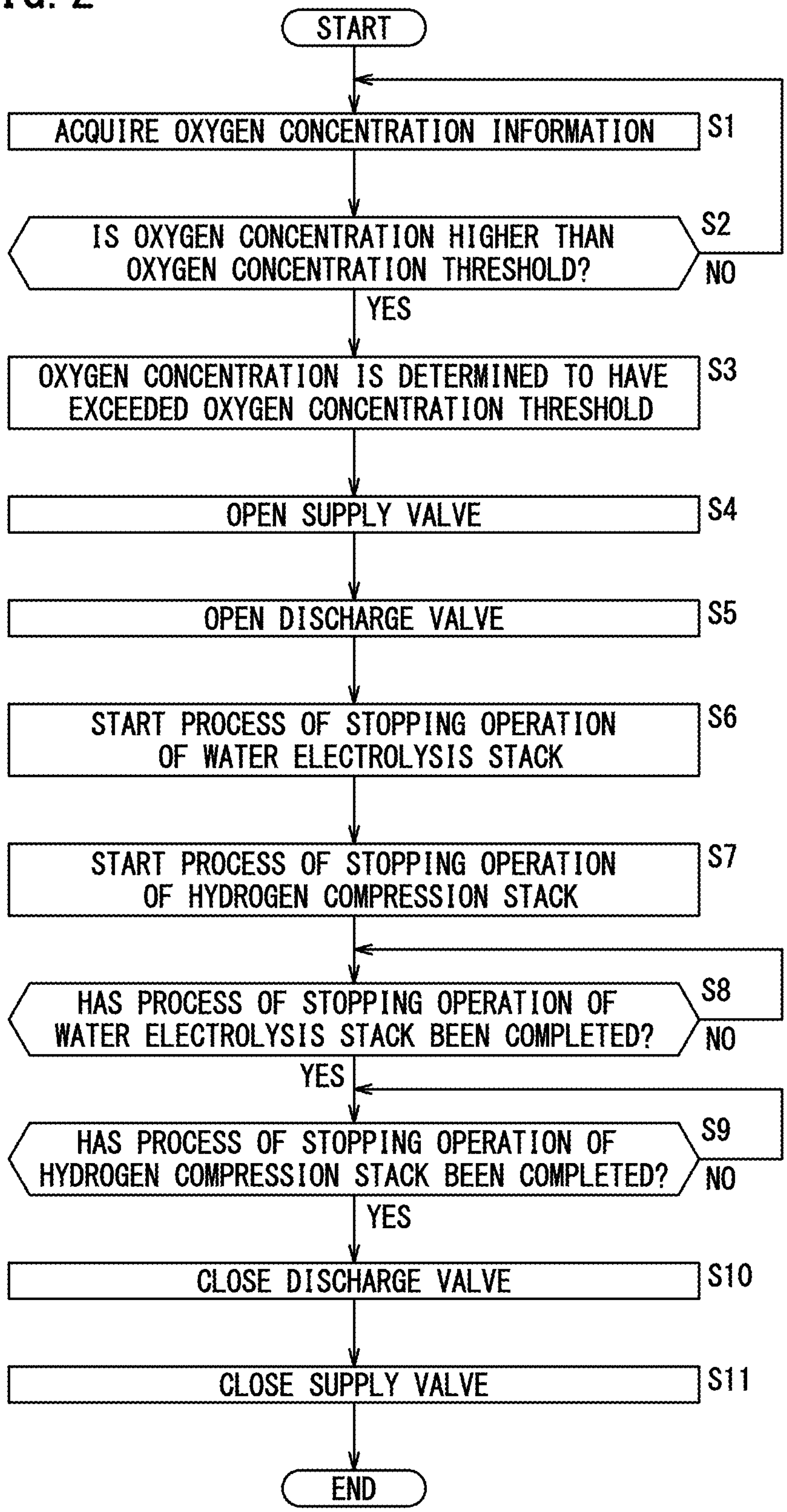
FIG. 1

10



80
CONTROL DEVICE
150
COMPUTATION UNIT
152
STORAGE UNIT
160
HYDROGEN COMPRESSION STACK CONTROL UNIT
162
SUPPLY CONTROL UNIT
164
DISCHARGE CONTROL UNIT
166
DETERMINATION UNIT
168
WATER ELECTROLYSIS STACK CONTROL UNIT
50
OXYGEN TANK
FUEL CELL
108
106
104
20
WATER ELECTROLYSIS STACK
20u
20a
20m
20c
MEA1
100
102
P
110, 110a
128
126
30p
30s
Lm
h
30b
70
GAS TANK
FUEL CELL
30
30r
30t
Ws
GAS-LIQUID SEPARATOR
124
122
112
P
110, 110b
110, 110c
130
114
40
HYDROGEN COMPRESSION STACK
40u
40a
40m
40c
MEA2
116
118
60
HYDROGEN TANK

