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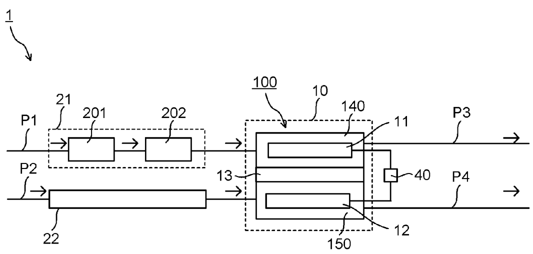
(54) ELECTROCHEMICAL REACTION DEVICE AND METHOD OF OPERATING ELECTROCHEMICAL REACTION DEVICE

(57) An electrochemical reaction device includes: an electrolytic unit that includes a cathode, an anode, a diaphragm, a cathode and an anode chamber; a first flow path through which a first fluid containing a reducible material flows, and; a second flow path through which a second fluid containing an oxidizable material flows; a third flow path through which a third fluid containing a reduction product flows; a fourth flow path through which a fourth fluid containing an oxidation product flows; a humidifier in the middle of the first flow path to humidify the first fluid; and a condenser in the middle of the first flow path so as to follow the humidifier and to treat the humidified first fluid and thus condenses a part of water vapor in the humidified first fluid to produce a condensed water, and to control a ratio of the condensed water in the humidified first fluid.

FIG. 1



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Description

FIELD

[0001] Arrangements relate to an electrochemical reaction device.

BACKGROUND

[0002] In recent years, fossil fuels such as petroleum or coal may be depleted, and alternately sustainably-usable renewable energy has been increasingly expected. Usage examples of the renewable energy, include a solar cell and a wind generator. These devices have a problem of changing a power generation amount in accordance with weather and a natural situation to prevent the electric power to stably supply. Such problem motivate motivates attempting to store the electric power generated by the renewable energy in a storage battery to stabilize the electric power. Unfortunately, the storage of electric power creates problems of requiring a cost for the storage battery, and producing losses in storing the power.

[0003] Such problem motivates focusing on technologies of converting electric energy into chemical substances (chemical energy). Examples of the technologies include a method of electrolyzing water to produce hydrogen using the electric power generated by the renewable energy, a method of electrochemically reducing carbon dioxide to produce at least one carbon compound such as carbon monoxide, formic acid, methanol, methane, acetic acid, ethanol, ethane, or ethylene, and a method of electrochemically reducing nitrogen to produce ammonia. The storage of these chemical substances in a cylinder or a tank has advantage over the storage of the electric power (electric energy) in the storage battery in the reduction of the cost of storing energy and the prevention of a storage loss.

[0004] Such electrochemical reaction is usually performed using a device provided with an electrolysis cell or a cell stack made by stacking the electrolysis cells. A use of the cell stack may cause precipitate solid salt made from liquid or gas used for the electrolysis reaction. For example, the electrolysis cell receiving an electrolytic solution to an anode and receiving a carbon dioxide gas to a cathode, may precipitate a carbonate at the cathode to prevent carbon dioxide from reaching a reaction field on a cathode catalyst to cause degradation in electrolysis cell performance or pressure abnormality inside the cell. This has motivated an inhibition method of salt precipitation and a removal method of the precipitated salt. Known examples of these methods include a method of supplying a rinse material such as water to a cell flow path from the outside of the cell, however this method is difficult to apply to the cell stack made by stacking a plurality of the electrolysis cells in particular. Providing a rinse material supply mechanism for each electrolysis cell increases a size of the device, whereas collectively supplying the rinse material to an inlet of the cell stack makes it difficult to appropriately divide and supply the rinse material to each electrolysis cell.

[0005] In contrast, known examples of the electrochemical reaction devices include an electrochemical reaction device capable of appropriately supplying the rinse material to each cell of the stack by providing an auxiliary flow path to circulate the rinse material and switching circulation directions through a valve operation to perform a rinse operation. Unfortunately, this device requires a complicated piping structure provided with a switching mechanism, which requires a new method of supplying the rinse material.

RELEVANT REFERENCES

Patent Reference

[0006] Reference 1: JPA2022-141239

Non-patent Reference

[0007] Reference 2:J. Disch et al., J. Mater. Chem. A, 11, 7344-7357 (2023).

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 is a schematic diagram illustrating an example configuration of an electrochemical reaction device of an arrangement.
FIG. 2 is a schematic view illustrating another example configuration of an electrolytic unit 10.
FIG. 3 is a schematic view illustrating another example configuration of the electrolytic unit 10.
FIG. 4 is a schematic sectional view illustrating an example structure of a condenser 202.
FIG. 5 is a schematic diagram illustrating another example configuration of the electrochemical reaction device of the arrangement.
FIG. 6 is a schematic diagram illustrating another example configuration of the electrochemical reaction device of the arrangement.
FIG. 7 is a schematic sectional view illustrating an example configuration of the electrolytic unit 10 illustrated in FIG. 6.
FIG. 8 is a schematic view illustrating an example structure of an auxiliary flow path plate 221.
FIG. 9 is a schematic view illustrating the example structure of the auxiliary flow path plate 221.
FIG. 10 is a schematic view illustrating the example structure of the auxiliary flow path plate 221.
FIG. 11 is a schematic view illustrating an example structure of an auxiliary flow path plate 222.
FIG. 12 is a schematic view illustrating the example structure of the auxiliary flow path plate 222.
FIG. 13 is a schematic view illustrating the example structure of the auxiliary flow path plate 222.

FIG. 14 is a schematic view illustrating an example structure of an auxiliary flow path plate 223.

FIG. 15 is a schematic view illustrating the example structure of the auxiliary flow path plate 223.

FIG. 16 is a schematic view illustrating the example structure of the auxiliary flow path plate 223.

FIG. 17 is a schematic view illustrating the other example structure of the auxiliary flow path plate 222.

FIG. 18 is a schematic view illustrating the other example structure of the auxiliary flow path plate 223.

FIG. 19 is a schematic sectional view illustrating the other example configuration of the electrolytic unit 10.

FIG. 20 is a schematic view illustrating an example structure of an auxiliary flow path plate 221.

FIG. 21 is a schematic view illustrating the example structure of the auxiliary flow path plate 211.

FIG. 22 is a schematic view illustrating the example structure of the auxiliary flow path plate 211.

FIG. 23 is a schematic view illustrating an example structure of an auxiliary flow path plate 212.