FIG. 2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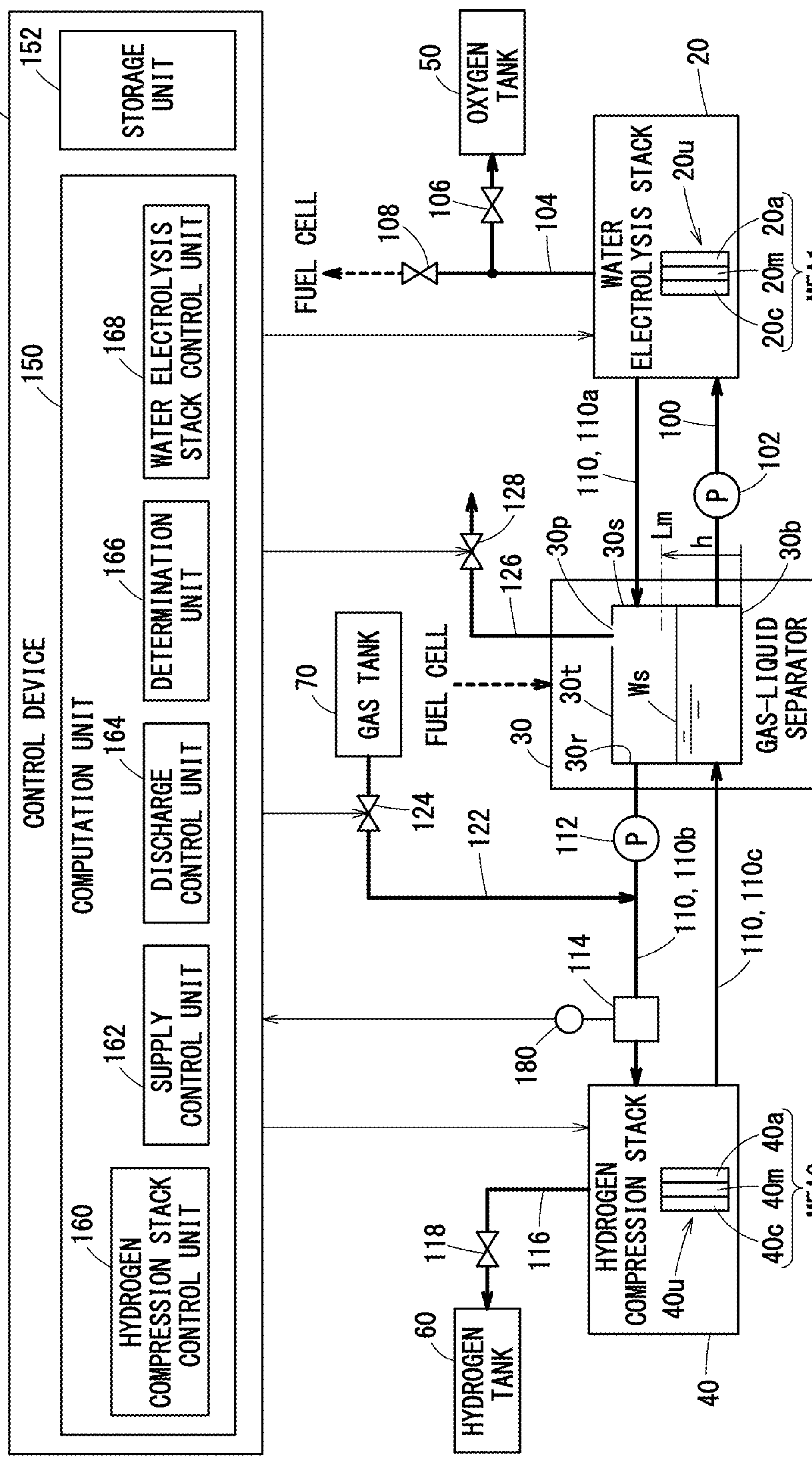
ACQUIRE OXYGEN CONCENTRATION INFORMATION
S1
IS OXYGEN CONCENTRATION HIGHER THAN OXYGEN CONCENTRATION THRESHOLD?
S2
NO
YES
OXYGEN CONCENTRATION IS DETERMINED TO HAVE EXCEEDED OXYGEN CONCENTRATION THRESHOLD
S3
OPEN SUPPLY VALVE
S4
OPEN DISCHARGE VALVE
S5
START PROCESS OF STOPPING OPERATION OF WATER ELECTROLYSIS STACK
S6
START PROCESS OF STOPPING OPERATION OF HYDROGEN COMPRESSION STACK
S7
HAS PROCESS OF STOPPING OPERATION OF WATER ELECTROLYSIS STACK BEEN COMPLETED?
S8
NO
YES
HAS PROCESS OF STOPPING OPERATION OF HYDROGEN COMPRESSION STACK BEEN COMPLETED?
S9
NO
YES
CLOSE DISCHARGE VALVE
S10
CLOSE SUPPLY VALVE
S11
END

FIG. 3

10



80
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HYDROGEN COMPRESSION STACK CONTROL UNIT
162
SUPPLY CONTROL UNIT
164
DISCHARGE CONTROL UNIT
166
DETERMINATION UNIT
168
WATER ELECTROLYSIS STACK CONTROL UNIT
50
OXYGEN TANK
106
108
104
FUEL CELL
20
WATER ELECTROLYSIS STACK
20u
20a
20m
20c
MEA1
110, 110a
100
102
P
128
126
30p
30s
Lm
h
30b
70
GAS TANK
FUEL CELL
30
30r
30t
Ws
GAS-LIQUID SEPARATOR
124
122
112
110, 110b
110, 110c
114
180
HYDROGEN COMPRESSION STACK
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40m
40c
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40u
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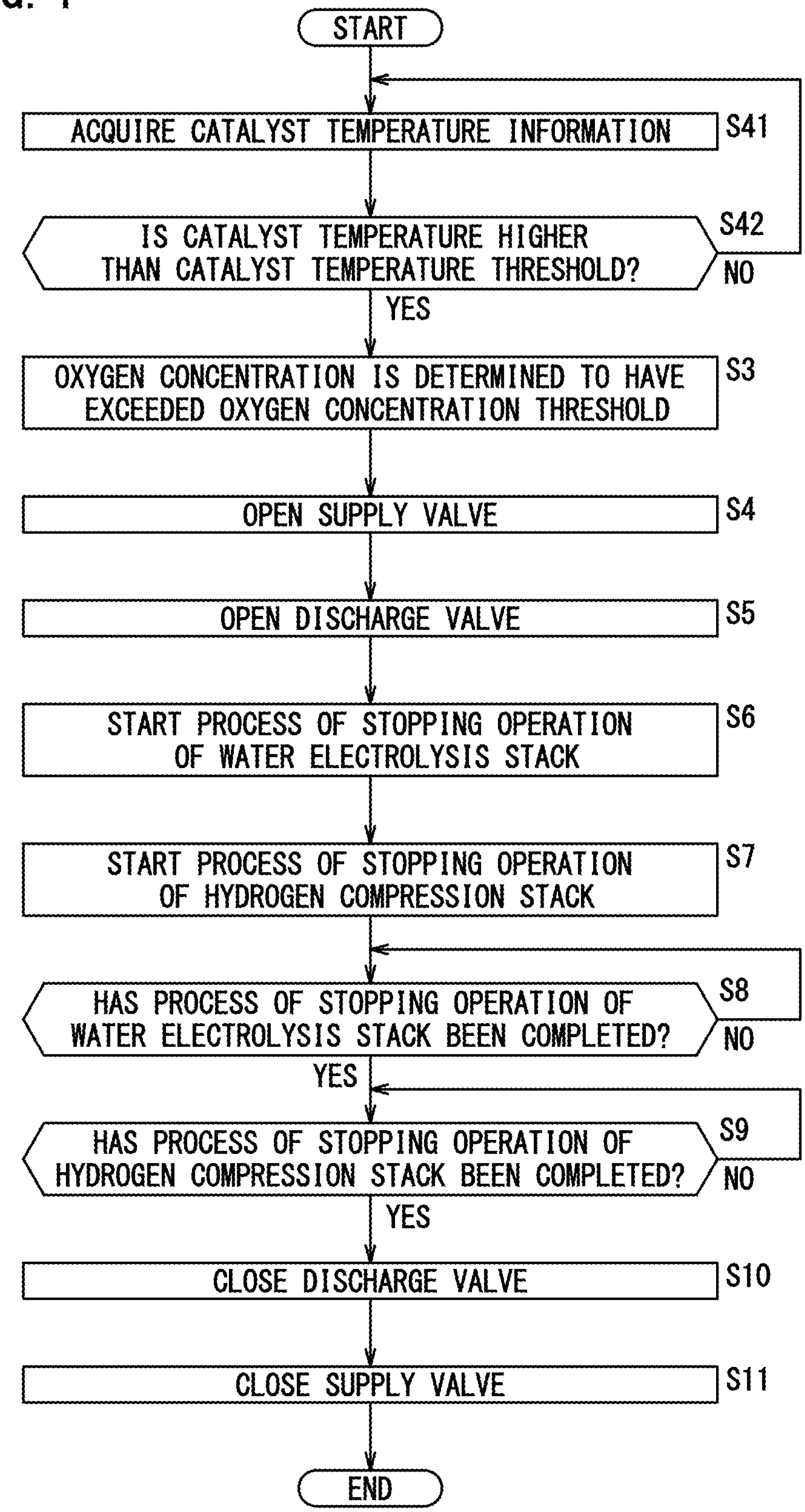
116
118
60
HYDROGEN TANK

FIG. 4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S3
OPEN SUPPLY VALVE
S4
OPEN DISCHARGE VALVE
S5
START PROCESS OF STOPPING OPERATION OF WATER ELECTROLYSIS STACK
S6
START PROCESS OF STOPPING OPERATION OF HYDROGEN COMPRESSION STACK
S7
HAS PROCESS OF STOPPING OPERATION OF WATER ELECTROLYSIS STACK BEEN COMPLETED?
S8
NO
YES
HAS PROCESS OF STOPPING OPERATION OF HYDROGEN COMPRESSION STACK BEEN COMPLETED?
S9
NO
YES
CLOSE DISCHARGE VALVE
S10
CLOSE SUPPLY VALVE
S11
END

WATER ELECTROLYSIS SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2024-020103 filed on Feb. 14, 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 water electrolysis 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 2022-083098 A discloses a hydrogen/oxygen producing system. Oxygen gas and hydrogen gas generated by the hydrogen/oxygen producing system can be supplied to a tank for a fuel cell or the like. The hydrogen/oxygen producing system includes a water electrolysis apparatus. In the water electrolysis apparatus, water is electrolyzed by a current flowing through an anode and a cathode provided on both surfaces of an electrolyte membrane. Hydrogen gas is generated at the cathode, and high-pressure oxygen gas is generated at the anode. Oxygen gas is less likely to permeate through the electrolyte membrane than hydrogen gas. Since the oxygen gas is at a high pressure, the occurrence of crossover in which hydrogen permeates through the electrolyte membrane is suppressed.

SUMMARY OF THE INVENTION

[0005] Recently, it has been desired to improve safety when an abnormality occurs in a water electrolysis system.

[0006] The present invention has the object of solving the aforementioned problem, thereby contributing to energy efficiency.

[0007] According to an aspect of the present disclosure, there is provided a water electrolysis system, comprising: a water electrolysis stack including a membrane electrode assembly in which an electrolyte membrane is sandwiched between an anode and a cathode, the water electrolysis stack being configured to generate oxygen gas and hydrogen gas by electrolyzing water; a gas-liquid separator configured to separate the hydrogen gas generated by the water electrolysis stack from water that has not been electrolyzed by the water electrolysis stack; a hydrogen compression stack including a membrane electrode assembly in which an electrolyte membrane is sandwiched between an anode and a cathode, the hydrogen compression stack being configured to compress the hydrogen gas separated by the gas-liquid separator; a gas tank configured to store an inert gas and connected to a hydrogen flow path that connects the water electrolysis stack and the hydrogen compression stack to each other via the gas-liquid separator; a supply valve configured to, when opened, supply the inert gas stored in the gas tank to the hydrogen flow path; and a supply control unit configured to open the supply valve in a case where an oxygen concentration, which is a concentration of oxygen gas that has flowed into the hydrogen flow path, exceeds an oxygen concentration threshold determined in advance.

[0008] According to the present invention, safety when an abnormality occurs in the water electrolysis system can be improved.

[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.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a diagram illustrating a configuration of a water electrolysis system according to an embodiment;

[0011] FIG. **2** is a flowchart showing an operation example of a control device;

[0012] FIG. **3** is a diagram illustrating a configuration of the water electrolysis system according to a modification; and

[0013] FIG. **4** is a flowchart showing an operation example of the control device.

DETAILED DESCRIPTION OF THE INVENTION

[0014] A water electrolysis system according to an embodiment will be described with reference to the drawings. FIG. **1** is a diagram illustrating a configuration of a water electrolysis system **10** according to the present embodiment. The water electrolysis system **10** includes a water electrolysis stack **20**, a gas-liquid separator **30**, a hydrogen compression stack **40**, an oxygen tank **50**, a hydrogen tank **60**, a gas tank **70**, and a control device **80**.

[0015] The water electrolysis stack **20** generates oxygen gas and hydrogen gas by electrolyzing water. The water is supplied from the gas-liquid separator **30**. The gas-liquid separator **30** separates the hydrogen gas generated by the water electrolysis stack **20** from the water that has not been electrolyzed by the water electrolysis stack **20**. The gas-liquid separator **30** stores the separated water. The hydrogen compression stack **40** compresses the hydrogen gas separated by the gas-liquid separator **30**. The oxygen tank **50** stores the oxygen gas generated by the water electrolysis stack **20**. The hydrogen tank **60** stores the hydrogen gas compressed by the hydrogen compression stack **40**.

[0016] The oxygen gas stored in the oxygen tank **50** and the hydrogen gas stored in the hydrogen tank **60** are used in a member other than the water electrolysis system **10**. The other member is, for example, a fuel cell. A part of the oxygen gas generated by the water electrolysis stack **20** may be supplied to the fuel cell without being stored. A part of the hydrogen gas compressed by the hydrogen compression stack **40** may be supplied to the fuel cell without being stored. The gas tank **70** stores an inert gas. The inert gas is, for example, nitrogen gas or noble gas. The control device **80** controls respective members constituting the water electrolysis system **10**. Details of the control by the control device **80** will be described later.

[0017] The water electrolysis system **10** includes a water supply flow path **100** and a pump **102**. The water supply flow path **100** is a flow path that connects the gas-liquid separator **30** and the water electrolysis stack **20**. The pump **102** sucks water stored in the gas-liquid separator **30**, and discharges the water to the water supply flow path **100**. The water discharged by the pump **102** flows through the water supply flow path **100** and is supplied to the water electrolysis stack **20**.

[0018] A plurality of unit cells **20***u* are stacked in the water electrolysis stack **20**. Each of the unit cells **20***u* electrolyzes water. The unit cells **20***u* each include a membrane electrode assembly MEA**1**. The membrane electrode assembly MEAL includes an electrolyte membrane **20***m*, an anode **20***a*, and a cathode **20***c*. The electrolyte membrane **20***m* is sandwiched between the anode **20***a* and the cathode **20***c*. The electrolyte membrane **20***m* is, for example, an anion exchange membrane. Hydroxide ions OH^-, which will be described later, can be conducted through the anion exchange membrane.

[0019] A voltage is applied from a power supply to the anode **20***a* and the cathode **20***c*. A potential difference is generated between the anode **20***a* and the cathode **20***c*. The water supplied to the water electrolysis system **10** receives electrons from the cathode **20***c*. That is, a reduction reaction occurs. This reduction reaction generates hydrogen gas (H_2) and hydroxide ions OH^- at the cathode **20***c*.