FIG. 24 is a schematic view illustrating the example structure of the auxiliary flow path plate 212.

FIG. 25 is a schematic view illustrating the example structure of the auxiliary flow path plate 212.

FIG. 26 is a schematic view illustrating an example structure of an auxiliary flow path plate 213.

FIG. 27 is a schematic view illustrating the example structure of the auxiliary flow path plate 213.

FIG. 28 is a schematic view illustrating the example structure of the auxiliary flow path plate 213.

FIG. 29 is a schematic view illustrating the other example structure of the auxiliary flow path plate 212.

FIG. 30 is a schematic view illustrating the other example structure of the auxiliary flow path plate 213.

FIG. 31 is a schematic diagram illustrating another example configuration of the electrochemical reaction device of the arrangement.

FIG. 32 is a schematic diagram illustrating the other example configuration of the electrochemical reaction device of the arrangement.

DETAILED DESCRIPTION

[0009] An electrochemical reaction device of an arrangement includes: an electrolytic unit comprising a cathode, an anode, a diaphragm between the cathode and the anode, a cathode chamber facing on the cathode, and an anode chamber facing on the anode; a first flow path through which a first fluid flows, the first flow path being connected to an inlet of the cathode chamber, and the first fluid containing a reducible material to be supplied to the cathode chamber; a second flow path through which a second fluid flows, the second flow path being connected to an inlet of the anode chamber, and the second fluid containing an oxidizable material to be supplied to the anode chamber; a third flow path through which a third fluid flows, the third flow path being connected to an outlet of the cathode chamber, the third fluid being discharged from the cathode chamber, and the third fluid containing a reduction product; a fourth flow path through which a fourth fluid flows, the fourth flow path being connected to an outlet of the anode chamber, the fourth fluid being discharged from the anode chamber, and the fourth fluid containing an oxidation product; a humidifier provided in the middle of the first flow path and configured to humidify the first fluid; and a condenser provided in the middle of the first flow path so as to follow the humidifier, the condenser being configured to treat the humidified first fluid and thus condense a part of water vapor in the humidified first fluid to produce a condensed water, and to control a ratio of the condensed water in the humidified first fluid.

[0010] Hereinafter, an arrangement will be described with reference to the drawings. In each arrangement presented below, substantially the same constituent parts are denoted by the same reference signs, and a description thereof may be partially omitted. The drawings are schematic, and the relation of the thickness and planar dimension, a thickness ratio among the parts, and so on may be different from actual ones.

[0011] In this specification, "connecting" may include not only directly connecting but also indirectly connecting unless otherwise specified.

[0012] FIG. 1 is a schematic diagram illustrating an example configuration of an electrochemical reaction device of the arrangement. FIG. 1 illustrates an example configuration of an electrochemical reaction device 1. The electrochemical reaction device 1 has an electrolytic unit 10, a flow path P1, a flow path P2, a flow path P3, a flow path P4, a cathode supply part 21, and an anode supply part 22.

[0013] The electrolytic unit 10 can perform at least one electrolytic reaction, for example. The electrolytic unit 10 has a cathode 11, an anode 12, a diaphragm 13, a cathode chamber 140, and an anode chamber 150.

[0014] The electrolytic unit 10 may have a membrane electrode assembly, for example. FIG. 2 is a schematic view illustrating another example configuration of the electrolytic unit 10. The electrolytic unit 10 may have the cathode 11, the anode 12, the diaphragm 13, a flow path plate 14, a flow path plate 15, a current collector 16, and a current collector 17, as illustrated in FIG. 2. FIG. 2 illustrates an X axis, a Y axis, and a Z axis. The X axis, the Y axis, and the Z axis perpendicularly cross one another. The Z axis is along a thickness direction of the electrolytic unit 10. FIG. 2 illustrates a part of an X-Z cross section including the X axis and the Z axis. The cathode 11, the anode 12, and the diaphragm 13 may be stacked to form an electrolysis cell 100 having a membrane electrode assembly MEA.

[0015] The cathode 11 is a reduction electrode for performing a reduction reaction of at least one reducible material (at least one substance to be reduced) to produce a reduction product, for example. At least one reducible material includes carbon dioxide or nitrogen, for example. The cathode 11 reduces carbon dioxide to produce a carbon compound, or reduces nitrogen to produce a nitrogen compound such as ammonia, for example. Examples of the carbon compound include carbon monoxide, formic acid, methanol, methane, ethanol, ethane, ethylene, formaldehyde, ethylene glycol, acetic acid, propanol, and so on. The cathode 11 may perform a side reaction of reducing water to produce hydrogen in addition to reducing carbon dioxide or nitrogen.

[0016] The cathode 11 has a cathode catalyst which accelerates the reduction reaction of reducing at least one reducible material, for example. The cathode catalyst can be formed using an activation energy-reducing material for reducing at least one reducible material, for example. In other words, the cathode catalyst can be formed using a material which lowers an overvoltage at the time of producing the reduction product by the reduction reaction of at least one reducible material, for example.

[0017] The cathode 11 may have a first surface in contact with the diaphragm 13, and a second surface facing on the cathode chamber 140. Further, the cathode 11 may have a gas diffusion layer and a cathode catalyst layer, for example. The cathode 11 may have a porous layer denser than the gas diffusion layer between the gas diffusion layer and the cathode catalyst layer. The gas diffusion layer is disposed on the cathode chamber 140 side, and the cathode catalyst layer is disposed on the diaphragm 13. At least part of the cathode catalyst layer may extend into the gas diffusion layer. The cathode catalyst layer preferably has catalyst nanoparticles, a catalyst nanostructure, or the like. The gas diffusion layer can be formed using, for example, carbon paper, carbon cloth, or the like, and water repellent treatment is performed thereon. An electrolytic solution and ions from the anode 12 can be supplied to the cathode catalyst layer through the diaphragm 13. A cathode supply fluid can be supplied to the gas diffusion layer in the cathode chamber 140, and the reduction product can be discharged from the cathode chamber 140 through the gas diffusion layer. The reduction reaction occurs in the vicinity of the boundary of the gas diffusion layer and the cathode catalyst layer, and the gaseous product is discharged through the gas diffusion layer from a cathode flow path to the outside of the electrolysis cell 100.