[0020] The hydroxide ions OH-generated at the cathode **20***c* are conducted to the anode **20***a* by the electrolyte membrane **20***m* in accordance with the potential difference between the two electrodes. An oxidation reaction occurs at the anode **20***a*. The hydroxide ions OH-release electrons to the anode **20***a* by the oxidation reaction. As a result, oxygen gas (**02**) and water (H_2O) are generated at the anode **20***a*.

[0021] The water electrolysis system **10** includes an oxygen supply flow path **104**, a back pressure valve **106**, and a pressure regulating valve **108**. The oxygen supply flow path **104** includes a flow path that connects the water electrolysis stack **20** and the oxygen tank **50**, and a flow path that connects the water electrolysis stack **20** and the fuel cell. The back pressure valve **106** is provided in the flow path that connects the water electrolysis stack **20** and the oxygen tank **50**. The pressure regulating valve **108** is provided in the flow path that connects the water electrolysis stack **20** and the fuel cell.

[0022] The oxygen gas generated at the anode **20***a* by the water electrolysis stack **20** flows through the oxygen supply flow path **104** and is supplied to the oxygen tank **50** and the fuel cell. The back pressure valve **106** keeps the pressure of the oxygen gas flowing from the anode **20***a* to the back pressure valve **106** and the pressure of the oxygen gas flowing from the anode **20***a* to the pressure regulating valve **108** higher than the pressure of the hydrogen gas generated at the cathode **20***c*. In this manner, a differential pressure is generated across the electrolyte membrane **20***m*.

[0023] The differential pressure generated across the electrolyte membrane **20***m* causes water (water molecules) produced at the anode **20***a* to diffuse through the electrolyte membrane **20***m* and move to the cathode **20***c*. The water that has moved to the cathode **20***c* is used for the above-described reduction reaction at the cathode **20***c*. The differential pressure across the electrolyte membrane **20***m* reduces the crosstalk in which the hydrogen gas generated at the cathode **20***c* moves to the anode **20***a*.

[0024] The water electrolysis system **10** includes a hydrogen flow path **110**. The hydrogen flow path **110** is a flow path that connects the water electrolysis stack **20** and the hydrogen compression stack **40** to each other via the gas-liquid separator **30**. As shown in FIG. **1**, the hydrogen flow path **110** includes a section **110***a* between the water electrolysis stack **20** and the gas-liquid separator **30**, a section **110***b* between the gas-liquid separator **30** and the hydrogen compression stack **40**, and a section **110***c* between the gas-liquid separator **30** and the hydrogen compression stack **40**, which is different from the section **110***b*.

[0025] The hydrogen gas generated at the cathode **20***c* by the water electrolysis stack **20**, and the water that has not been electrolyzed by the water electrolysis stack **20** flow through the section **110***a* of the hydrogen flow path **110** and are separated by the gas-liquid separator **30**. Water contained in a reactant off-gas discharged from the above-described fuel cell further flows into the gas-liquid separator **30**. The water separated by the gas-liquid separator **30** is stored upward from a bottom part **30***b* of the gas-liquid separator **30** by the action of gravity. The hydrogen gas is located above the stored water.

[0026] In FIG. **1**, a storable water level Lm of the gas-liquid separator **30** is shown at a position of a height h from the bottom part **30***b* of the gas-liquid separator **30**. The water level of the water stored in the gas-liquid separator **30** is maintained at the storable water level Lm or lower. As described above, the water stored in the gas-liquid separator **30** can flow through the water supply flow path **100** and be supplied to the water electrolysis stack **20**.

[0027] The hydrogen gas stored in the gas-liquid separator **30** can flow through the section **110***b* of the hydrogen flow path **110** and be supplied to the hydrogen compression stack **40**. The water electrolysis system **10** includes a pump **112**. The pump **112** sucks the hydrogen gas separated by the gas-liquid separator **30** and discharges the hydrogen gas to the section **110***b* of the hydrogen flow path **110**. The hydrogen gas discharged from the pump **112** flows through the section **110***b* of the hydrogen flow path **110** and is supplied to the hydrogen compression stack **40**.

[0028] A part of the reactant off-gas discharged from the fuel cell may be mixed in the water flowing into the gas-liquid separator **30** from the fuel cell. The reactant off-gas may contain oxygen gas. Therefore, the oxygen gas may be mixed with the hydrogen gas in the hydrogen flow path **110**. The water electrolysis system **10** includes an oxygen removal device **114**. The oxygen removal device **114** includes a catalyst such as palladium. The catalyst is disposed in the section **110***b* of the hydrogen flow path **110** to remove the oxygen gas present in the hydrogen flow path **110**.

[0029] A plurality of unit cells **40***u* are stacked in the hydrogen compression stack **40**. Each of the unit cells **40***u* compresses the hydrogen gas. The unit cells **40***u* each include a membrane electrode assembly MEA**2**. The membrane electrode assembly MEA**2** includes an electrolyte membrane **40***m*, an anode **40***a*, and a cathode **40***c*. The electrolyte membrane **40***m* is sandwiched between the anode **40***a* and the cathode **40***c*. The electrolyte membrane **40***m* is, for example, a proton exchange membrane. Protons, which are a type of hydrogen ion H^+, can be conducted through the proton exchange membrane.

[0030] A voltage is applied from a power supply to the anode **40***a* and the cathode **40***c*. A potential difference is generated between the anode **40***a* and the cathode **40***c*. The hydrogen gas supplied to the hydrogen compression stack **40** emits electrons at the anode **40***a*. As a result, protons are generated at the anode **40***a*. The protons generated at the anode **40***a* are conducted to the cathode **40***c* by the electrolyte membrane **40***m* in accordance with the potential difference between the two electrodes. The protons (H^+) conducted from the anode **40***a* to the cathode **40***c* receive electrons from the cathode **40***c*. As a result, high-pressure compressed hydrogen gas (H_2) is generated at the cathode **40***c*.

[0031] The water electrolysis system **10** includes a hydrogen supply flow path **116** and a back pressure valve **118**. The hydrogen supply flow path **116** is a flow path that connects the hydrogen compression stack **40** and the hydrogen tank **60**. The back pressure valve **118** is provided in the hydrogen supply flow path **116**. The hydrogen gas generated at the cathode **40***c* by the hydrogen compression stack **40** can flow through the hydrogen supply flow path **116** and be supplied to the hydrogen tank **60**.

[0032] The hydrogen gas generated at the cathode **40***c* is at a high pressure as described above. The back pressure valve **118** keeps the pressure of the hydrogen gas flowing from the cathode **40***c* to the back pressure valve **118** higher than the pressure of the hydrogen gas supplied to the anode **40***a*. The hydrogen gas that has not been compressed by the hydrogen compression stack **40** flows through the section **110***c* of the hydrogen flow path **110** and returns to the gas-liquid separator **30**.

[0033] As described above, in the water electrolysis stack **20**, the oxygen gas generated at the anode **20***a* is kept at a higher pressure than the hydrogen gas generated at the cathode **20***c*.

[0034] That is, the internal pressure of the hydrogen flow path **110** is lower than the pressure of the oxygen gas flowing from the anode **20***a* to the back pressure valve **106** or the pressure regulating valve **108**.

[0035] It is assumed that the electrolyte membrane **20***m* is damaged in one or a plurality of unit cells **20***u* of the water electrolysis stack **20** due to some abnormality in the water electrolysis stack **20**. In this case, a large amount of high-pressure oxygen gas may flow into the low-pressure hydrogen flow path **110**. When a large amount of oxygen gas flows into the hydrogen flow path **110**, the oxygen removal device **114** cannot completely remove the oxygen gas, and the oxygen gas may reach the hydrogen compression stack **40**.

[0036] Since a voltage has been applied to the plurality of unit cells **40***u* of the hydrogen compression stack **40**, if not only the hydrogen gas but also the oxygen gas is supplied to the hydrogen compression stack **40**, safety may be reduced. In addition, in the oxygen removal device **114**, a large amount of oxygen gas may come into contact with the catalyst, and thus heat may be generated. The heat generation may also reduce safety.

[0037] In order to improve safety, in the water electrolysis system **10** according to the present embodiment, an oxygen concentration, which is the concentration of the oxygen gas that has flowed into the hydrogen flow path **110**, is determined. In a case where the oxygen concentration exceeds an oxygen concentration threshold determined in advance, a purge process of the inside of the hydrogen flow path **110** by an inert gas is performed. The oxygen concentration can be reduced by the purge process. This can improve safety when an abnormality occurs in the water electrolysis system **10**.

[0038] By performing a process of stopping the operation of the water electrolysis stack **20** in parallel with the purge process, the amount of oxygen gas flowing into the hydrogen flow path **110** can be reduced. Further, by performing a process of stopping the operation of the hydrogen compression stack **40** in parallel with the purge process, the voltage application to the plurality of unit cells **40***u* is stopped. This can further improve safety. A configuration for realizing the purge process of the inside of the hydrogen flow path **110** by the inert gas will be described with reference to FIG. **1**.

[0039] The gas tank **70** stores a high-pressure inert gas. The water electrolysis system **10** includes a gas supply flow path **122** for the inert gas, and a supply valve **124** for the inert gas. The gas supply flow path **122** is a flow path that connects the gas tank **70** and the section **110***b* of the hydrogen flow path **110**. The gas supply flow path **122** is connected to the hydrogen flow path **110** at a location between the pump **112** and the oxygen removal device **114**. That is, the gas tank **70** is connected to the section **110***b* of the hydrogen flow path **110** on the upstream of the oxygen removal device **114**.

[0040] The supply valve **124** is provided in the gas supply flow path **122**. When the supply valve **124** is opened, the high-pressure inert gas stored in the gas tank **70** is supplied to the section **110***b* of the hydrogen flow path **110**. Consequently, the inert gas supplied to the hydrogen flow path **110** can reduce the oxygen concentration in the hydrogen flow path **110**. The inert gas supplied to the hydrogen flow path **110** further flows into the oxygen removal device **114** and the hydrogen compression stack **40**, and also reduces the oxygen concentration in the oxygen removal device **114** and the hydrogen compression stack **40**.

[0041] The high-pressure inert gas flows into the hydrogen flow path **110** in the section **110***b* downstream of the gas-liquid separator **30**, and also flows into the oxygen removal device **114** and the hydrogen compression stack **40**, whereby the oxygen concentration can be rapidly reduced. Thereafter, the inert gas flows through the section **110***c* of the hydrogen flow path **110** and flows into the gas-liquid separator **30**.

[0042] The inert gas that has flowed into the gas-liquid separator **30** is introduced into a space **30***r* located above a water surface Ws of the water stored in the gas-liquid separator **30**. The inert gas, the oxygen gas, the hydrogen gas, and the like are present in the space **30***r*. The gas-liquid separator **30** is provided with an opening **30***p*. The opening **30***p* is provided at a portion of the gas-liquid separator **30** that is located above the storable water level Lm. The portion of the gas-liquid separator **30** that is located above the storable water level Lm is, for example, a region of a side surface **30***s* of the gas-liquid separator **30** that is located above the storable water level Lm, or an upper surface **30***t* of the gas-liquid separator **30**. In the example shown in FIG. **1**, the opening **30***p* is provided in the upper surface **30***t* of the gas-liquid separator **30**. This prevents the opening **30***p* from being submerged in the water stored in the gas-liquid separator **30**.

[0043] The water electrolysis system **10** includes a discharge flow path **126** and a discharge valve **128**. One end of the discharge flow path **126** communicates with the opening **30***p* of the gas-liquid separator **30**. That is, the discharge flow path **126** communicates, via the opening **30***p*, with the space **30***r* located above the water surface Ws in the gas-liquid separator **30**. The other end of the discharge flow path **126** communicates with the outside.

[0044] The discharge valve **128** is provided in the discharge flow path **126**. When the discharge valve **128** is opened, the discharge flow path **126** communicates with the outside. In this case, the gas existing in the space **30***r* in the gas-liquid separator **30** can be discharged to the outside. In this manner, the purge process of the inside of the hydrogen flow path **110** by the inert gas is performed. That is, the oxygen gas in the hydrogen flow path **110** can be discharged to the outside together with the inert gas. Therefore, the oxygen concentration in the hydrogen flow path **110** is sufficiently reduced, and the safety of the water electrolysis system **10** can be further improved.

[0045] As described above, the purge process of the inside of the hydrogen flow path **110** by the inert gas is performed in a case where the oxygen concentration exceeds the oxygen concentration threshold determined in advance. Therefore, the water electrolysis system **10** includes a concentration sensor **130** for measuring the oxygen concentration in the hydrogen flow path **110**. Oxygen concentration information, which is information about the oxygen concentration measured by the concentration sensor **130**, is supplied to the control device **80**.

[0046] As described above, the control device **80** controls respective members constituting the water electrolysis system **10**. The control device **80** includes a computation unit **150** and a storage unit **152**. The computation unit **150** includes a processor such as a central processing unit (CPU) or a graphics processing unit (GPU). That is, the computation unit **150** includes processing circuitry.

[0047] The storage unit **152** is a computer-readable storage medium. The storage unit **152** includes a volatile memory such as a random access memory (RAM), and a non-volatile memory such as a read only memory (ROM) or a flash memory. The volatile memory is used as a working memory of the processor. The non-volatile memory stores a program executed by the processor, and other necessary data. The program stored in the storage unit **152** is executed to control the respective members constituting the water electrolysis system **10**.

[0048] The computation unit **150** includes a hydrogen compression stack control unit **160**, a supply control unit **162**, a discharge control unit **164**, a determination unit **166**, and a water electrolysis stack control unit **168**. The computation unit **150** executes the program stored in the storage unit **152**, thereby realizing the hydrogen compression stack control unit **160**, the supply control unit **162**, the discharge control unit **164**, the determination unit **166**, and the water electrolysis stack control unit **168**.