[0018] Examples of the cathode catalyst include a metal material such as a metal such as gold (Au), silver (Ag), copper (Cu), platinum (Pt), palladium (Pd), nickel (Ni), cobalt (Co), iron (Fe), manganese (Mn), titanium (Ti), cadmium (Cd), zinc (Zn), indium (In), gallium (Ga), lead (Pb), or tin (Sn), or, an alloy or an intermetallic compound containing at least one of the above metals, a carbon material such as carbon (C), graphene, CNT (carbon nanotube), fullerene, or ketjen black, or a metal complex such as a Ru complex or a Re complex. The cathode catalyst layer can have a shape such as a plate shape, a mesh shape, a wire shape, a particle shape, a porous shape, a thin film shape, or an island shape.

[0019] The anode 12 is an oxidation electrode for performing an oxidation reaction of at least one oxidizable material (substance to be oxidized) to thereby produce an oxidation product, for example. At least one oxidizable material includes water, for example. The anode 12 oxidizes the oxidizable material such as a substance and ions in an electrolytic solution (anode solution) to produce oxygen, for example.

[0020] The anode 12 may have a first surface in contact with the diaphragm 13, and a second surface facing on the anode chamber 150. The anode 12 has an anode catalyst which accelerates the oxidation reaction of oxidizing water to produce oxygen, for example. The anode catalyst can be formed using a material which reduces an activation energy at the time of oxidizing the oxidizable material, in other words, a material which lowers a reaction overvoltage, for example. Examples of the oxidation reaction in the anode 12 include a reaction of oxidizing water to produce oxygen and a hydrogen peroxide solution, a reaction of oxidizing chloride ions (Cl^-) to produce chlorine, a reaction of oxidizing carbonate ions or hydrogen carbonate ions to produce carbon dioxide, and the like.

[0021] Examples of the anode catalyst include a metal such as platinum (Pt), palladium (Pd), iridium (Ir), or nickel (Ni), an alloy or an intermetallic compound containing the metals, a binary metal oxide such as a manganese oxide (Mn-O), an iridium oxide (Ir-O), a nickel oxide (Ni-O), a cobalt oxide (Co-O), an iron oxide (Fe-O), a tin oxide (Sn-O), an indium oxide (In-O), a ruthenium oxide (Ru-O), a lithium oxide (Li-O), or a lanthanum oxide (La-O), a ternary metal oxide such as Ni-Co-O, Ni-Fe-O, La-Co-O, Ni-La-O, or Sr-Fe-O, a quaternary metal oxide such as Pb-Ru-Ir-O or La-Sr-Co-O, or a metal complex such as a Ru complex or an Fe complex.

[0022] The anode 12 may include a base material having a structure capable of moving an anode supply fluid and ions between the diaphragm 13 and the anode chamber 150, for example, a porous structure such as a mesh material, a punching material, a porous body, or a metal fiber sintered member. The base material may be composed of a metal material such as a metal such as titanium (Ti), nickel (Ni), or iron (Fe), or, an alloy (for example, SUS) containing at least one of these metals, or may be composed of the above-described anode catalyst. When an oxide is used as the anode catalyst, a catalyst layer is preferably formed in a manner that the anode catalyst is made to adhere to or stacked on a surface of the base material made of the metal material. The anode catalyst may have nanoparticles, a nanostructure, a nanowire, or the like for the purpose of increasing the oxidation reaction. The nanostructure is a structure in which nanoscale irregularities are formed on a surface of the catalyst material.

[0023] The diaphragm 13 is provided between the cathode 11 and the anode 12. The diaphragm 13 can divide the cathode chamber 140 and the anode chamber 150. The diaphragm 13 can move ions such as hydrogen ions (H^+), hydroxide ions (OH^-), hydrogen carbonate ions (HCO_3^-), or carbonate ions (CO_3^{2-}). The diaphragm 13 allows formation of the electrolysis cell 100 having a two-chamber structure. The diaphragm 13 may be provided in contact with the cathode 11 and the anode 12.

[0024] The diaphragm 13 is formed using an ion exchange membrane capable of moving ions and the electrolytic solution between the cathode 11 and the anode 12, and capable of separating the cathode chamber 140 and the anode chamber 150, or the like. Examples of the ion exchange membrane include NEOSEPTA (registered trademark) of ASTOM Corporation, Selemion (registered trademark) of AGC Inc., Aciplex (registered trademark) of Asahi Kasei Corporation, Fumasep (registered trademark), Fumapem (registered trademark) of Fumatech GmbH, Nafion (registered trademark) which is a fluorocarbon resin made by sulfonating and polymerizing tetrafluoroethylene of Du Pont de Nemours, Inc., Lewabrane (registered trademark) of LANXESS AG, IONSEP (registered trademark) of IONTECH Inc., Mustang (registered trademark) of PALL Corporation, RALEX (registered trademark) of mega Corporation, and Gore-Tex (registered trademark) of Gore-Tex Co., Ltd. However, other than the ion exchange membrane, a glass filter, a porous polymeric membrane, a porous insulating material, or the like may be applied to the diaphragm 13 as long as they are each a material capable of moving ions between the anode and the cathode.

[0025] Other than the ion exchange membrane, the diaphragm 13 may be formed using a porous membrane of a silicone resin, a fluorine-based resin (perfluoroalkoxyalkane (PFA), perfluoroethylene propene copolymer (FEP), polytetrafluoroethylene (PTFE), ethylene-tetrafluoroethylene copolymer (ETFE), polyvinylidene fluoride (PVDF), polychlorotrifluoroethylene (PCTFE), ethylene-chlorotrifluoroethylene copolymer (ECTFE), or the like), polyethersulfone (PES), or ceramics, a filling filled with glass filter, agar, and the like, an insulating porous body such as zeolite or an oxide, or the like. In particular, a hydrophilic porous membrane never causes clogging due to air bubbles, and is thus preferable as the diaphragm 13.

[0026] The cathode chamber 140 is provided to face on the cathode 11, and can form the cathode flow path, for example. The cathode 11 may be disposed in the cathode chamber 140 as illustrated in FIG. 1. The cathode chamber 140 has an inlet for supplying the cathode supply fluid to the cathode chamber 140, and an outlet for discharging a cathode discharge fluid from the cathode chamber 140.