[0049] At least part of the hydrogen compression stack control unit **160**, the supply control unit **162**, the discharge control unit **164**, the determination unit **166**, and the water electrolysis stack control unit **168** may be realized by an integrated circuit such as an application specific integrated circuit (ASIC) or a field programmable gate array (FPGA), or an electronic circuit including a discrete device.

[0050] The hydrogen compression stack control unit **160** controls the operation of the hydrogen compression stack **40**. The water electrolysis stack control unit **168** controls the operation of the water electrolysis stack **20**. The supply control unit **162** controls the supply valve **124** for the inert gas. The discharge control unit **164** controls the discharge valve **128** provided in the discharge flow path **126**. The determination unit **166** determines whether or not the oxygen concentration, which is the concentration of the oxygen gas that has flowed into the hydrogen flow path **110**, has exceeded the oxygen concentration threshold determined in advance. The oxygen concentration threshold is determined in advance by an experiment or the like, and is stored in the storage unit **152**.

[0051] The water electrolysis stack control unit **168** starts a start-up process for the water electrolysis stack **20**. The hydrogen compression stack control unit **160** starts a start-up process for the hydrogen compression stack **40**. When the start-up process for the water electrolysis system **10** is started in this manner, the determination unit **166** repeatedly acquires the oxygen concentration information from the concentration sensor **130**. The determination unit **166** determines whether or not the oxygen concentration in the hydrogen flow path **110** has exceeded the oxygen concentration threshold based on the acquired oxygen concentration information.

[0052] In a case where the determination unit **166** determines that the oxygen concentration has exceeded the oxygen concentration threshold, the supply control unit **162**, the discharge control unit **164**, the water electrolysis stack control unit **168**, and the hydrogen compression stack control unit **160** perform the following control, respectively. Specifically, the supply control unit **162** controls the supply valve **124** to open the supply valve **124**. The discharge control unit **164** controls the discharge valve **128** to open the discharge valve **128**. The water electrolysis stack control unit **168** controls the water electrolysis stack **20** to start the process of stopping the operation of the water electrolysis stack **20**. This suppresses the generation of oxygen gas, and the safety of the water electrolysis system **10** can be therefore further improved.

[0053] The hydrogen compression stack control unit **160** controls the hydrogen compression stack **40** to start the process of stopping the operation of the hydrogen compression stack **40**. This reduces the possibility that the hydrogen gas and the oxygen gas supplied to the hydrogen compression stack **40** react with each other, and the safety of the water electrolysis system **10** can be therefore further improved.

[0054] The water electrolysis stack control unit **168** monitors the operation state of the water electrolysis stack **20**, and determines whether or not the process of stopping the operation of the water electrolysis stack **20** has been completed. The hydrogen compression stack control unit **160** monitors the operation state of the hydrogen compression stack **40**, and determines whether or not the process of stopping the operation of the hydrogen compression stack **40** has been completed.

[0055] In a case where the water electrolysis stack control unit **168** determines that the process of stopping the operation of the water electrolysis stack **20** has been completed, and the hydrogen compression stack control unit **160** determines that the process of stopping the operation of the hydrogen compression stack **40** has been completed, the discharge control unit **164** and the supply control unit **162** perform the following control, respectively. Specifically, the discharge control unit **164** controls the discharge valve **128** to close the discharge valve **128**. Further, the supply control unit **162** controls the supply valve **124** to close the supply valve **124**.

[0056] By the process of stopping the operation of the water electrolysis stack **20** being completed, the generation of the oxygen gas is stopped. The safety of the water electrolysis system **10** can be further improved by stopping the generation of the oxygen gas. Further, by the process of stopping the operation of the hydrogen compression stack **40** being completed, the compression of the hydrogen gas is stopped. The safety of the water electrolysis system **10** can be further improved by stopping the compression of the hydrogen gas.

[0057] While the process of stopping the operation of the water electrolysis stack **20** is in progress, the generation of the oxygen gas and the hydrogen gas is continued, but the amounts of generated oxygen gas and generated hydrogen gas are gradually reduced. If the amounts of the generated gases are rapidly reduced, the electrolyte membrane **20***m* of the water electrolysis stack **20** and the electrolyte membrane **40***m* of the hydrogen compression stack **40** may be expanded due to the rapid pressure reduction inside the water electrolysis system **10**. This may cause further damage to the electrolyte membrane **20***m* of the water electrolysis stack **20** or the electrolyte membrane **40***m* of the hydrogen compression stack **40**.

[0058] In order to prevent such damage, it is necessary to control the pressure reduction rate inside the water electrolysis system **10**. Therefore, it is preferable that the supply of the inert gas to the hydrogen flow path **110** is continued. Therefore, the supply control unit **162** does not close the supply valve **124** until the operation of the water electrolysis stack **20** and the operation of the hydrogen compression stack **40** are both stopped. That is, the supply valve **124** is kept open. As a result, the oxygen concentration in the hydrogen flow path **110** is suppressed to be low.

[0059] Therefore, the process of stopping the operation of the water electrolysis stack **20** and the process of stopping the operation of the hydrogen compression stack **40** can be performed while preventing further damage to the electrolyte membrane **20***m* of the water electrolysis stack **20** or the electrolyte membrane **40***m* of the hydrogen compression stack **40** in a state where the oxygen concentration in the hydrogen flow path **110** is suppressed to be low. Therefore, the safety of the water electrolysis system **10** can be further improved.

[0060] In addition, after the operation of the water electrolysis stack **20** and the operation of the hydrogen compression stack **40** are both stopped, the discharge valve **128** is closed. When the discharge valve **128** is closed, even if the outside atmospheric pressure is low or there is no atmosphere outside, the water electrolysis system **10** can be prevented from being damaged due to a pressure drop inside the water electrolysis system **10**. Further, by closing the supply valve **124**, it is possible to prevent the water electrolysis system **10** from being damaged due to a pressure rise inside the water electrolysis system **10**, and to prevent the inert gas stored in the gas tank **70** from being wastefully consumed.

[0061] FIG. **2** is a flowchart showing an operation example of the control device **80**. When the start-up process for the water electrolysis system **10** is started, a safety control process procedure for the water electrolysis system **10** shown in FIG. **2** is started. This process procedure is performed by the computation unit **150** of the control device **80** executing a program stored in the storage unit **152**.

[0062] When this process procedure is started, the determination unit **166** acquires the oxygen concentration information from the concentration sensor **130** in step S**1**. In step S**2**, the determination unit **166** determines whether or not the oxygen concentration in the hydrogen flow path **110** indicated by the oxygen concentration information acquired in step S**1** is higher than the oxygen concentration threshold stored in the storage unit **152**. If the determination result in step S**2** is affirmative (YES), the process procedure proceeds to step S**3**. If the determination result in step S**2** is negative (NO), the process procedure returns to step S**1**.