[0027] The composition of the cathode supply fluid through the cathode chamber 140 transforms, and the cathode supply fluid is discharged outside the electrolytic unit 10. A fluid discharged from the electrolytic unit 10 is called the cathode discharge fluid. The cathode discharge fluid contains an objective product, which is separated and recovered as necessary. The cathode discharge fluid may be subjected to gas/liquid separation to make a part of a gas phase flow together into the cathode supply fluid. This method is effective in increasing a conversion ratio of a reactant in the cathode supply fluid. Further, the cathode discharge fluid can also be subjected to the gas/liquid separation to make a part or the whole of a liquid phase flow together into the anode supply fluid.

[0028] The anode chamber 150 is provided to face on the anode 12, and can form an anode flow path, for example. The anode chamber 150 has an inlet for supplying an anode supply fluid to the anode chamber 150, and an outlet for discharging an anode discharge fluid from the anode chamber 150, as illustrated in FIG. 1.

[0029] The anode supply fluid in the anode chamber 150 transforms its composition, and is discharged outside the electrolytic unit 10. A fluid discharged from the anode chamber 150 is called the anode discharge fluid. The anode discharge fluid contains a gas such as oxygen to be produced in the anode 12. The anode discharge fluid may be subjected to the gas/liquid separation to make a part or the whole of a liquid phase flow together into the anode supply fluid. Without supplying the anode supply fluid from the external system, the liquid phase part of the anode discharge fluid is regarded as the anode supply fluid, and supplied to the anode chamber 150, and thereby the anode supply fluid can be circulated.

[0030] The flow path plate 14 forms the cathode chamber 140, for example. The cathode chamber 140 is provided in a surface of the flow path plate 14 to face on the cathode 11, which allows formation of the cathode flow path.

[0031] The flow path plate 15 forms the anode chamber 150, for example. The anode chamber 150 is provided in a surface of the flow path plate 15 to face on the anode 12, which allows formation of the anode flow path.

[0032] At least one of the flow path plate 14 and the flow path plate 15 preferably has at least one of a land (projection) 141 and a land 151. The land 141 and the land 151 are provided for mechanical retention and electrical continuity. The land 141 is provided in contact with the cathode 11. The land 151 is provided in contact with the anode 12. The land 141 and the land 151 are preferably provided alternately to make a flow of the fluids uniform. With the land 141 and the land 151 provided in this manner, the cathode flow path and the anode flow path each have a shape meandering along the surface.

[0033] The flow path plate 14 and the flow path plate 15 are preferably formed using a material having low chemical reactivity and high conductivity. Examples of such a material include a metal material such as titanium or SUS, a carbon material, or the like. Further, between each of the flow path plates and a member adjacent thereto, a member such as packing whose illustration is omitted may be sandwiched as necessary.

[0034] The current collector 16 is stacked across the flow path plate 14 from the cathode 11, and electrically connected to the cathode 11. The current collector 17 is stacked across the flow path plate 15 from the cathode 12, and electrically connected to the anode 12. The current collector 16 and the current collector 17 are electrically connected to a power supply 40 via, for example, a wiring line or the like. The current collector 16 and the current collector 17 are preferably formed using a material having high conductivity.

[0035] The power supply 40 can supply electric power to the electrolytic unit 10, for example. The power supply 40 is electrically connected to the cathode 11 and the anode 12 via the flow path plate 14, the flow path plate 15, the current collector 16, and the current collector 17, for example. The power supply 40 can feed the electric power for performing the electrolytic reaction such as the oxidation reaction and the reduction reaction to the electrolytic unit 10, and is electrically connected to the cathode 11 and the anode 12. The reduction reaction in the cathode 11 and the oxidation reaction in the anode 12 are performed using electric energy supplied from the power supply 40. The power supply 40 and the current collector 16, and, the power supply 40 and the current collector 17 are each connected therebetween via at least one wiring, for example. The electrochemical reaction device 1 may have an electric device such as an inverter, a converter, or a battery, the electric device being provided on the connection between the electrolytic unit 10 and the power supply 40. A drive system of the electrolytic unit 10 may be a constant-voltage system or may be a constant-current system.

[0036] The power supply 40 may be a common commercial power source, a battery, or the like, or may be a power supply which converts renewable energy into electric energy and supplies it. Examples of these power supplies include a power supply which converts kinetic energy or potential energy such as wind power, water power, geothermal power or tidal power into electric energy, a power supply such as a solar cell having a photoelectric conversion element which converts light energy into electric energy, a power supply such as a fuel cell or a storage battery which converts chemical energy into electric energy, and a power supply such as a device which converts vibrational energy such as sound into electric energy. The photoelectric conversion element has a function of performing charge separation by using light energy of irradiated sunlight or the like. Examples of the photoelectric conversion element include a pin-junction solar cell, a pn-junction solar cell, an amorphous silicon solar cell, a multijunction solar cell, a single crystal silicon solar cell, a polycrystalline silicon solar cell, a dye-sensitized solar cell, an organic thin-film solar cell, and the like. Further, the photoelectric conversion element may be stacked with at least one of the cathode 11 and the anode 12 inside the electrolytic unit 10.

[0037] The electrolysis cell 100 is sandwiched by a pair of non-illustrated support plates, and further fastened by bolts or the like. The membrane electrode assembly MEA included in the electrolysis cell 100, may be horizontally disposed, or may be vertically disposed. For the horizontal disposition of the membrane electrode assembly MEA, one of the cathode 11 and the anode 12 may be disposed over the other.

[0038] The electrolytic unit 10 may have a cell stack formed by stacking a plurality of the electrolysis cells 100, for example. FIG. 3 is a schematic view illustrating another example configuration of the electrolytic unit 10. FIG. 3 illustrates a part of an X-Z cross section including the X axis and the Z axis. The electrolytic unit 10 may have a plurality of the membrane electrode assemblies MEA, the flow path plate 14, the flow path plate 15, the current collector 16, the current collector 17, and a flow path plate 18, as illustrated in FIG. 3. FIG. 3 illustrates a plurality of the cathodes 11, a plurality of the anodes 12, a plurality of the diaphragms 13, a plurality of the cathode chambers 140, and a plurality of the anode chambers 150. The membrane electrode assemblies MEA are provided between the current collector 16 and the current collector 17 to form the cell stack. The formation of the cell stack increases a reaction amount of the reducible material per unit area, which allows an increase in a production amount of the reduction product, for example. The number of the electrolysis cells 100 to be stacked is preferably not less than 10 nor more than 150, for example.