[0063] In step S**3**, the determination unit **166** determines that the oxygen concentration in the hydrogen flow path **110** has exceeded the oxygen concentration threshold. In step S**4**, the supply control unit **162** opens the supply valve **124**. In step S**5**, the discharge control unit **164** opens the discharge valve **128**.

[0064] In step S**6**, the water electrolysis stack control unit **168** starts the process of stopping the operation of the water electrolysis stack **20**. In step S**7**, the hydrogen compression stack control unit **160** starts the process of stopping the operation of the hydrogen compression stack **40**. In step S**8**, the water electrolysis stack control unit **168** determines whether or not the process of stopping the operation of the water electrolysis stack **20** has been completed. If the determination result in step S**8** is affirmative (YES), the process procedure proceeds to step S**9**. If the determination result in step S**8** is negative (NO), the process procedure repeats the process of step S**8**.

[0065] In step S**9**, the hydrogen compression stack control unit **160** determines whether or not the process of stopping the operation of the hydrogen compression stack **40** has been completed. If the determination result in step S**9** is affirmative (YES), the process procedure proceeds to step S**10**. If the determination result in step S**9** is negative (NO), the process procedure repeats the process of step S**9**. In step S**10**, the discharge control unit **164** closes the discharge valve **128**. In step S**11**, the supply control unit **162** closes the supply valve **124**. When the process of step S**11** is completed, the process procedure is ended.

[0066] It should be noted that, when the operation of the water electrolysis stack **20** is stopped, high-pressure oxygen gas is not generated. In that case, sufficient safety can be ensured. Therefore, the process of stopping the operation of the hydrogen compression stack **40** may not necessarily be performed.

[0067] The above-described embodiment may be modified as follows. In the following modification, description overlapping with that of the above-described embodiment will be omitted.

(Modification)

[0068] In the embodiment described above, the water electrolysis system **10** includes the concentration sensor **130** for measuring the oxygen concentration in the hydrogen flow path **110**. However, instead of the oxygen concentration being measured by the concentration sensor **130**, a catalyst temperature, which is the temperature of a catalyst provided in the oxygen removal device **114**, may be measured. FIG. **3** is a diagram illustrating a configuration of the water electrolysis system **10** according to the present modification. The water electrolysis system **10** shown in FIG. **3** includes a temperature sensor **180** for measuring the catalyst temperature. Catalyst temperature information, which is information about the catalyst temperature measured by the temperature sensor **180**, is supplied to the control device **80**.

[0069] When the oxygen concentration in the hydrogen flow path **110** increases, a large amount of oxygen gas may come into contact with the catalyst in the oxygen removal device **114**, and thus heat may be generated. Therefore, the determination unit **166** may determine that the oxygen concentration in the hydrogen flow path **110** has exceeded the oxygen concentration threshold, based on the catalyst temperature measured by the temperature sensor **180**, and the correspondence relationship between the oxygen concentration and the catalyst temperature.

[0070] Specifically, in a case where the catalyst temperature exceeds a catalyst temperature threshold determined in advance, it is determined that the oxygen concentration in the hydrogen flow path **110** has exceeded the oxygen concentration threshold. The correspondence relationship between the oxygen concentration and the catalyst temperature is determined in advance by an experiment or the like, and is stored in the storage unit **152**. Further, based on the correspondence relationship, the catalyst temperature threshold is determined in advance in correspondence with the above-described oxygen concentration threshold, and is stored in the storage unit **152**.

[0071] When the start-up process for the water electrolysis system **10** is started, the determination unit **166** repeatedly acquires the catalyst temperature information from the temperature sensor **180**. The determination unit **166** determines whether or not the oxygen concentration in the hydrogen flow path **110** has exceeded the oxygen concentration threshold based on the acquired catalyst temperature information. When the oxygen concentration increases, the catalyst temperature rises rapidly. Therefore, it is easy to detect that the oxygen concentration in the hydrogen flow path **110** has exceeded the oxygen concentration threshold.

[0072] In a case where the determination unit **166** determines that the oxygen concentration has exceeded the oxygen concentration threshold, the supply control unit **162** controls the supply valve **124** to open the supply valve **124**. Further, the discharge control unit **164** controls the discharge valve **128** to open the discharge valve **128**. Furthermore, the water electrolysis stack control unit **168** controls the water electrolysis stack **20** to start the process of stopping the operation of the water electrolysis stack **20**. The hydrogen compression stack control unit **160** controls the hydrogen compression stack **40** to start the process of stopping the operation of the hydrogen compression stack **40**.

[0073] FIG. **4** is a flowchart showing an operation example of the control device **80**. When the start-up process for the water electrolysis system **10** is started, the safety control process procedure for the water electrolysis system **10** shown in FIG. **4** is started. This process procedure is performed by the computation unit **150** of the control device **80** executing a program stored in the storage unit **152**. The same steps as those described above with reference to FIG. **2** are denoted by the same reference numerals, and the description thereof will be appropriately omitted.

[0074] When this process procedure is started, the determination unit **166** acquires the catalyst temperature information from the temperature sensor **180** in step S**41**. In step S**42**, the determination unit **166** determines whether or not the catalyst temperature indicated by the catalyst temperature information acquired in step S**41** is higher than the catalyst temperature threshold stored in the storage unit **152**. If the determination result in step S**42** is affirmative (YES), the process procedure proceeds to step S**3**. If the determination result in step S**42** is negative (NO), the process procedure returns to step S**41**.

[0075] The following supplementary notes are further disclosed in relation to the above-described embodiment and modification.

Supplementary Note 1

[0076] The water electrolysis system (**10**) according to the present disclosure includes: the water electrolysis stack (**20**) including the membrane electrode assembly (MEA**1**) in which the electrolyte membrane (**20***m*) is sandwiched between the anode (**20***a*) and the cathode (**20***c*), the water electrolysis stack being configured to generate oxygen gas and hydrogen gas by electrolyzing water; the gas-liquid separator (**30**) configured to separate the hydrogen gas generated by the water electrolysis stack from water that has not been electrolyzed by the water electrolysis stack; the hydrogen compression stack (**40**) including the membrane electrode assembly (MEA**2**) in which the electrolyte membrane (**40***m*) is sandwiched between the anode (**40***a*) and the cathode (**40***c*), the hydrogen compression stack being configured to compress the hydrogen gas separated by the gas-liquid separator; the gas tank (**70**) configured to store an inert gas and connected to the hydrogen flow path (**110**) that connects the water electrolysis stack and the hydrogen compression stack to each other via the gas-liquid separator; the supply valve (**124**) configured to, when opened, supply the inert gas stored in the gas tank to the hydrogen flow path; and the supply control unit (**162**) configured to open the supply valve in a case where the oxygen concentration, which is the concentration of the oxygen gas that has flowed into the hydrogen flow path, exceeds the oxygen concentration threshold determined in advance. According to such a configuration, safety when an abnormality occurs in the water electrolysis system can be improved.