[0039] When the electrolytic unit 10 has the electrolysis cells 100, the cathode supply fluid and the anode supply fluid supplied to each of the cells can be divided from a smaller number of wiring lines than the number of the electrolysis cells 100 to each of the cell. Further, the cathode discharge fluid and the anode discharge fluid discharged from each of the cells can be collected to a smaller number of wiring lines than the number of the electrolysis cells 100. Dividing the cathode supply fluid and the anode supply fluid and the collection of the cathode discharge fluid and the anode discharge fluid may be performed outside the electrolytic unit 10, or may be performed inside the electrolytic unit 10. Here, the inside of the electrolytic unit 10 indicates a part in which the electrolysis cells 100 are sandwiched by a pair of support plates, and further fastened by the bolts or the like.

[0040] The flow path plate 18 is a bipolar plate having the cathode chamber 140 and the anode chamber 150, for example. The flow path plate 18 is provided between the membrane electrode assemblies MEA, and divides the electrolysis cells 100. The cathode 11 and the anode 12 adjacent to the flow path plate 18 may be electrically connected via the flow path plate 18. The electrolysis cells 100 are stacked and sandwiched by a pair of the support plates, and further fastened by the bolts or the like to be fixed. The cell stack may be formed by horizontally or vertically disposing the membrane electrode assemblies MEA. When the membrane electrode assemblies MEA are horizontally disposed, the cathode 11 or the anode 12 may be disposed on the top surface of the cell stack.

[0041] The cathode chamber 140 of the flow path plate 18 is provided on a first surface of the bipolar plate, and faces on the cathode 11 of one of the membrane electrode assemblies MEA, for example. The inlet of the cathode chamber 140 of the flow path plate 18 is connected to the flow path P1. The outlet of the cathode chamber 140 of the flow path plate 18 is connected to the flow path P3.

[0042] The anode chamber 150 of the flow path plate 18 is provided on a second surface of the bipolar plate across the bipolar plate from the first surface of the bipolar plate, and faces on the anode 12 of the other of the membrane electrode assemblies MEA, for example. The inlet of the anode chamber 150 of the flow path plate 18 is connected to the flow path P2. The outlet of the anode chamber 150 of the flow path plate 18 is connected to the flow path P4.

[0043] The cathode supply fluid is a cathode supply gas or a two-phase fluid (a gas-liquid two-phase fluid) of the cathode supply gas and a cathode supply liquid, for example. The cathode supply gas contains at least one gas selected from carbon dioxide, nitrogen, argon, and water vapor, for example. The cathode supply gas may be a mixed gas of at least two gases selected from carbon dioxide, nitrogen, argon, and water vapor. The cathode supply liquid contains water, for example.

[0044] The cathode supply fluid is prepared in the cathode supply part 21, and is supplied to the electrolytic unit 10, for example. The cathode supply part 21 includes a humidifier 201 and a condenser 202. The cathode supply part 21 may include a bypass pipe through which the fluid flows with the fluid bypassing the humidifier 201 and the condenser 202 while the humidifier 201 and the condenser 202 being not used. A system for supplying the cathode supply fluid, which has the cathode supply part 21, may have a gas cylinder, a flow rate control part, a pressure control part, and so on.

[0045] The anode supply fluid contains water, for example. The water may be in a state of liquid water, or in a state of water vapor. When the anode supply fluid does not contain any gas phases, and consists of a liquid phase, this fluid is hereinafter also called an anode aqueous solution. Examples of the anode aqueous solution include an aqueous solution containing any electrolyte. Examples of the aqueous solution containing the electrolyte include an aqueous solution containing at least one selected from hydroxide ions (OH^-), hydrogen ions (H^+), potassium ions (K^+), sodium ions (Na^+), lithium ions (Li^+), chloride ions (Cl^-), bromide ions (Br-), iodide ions (I^-), nitrate ions (NO_3^-), sulfate ions (SO_4^{2-}), phosphate ions (PO_4^{2-}), borate ions (BO_3^{3-}), carbonate ions (CO_3^{2-}), and hydrogen carbonate ions (HCO_3^-). The anode aqueous solution may be made of an alkaline solution having a high concentration of an electrolyte such as a potassium hydroxide or a sodium hydroxide to reduce an electrical resistance of the solution.

[0046] The anode supply fluid is supplied to the electrolytic unit 10 via the anode supply part 22. For example, when the anode supply fluid is the anode aqueous solution, a system for supplying the anode supply fluid supply and adjacent to the inlet of the anode chamber 150, which includes the anode supply part 22, has at least one device selected tom a pressure control part, an anode aqueous solution tank, a flow rate control part (a pump), a reference electrode, a pressure gauge, and a temperature controlling mechanism. The anode aqueous solution is subjected to control of a flow rate, a pressure, and a temperature in the system for supplying the anode supply fluid supply, and supplied to the anode chamber 150.

[0047] The humidifier 201 can humidify the cathode supply fluid supplied from a cathode-supply-fluid supply source for the cathode supply fluid, the cathode-supply-fluid supply source including the gas cylinder, for example. The humidifier 201 is provided in the middle of the flow path P1. The cathode supply fluid is preferably only the gas phase in the previous stage of the humidifier 201. The humidifier 201 can mix water vapor into the cathode supply fluid to be supplied from the previous stage of the humidifier 201. Examples of the humidification method using the humidifier 201, include a method of babbling the gas in liquid water, a method of providing a vaporizer in the flow path of the gas to pour the liquid water into the vaporizer to evaporate the liquid water, and a method of spraying and evaporating the liquid water in the gas, but the humidification method is not limited to these methods.

[0048] The humidifier 201 can preferably control an amount of the water vapor to be mixed into the cathode supply fluid supplied from the previous stage of the humidifier 201. Example methods of regulating the water vapor amount, include a method of specifying a temperature of the liquid water used for the bubbling, a method of specifying a total amount and a rate of the liquid water poured into the vaporizer, and a method of specifying a total amount and a rate of the liquid water discharged from a sprayer, but the method of regulating the water vapor amount is not limited to these methods. The humidified cathode supply fluid to be discharged from the humidifier 201 is preferably only the gas phase, but may contain a liquid phase.

[0049] The condenser 202 is provided in the middle of the flow path P1 and follows the humidifier 201, and partially condenses the water vapor contained in the humidified cathode supply fluid supplied to the condenser 202 to thereby produce condensed water. The condenser 202 can control an amount of the condensed water produced in the humidified cathode supply fluid (a ratio of the condensed water). Example methods of controlling the amount of the condensed water, include a method of controlling a temperature in a processing chamber of the condenser 202, and a method of controlling a pressure in the processing chamber of the condenser 202. The other methods of controlling the amount of the condensed water include a method of specifying a temperature and a heat exchange amount of the cathode supply fluid in the condenser 202, a method of specifying a pressure of the cathode supply fluid in the condenser 202, and the like, but these methods are not limited. The condenser 202 may have a temperature controller.

[0050] An amount of the condensed water produced by the condenser 202 can be preferably quantitatively determined. For this purpose, an amount of the water vapor contained in the cathode supply fluid supplied from the previous stage of the condenser 202 is preferably determined. Example methods of determining the water vapor amount, include a method of installing a dew-point meter directly before the condenser 202. The dew-point meter may be incorporated as a part of the condenser 202. When the condensed water is produced by temperature regulation in particular, making a temperature of the fluid inside the condenser 202 lower than a dew point of the cathode supply fluid in the previous stage of the condenser 202 allows the production of the condensed water.

[0051] FIG. 4 is a schematic sectional view illustrating an example structure of the condenser 202. FIG. 4 illustrates a part of a Y-Z cross section including the Y axis and the Z axis. The condenser 202 may have a heater 2021, a cooler 2022, and a heat insulator 2023, as illustrated in FIG. 4.

[0052] The heater 2021 is provided around a pipe 2020. The heater 2021 is provided between the pipe 2020 and the heat insulator 2023. The condenser 202 may have a plurality of the heaters 2021, as illustrated in FIG. 4. The heaters 2021 are provided along an outer peripheral surface of the pipe 2020, for example.

[0053] The cooler 2022 is provided around the pipe 2020. The cooler 2022 is provided between the pipe 2020 and the heat insulator 2023. The condenser 202 may have a plurality of the coolers 2022, as illustrated in FIG. 4. The coolers 2022 are provided along the outer peripheral surface of the pipe 2020, for example. One of the heaters 2021 and one of the coolers 2022 may be disposed alternately along the outer peripheral surface of the pipe 2020, for example.

[0054] The heat insulator 2023 is provided to cover the pipe 2020, the heaters 2021, and the coolers 2022.

[0055] The pipe 2020 has an inner peripheral surface surrounding a space S through which the cathode supply fluid flows. The pipe 2020 forms the flow path P1. The pipe 2020 is preferably formed using a material having high heat conductivity. The condenser 202 may have a temperature sensor on the inner peripheral surface of the pipe 2020, and the temperature sensor may directly measure a temperature of the cathode supply fluid flowing through the space S.

[0056] Examples of the condenser 202 may include a heat exchanger. The heat exchanger may have the temperature sensor, and the temperature sensor may directly measure the temperature of the cathode supply fluid flowing through the space S.

[0057] an example of the electrochemical reaction device of the arrangement can be operated by supplying the cathode supply fluid to the cathode chamber 140 through the flow path P1, supplying the anode supply fluid to the anode chamber 150 through the flow path P2, supplying current or voltage from the power supply 40 to the electrolysis cell 10, for example, to reduce the reducible material to produce the reduction product in the cathode 11 and to oxidize the oxidizable material to produce the oxidation product in the anode 12 and thus perform the electrolytic reaction. Arrows illustrated in FIG. 1 illustrate directions in which the fluids flow.

[0058] The example of the electrochemical reaction device of the arrangement, has the condenser 202 following the humidifier 201 to enable mixing water into the cathode supply fluid in a simple device configuration without using a complicated piping structure having a switch with a valve such as a multiport valve, and/or an auxiliary machine such as a pump to serve power, for example.

[0059] The supply of the water vapor to the cathode chamber 140 increases a relative humidity of the gas phase in the catalyst layer and the gas diffusion layer of the cathode 11, preventing from the water to evaporate from the liquid phase. Accordingly, this can effectively prevent forming solid salt. However, the water vapor is insufficiently effective in view of a removal of the produced salt. On the other hand, the supply of the liquid water to the cathode chamber 140 causes the liquid water to effectively lower a salt concentration of the liquid phase in the catalyst layer and the gas diffusion layer of the cathode, to enable preventing the production of solid salt. Moreover, the supply of the liquid water to the cathode chamber 140 can effectively dissolve and wash away the solid salt in the cathode chamber 140 through the liquid water. Accordingly, if water to be supplied to the cathode chamber 140 has constant amount, it is more effective in the removal of the salt if the water vapor made from the supplied water is partly condensed and supplied to the cathode chamber 140 rather than all of the water vapor as it is. The example of the electrochemical reaction device of the arrangement, partly condense the water vapor in the cathode supply fluid to mix the liquid water to enable operating the electrochemical reaction device with a high effect of removing the salt. This can provide the electrochemical reaction device having a longer operating life and a simple structure.

[0060] The liquid water may enter into pores of the catalyst layer and the gas diffusion layer of the cathode 11 to block these pores. The blockage of the pores prevents supplying the reactive gas to a reaction field in the cathode catalyst layer to increase the cell resistance and decrease the product selectivity for the objective product. Such a phenomenon is called flooding. Accordingly, an amount of the condensed water produced using the condenser 202, which is an amount of substance and a volume per unit time, or a total production amount obtained by integrating these with a time during which the condensed water is produced, is preferably as small as possible within a range of securing the salt-precipitation inhibition and salt removal effects. Depending on circumstances, under the determination that avoiding the flooding is more important than aiming at the salt-precipitation inhibition and the salt removal, even though the salt-precipitation inhibition and salt removal effects are insufficient, an amount of the produced condensed water is required to be set to be small. A correct value of the amount of the condensed water is different depending on operation conditions of the electrolytic unit 10, properties of members to be used, or the like, and thus the determination on demand is preferable. The determination can be performed based on the result of monitoring a performance index of the electrolytic unit 10 during the operation. The determination may be performed by an operator of the electrolytic unit 10, or may be performed using algorithm implemented in a computer.

[0061] FIG. 5 is a schematic diagram illustrating another example configuration of the electrochemical reaction device of the arrangement. The cathode supply part 21 may have a plurality of the condensers 202, as illustrated in FIG. 5. For example, when the electrolytic unit 10 has the electrolysis cells 100, the number of the condensers 202 may be the same as the number of the electrolysis cells 100, or, may be larger or smaller than the number of the electrolysis cells 100. Further, the cathode supply part 21 may have a plurality of the humidifiers 201. The number of the humidifiers 201 may be the same as the number of the condensers 202, or, may be larger or smaller than the number of the condensers 202. Setting the number of the condensers 202 to be equal to or less than the number of the electrolysis cells 100 and setting the number of the humidifiers 201 to be equal to or less than the number of the condensers 202 allow the electrochemical reaction device to be made smaller.