Supplementary Note 2

[0077] In the water electrolysis system according to Supplementary Note 1, the gas tank may be connected to the section (**110***b*) of the hydrogen flow path, the section being located between the gas-liquid separator and the hydrogen compression stack. According to such a configuration, the inert gas can reduce the oxygen concentration in the hydrogen flow path, the oxygen removal device, and the hydrogen compression stack.

Supplementary Note 3

[0078] The water electrolysis system according to Supplementary Note 1 may further include: the discharge flow path (**126**) communicating with the opening (**30***p*) provided in the gas-liquid separator; the discharge valve (**128**) configured to, when opened, allow the discharge flow path to communicate with the outside; and the discharge control unit (**164**) configured to open the discharge valve in a case where the oxygen concentration exceeds the oxygen concentration threshold. According to such a configuration, the oxygen concentration in the hydrogen flow path is sufficiently reduced, and the safety of the water electrolysis system can be further improved.

Supplementary Note 4

[0079] In the water electrolysis system according to Supplementary Note 3, the opening may be provided at a portion of the gas-liquid separator that is located above the storable water level (Lm) of the gas-liquid separator. According to such a configuration, the opening can be prevented from being submerged in the water in the gas-liquid separator.

Supplementary Note 5

[0080] The water electrolysis system according to Supplementary Note 1 may further include the water electrolysis stack control unit (**168**) configured to control the water electrolysis stack to start the process of stopping the operation of the water electrolysis stack in a case where the oxygen concentration exceeds the oxygen concentration threshold. According to such a configuration, the generation of oxygen gas is suppressed, and the safety of the water electrolysis system can be therefore further improved.

Supplementary Note 6

[0081] In the water electrolysis system according to Supplementary Note 5, the supply valve may be kept open until the operation of the water electrolysis stack is stopped. According to such a configuration, the generation of oxygen gas is stopped, and the safety of the water electrolysis system can be therefore further improved.

Supplementary Note 7

[0082] The water electrolysis system according to Supplementary Note 5 may further include the hydrogen compression stack control unit (**160**) configured to control the hydrogen compression stack to start the process of stopping the operation of the hydrogen compression stack in a case where the oxygen concentration exceeds the oxygen concentration threshold. According to such a configuration, the possibility that the hydrogen gas and the oxygen gas supplied to the hydrogen compression stack react with each other is reduced, and the safety of the water electrolysis system can be therefore further improved.

Supplementary Note 8

[0083] In the water electrolysis system according to Supplementary Note 7, the supply valve may be kept open until both the operation of the water electrolysis stack and the operation of the hydrogen compression stack are stopped. According to such a configuration, the safety of the water electrolysis system can be further improved.

Supplementary Note 9

[0084] The water electrolysis system according to any one of Supplementary Notes 1 to 8 may further include: the catalyst disposed in the hydrogen flow path to remove the oxygen gas in the hydrogen flow path; and the determination unit (**166**) configured to determine that the oxygen concentration has exceeded the oxygen concentration threshold in a case where the catalyst temperature, which is the temperature of the catalyst, exceeds the catalyst temperature threshold determined in advance in correspondence with the oxygen concentration threshold based on the correspondence relationship between the oxygen concentration and the catalyst temperature, and the supply control unit may open the supply valve in a case where the determination unit determines that the oxygen concentration has exceeded the oxygen concentration threshold. According to such a configuration, it is easy to detect that the oxygen concentration in the hydrogen flow path has exceeded the oxygen concentration threshold.

[0085] Although the present disclosure has been described in detail, the present disclosure is not limited to the above-described individual embodiments. Various additions, replacements, modifications, partial deletions, and the like can be made to these embodiments without departing from the gist of the present disclosure or without departing from the gist of the present disclosure derived from the claims and equivalents thereof. Further, these embodiments can 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 are not limited to these. Furthermore, the same applies to a case where numerical values or mathematical expressions are used in the description of the above-described embodiments.

1. A water electrolysis system, comprising:

a water electrolysis stack including a membrane electrode assembly in which an electrolyte membrane is sandwiched between an anode and a cathode, the water electrolysis stack being configured to generate oxygen gas and hydrogen gas by electrolyzing water;

a gas-liquid separator configured to separate the hydrogen gas generated by the water electrolysis stack from water that has not been electrolyzed by the water electrolysis stack;

a hydrogen compression stack including a membrane electrode assembly in which an electrolyte membrane is sandwiched between an anode and a cathode, the hydrogen compression stack being configured to compress the hydrogen gas separated by the gas-liquid separator;

a gas tank configured to store an inert gas and connected to a hydrogen flow path that connects the water electrolysis stack and the hydrogen compression stack to each other via the gas-liquid separator;

a supply valve configured to, when opened, supply the inert gas stored in the gas tank to the hydrogen flow path; and

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 water electrolysis system to open the supply valve in a case where an oxygen concentration, which is a concentration of oxygen gas that has flowed into the hydrogen flow path, exceeds an oxygen concentration threshold determined in advance.

2. The water electrolysis system according to claim **1**, wherein

the gas tank is connected to a section of the hydrogen flow path, the section being located between the gas-liquid separator and the hydrogen compression stack.

3. The water electrolysis system according to claim **1**, further comprising:

a discharge flow path communicating with an opening provided in the gas-liquid separator; and

a discharge valve configured to, when opened, allow the discharge flow path to communicate with an outside,

wherein the one or more processors cause the water electrolysis system to open the discharge valve in the case where the oxygen concentration exceeds the oxygen concentration threshold.

4. The water electrolysis system according to claim **3**, wherein

the opening is provided at a portion of the gas-liquid separator that is located above a storable water level of the gas-liquid separator.

5. The water electrolysis system according to claim **1**, wherein

the one or more processors cause the water electrolysis system to control the water electrolysis stack to start a process of stopping an operation of the water electrolysis stack in the case where the oxygen concentration exceeds the oxygen concentration threshold.

6. The water electrolysis system according to claim **5**, wherein

the supply valve is kept open until the operation of the water electrolysis stack is stopped.

7. The water electrolysis system according to claim **5**, wherein

the one or more processors cause the water electrolysis system to control the hydrogen compression stack to start a process of stopping an operation of the hydrogen compression stack in the case where the oxygen concentration exceeds the oxygen concentration threshold.

8. The water electrolysis system according to claim **7**, wherein

the supply valve is kept open until both the operation of the water electrolysis stack and the operation of the hydrogen compression stack are stopped.

9. The water electrolysis system according to claim **1**, further comprising a catalyst disposed in the hydrogen flow path to remove oxygen gas in the hydrogen flow path, wherein

the one or more processors cause the water electrolysis system to:

determine that the oxygen concentration has exceeded the oxygen concentration threshold in a case where a catalyst temperature, which is a temperature of the catalyst, exceeds a catalyst temperature threshold that is determined in advance in correspondence with the oxygen concentration threshold based on a correspondence relationship between the oxygen concentration and the catalyst temperature; and

open the supply valve in a case where it is determined that the oxygen concentration has exceeded the oxygen concentration threshold.

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