[0062] When the electrolysis cells 100 share (use) the humidifier 201 and the condenser 202, the cathode supply fluid is to be shared (divided) among the electrolysis cells 100 for supplying the cathode supply fluid to the electrolysis cells 100. The cathode supply fluid may be divided at the previous stage of the humidifier 201, at the connection between the humidifier 201 and the condenser 202, or at the connection between the condenser 202 and the electrolysis cells 100.

[0063] When the electrolytic reaction using the reactant gas is performed in the cathodes 11 of the electrolysis cells 100, the flow path P1 is preferably designed so that the gas in the cathode supply fluid is appropriately divided to the electrolysis cells 100. The appropriately dividing indicates that the gas is evenly divided to all the electrolysis cells 100, for example, but is not limited to this indication. On the other hand, the flow path P1 designed considering such the gas dividing, may inappropriately divide the liquid to the electrolysis cells 100. Accordingly, dividing the cathode supply fluid in the subsequent stage of the condenser 202 may unbalance a ratio of the produced condensed water to the gas. Dividing the gas to the electrolysis cells 100 in the previous stage of the condenser 202, a stage in which the cathode supply fluid is mainly composed of the gas phase, and producing the condensed water by using the condenser 202 after the dividing allow appropriate supply of the condensed water to the electrolysis cells 100.

[0064] FIG. 6 is a schematic diagram illustrating another example configuration of the electrochemical reaction device of the arrangement. The condensers 202 may be provided in not the cathode supply part 21 but in the electrolytic unit 10 as illustrated in FIG. 6. When the condenser 202 is provided for each of the electrolysis cells 100, the condensers 202 are suitably provided in the electrolytic unit 10. When the electrolytic unit 10 has the electrolysis cells 100, the number of the condensers 202 may be the same as the number of the electrolysis cells 100, or, may be larger or smaller than the number of the electrolysis cells 100. Further, the cathode supply part 21 may have the humidifiers 201. The number of the humidifiers 201 may be the same as the number of the condensers 202, or, may be larger or smaller than the number of the condensers 202. Setting the number of the condensers 202 to be equal to or less than the number of the electrolysis cells 100 and setting the number of the humidifiers 201 to be equal to or less than the number of the condensers 202 allow the electrochemical reaction device to be made smaller. When the condensers 202 are provided in the electrolytic unit 10, the cathode supply fluid is to be divided for supplying the cathode supply fluid to the electrolysis cells 100, similarly to the example configuration illustrated in FIG. 5.

[0065] FIG. 7 is a schematic sectional view illustrating the example configuration of the electrolytic unit 10 illustrated in FIG. 6. FIG. 7 illustrates a part of an X-Z cross section. The electrolytic unit 10 has a first region forming the cell stack including the electrolysis cells 100, and a second region forming the condenser 202, as illustrated in FIG. 7. The second region is disposed adjacently to the first region. The first region can be heated and cooled. The second region may also be heated and cooled, and in this case, a temperature in the second region is controlled independently of a temperature in the first region. The current or the voltage from power supply 40 is supplied to only the first region. The first region and the second region may be fastened by a pair of the support plates, for example. The first region and the second region are provided in the electrolytic unit 10.

[0066] The cell stack having the electrolysis cells 100 illustrated in FIG. 7 has the membrane electrode assemblies MEA, the flow path plate 14, the flow path plate 15, the current collector 16, the current collector 17, and the flow path plate 18. For the other description of the electrolysis cell 100, the description of the electrolysis cell 100 illustrated in FIG. 3 can be referred to as required.

[0067] The condenser 202 illustrated in FIG. 7 has an auxiliary flow path plate 221, an auxiliary flow path plate 222, an auxiliary flow path plate 223, auxiliary plates 224, an auxiliary plate 225, and an auxiliary plate 226.

[0068] FIG. 8, FIG. 9, and FIG. 10 are each a schematic view illustrating an example structure of the auxiliary flow path plate 221. FIG. 8 is a schematic X-Y plan view of the auxiliary flow path plate 221 when viewed from above. FIG. 9 is a schematic X-Z sectional view of the auxiliary flow path plate 221. FIG. 10 is a schematic X-Y plan view of the auxiliary flow path plate 221 when viewed from below.

[0069] The auxiliary flow path plate 221 is a cathode auxiliary flow path plate having a flow path 227. The flow path 227 is a cathode auxiliary flow path, and is connected to the cathode flow path defined by the cathode chamber 140. The auxiliary flow path plate 221 may be disposed to extend from a side surface of the flow path plate 14, for example.

[0070] FIG. 11, FIG. 12, and FIG. 13 are each a schematic view illustrating an example structure of the auxiliary flow path plate 222. FIG. 11 is a schematic X-Y plan view of the auxiliary flow path plate 222 when viewed from above. FIG. 12 is a schematic X-Z sectional view of the auxiliary flow path plate 222. FIG. 13 is a schematic X-Y plan view of the auxiliary flow path plate 222 when viewed from below.

[0071] The auxiliary flow path plate 222 is an anode auxiliary flow path plate having a flow path 228. The flow path 228 is an anode auxiliary flow path, and is connected to the anode flow path defined by the anode chamber 150. The auxiliary flow path plate 222 may be disposed to extend from a side surface of the flow path plate 15, for example.

[0072] FIG. 14, FIG. 15, and FIG. 16 are each a schematic view illustrating an example structure of the auxiliary flow path plate 223. FIG. 14 is a schematic X-Y plan view of the auxiliary flow path plate 223 when viewed from above. FIG. 15 is a schematic X-Z sectional view of the auxiliary flow path plate 223. FIG. 16 is a schematic X-Y plan view of the auxiliary flow path plate 223 when viewed from below.

[0073] The auxiliary flow path plate 223 is an inter-cell auxiliary flow path plate provided between the auxiliary flow path plate 221 and the auxiliary flow path plate 222, for example. The auxiliary flow path plate 223 has the flow path 227 and the flow path 228. The flow path 227 is the cathode auxiliary flow path, and is connected to the cathode flow path defined by the cathode chamber 140 of the flow path plate 18. The flow path 228 is the anode auxiliary flow path, and is connected to the anode flow path defined by the anode chamber 150 of the flow path plate 18. The auxiliary flow path plate 223 may be disposed to extend from a side surface of the flow path plate 18, for example.

[0074] The auxiliary plate 224 is provided between the auxiliary flow path plate 221 and the auxiliary flow path plate 223 or between the auxiliary flow path plate 222 and the auxiliary flow path plate 223. FIG. 7 illustrates a plurality of the auxiliary plates 224 provided between the auxiliary flow path plate 221 and the auxiliary flow path plate 223 and between the auxiliary flow path plate 222 and the auxiliary flow path plate 223. The auxiliary plates 224 may each be disposed to extend from a side surface of the membrane electrode assembly MEA, for example.

[0075] The auxiliary plate 225 is provided across the auxiliary flow path plate 221 from the auxiliary flow path plate 223, for example. The auxiliary plate 225 is provided on an end portion of the condenser 202. The auxiliary plate 225 may be disposed to extend from a side surface of the current collector 16, for example.

[0076] The auxiliary plate 226 is provided across the auxiliary flow path plate 222 from the auxiliary flow path plate 223, for example. The auxiliary plate 226 is provided on an end portion of the condenser 202. The auxiliary plate 226 may be disposed to extend from a side surface of the current collector 17, for example.

[0077] Heating and cooling the second region forming the condenser 202 allow the condensation of the cathode supply fluid flowing through the cathode auxiliary flow path. This allows the cathode auxiliary flow path connected to the electrolysis cells 100 to function as the condenser.

[0078] A method of heating and cooling the second region includes, for example, a method of providing the heater 2021 and the cooler 2022 for the auxiliary plate 225 and the auxiliary plate 226, a method of providing the heater 2021 and the cooler 2022 for the auxiliary flow path plate 221, the auxiliary flow path plate 222, and the auxiliary flow path plate 223, a method of providing a sub-flow path through which a heat exchange fluid passes for the auxiliary flow path plate 221, the auxiliary flow path plate 222, and the auxiliary flow path plate 223, and the like, but is not limited to these methods.

[0079] FIG. 17 is a schematic view illustrating the other example structure of the auxiliary flow path plate 222. FIG. 17 is a schematic X-Y plan view of the auxiliary flow path plate 222 when viewed from above.

[0080] FIG. 18 is a schematic view illustrating the other example structure of the auxiliary flow path plate 223. FIG. 18 is a schematic X-Y plan view of the auxiliary flow path plate 223 when viewed from above.

[0081] As illustrated in FIG. 17 and FIG. 18, the auxiliary flow path plate 222 and the auxiliary flow path plate 223 may each have a sub-flow path 229. When the sub-flow path 229 is provided, the sub-flow path 229 is preferably not connected to the flow path 227 and the flow path 228. The sub-flow path 229 is formed on a surface on which the flow path 228 of the auxiliary flow path plate 222 is formed, or a surface on which the flow path 228 of the auxiliary flow path plate 223 is formed (a surface of the auxiliary flow path plate 223 across the auxiliary flow path plate 223 from the flow path 227), for example. The heat exchange fluid having a controlled temperature is flowed through the sub-flow path 229 to enable controlling the temperature of the second region to give a function of the condenser 202 to the flow path 227.

[0082] All elements of the condenser 202 may be formed using at least one insulator. As long as the insulation between the first region and the second region is secured, at least a part of the elements in the condenser 202 may be formed by at least one conductive material. The elements of the condenser 202 are preferably formed using at least one material having high heat conductivity. This promotes heat conduction in the second region, which allows accurate regulation of a temperature in the flow path 227 functioning as the condenser 202.

[0083] A thickness of the auxiliary flow path plate 221 is preferably the same as a thickness of the flow path plate 14. A thickness of the auxiliary flow path plate 222 is preferably the same as a thickness of the flow path plate 15. A thickness of the auxiliary flow path plate 223 is preferably the same as a thickness of the flow path plate 18. A thickness of the auxiliary plate 225 is preferably the same as a thickness of the current collector 16. A thickness of the auxiliary plate 226 is preferably the same as a thickness of the current collector 17. Further, compression ratios among the members when they are fastened by a pair of non-illustrated support plates are also further preferably almost the same. The auxiliary plate 224 and the auxiliary flow path plate MEA may differ in the compression ratio, but a thickness of the auxiliary plate 224 when it is fastened by a pair of support plates, which is not illustrated, is preferably the same as a thickness of the membrane electrode assembly MEA when it is fastened by a pair of non-illustrated support plates. The auxiliary flow path plate 221 may be made to adhere to the flow path plate 14 in advance. The auxiliary flow path plate 222 may be made to adhere to the flow path plate 15 in advance. The auxiliary flow path plate 223 may be made to adhere to the flow path plate 18 in advance. The auxiliary plate 225 may be made to adhere to the current collector 16 in advance. The auxiliary plate 226 may be made to adhere to the current collector 17 in advance. Further, in place of the auxiliary plate 224, the membrane electrode assembly MEA may be formed to extend from the first region to the second region.

[0084] The cathode supply part 21 may be provided with the humidifier 201 and the condenser 202 in the electrolytic unit 10. FIG. 19 is a schematic sectional view illustrating the other example configuration of the electrolytic unit 10. The electrolytic unit 10 has the first region forming the cell stack including the electrolysis cells 100, the second region forming the condenser 202, and a third region forming humidifier 201, as illustrated in FIG. 19. The second region is provided to precede the first region, and disposed adjacently to the first region. The third region is provided to precede the second region, and disposed adjacently to the second region. The first region can be heated and cooled. The second region and the third region may also be heated and cooled, and in this case, a temperature in the second region and a temperature in the third region are controlled independently of the temperature in the first region. The current or the voltage from power supply 40 is supplied to only the first region. The first region, the second region, and the third region may be fastened by a pair of the support plates, for example. The first region, the second region, and the third region are provided in the electrolytic unit 10.

[0085] The cell stack including the electrolysis cells 100 illustrated in FIG. 19 has the membrane electrode assemblies MEA, the flow path plate 14, the flow path plate 15, the current collector 16, the current collector 17, and the flow path plate 18. For the other description of the electrolysis cell 100, the description of the electrolysis cell 100 illustrated in FIG. 3 and FIG. 7 can be referred to as required.

[0086] The condenser 202 illustrated in FIG. 19 has the auxiliary flow path plate 221, the auxiliary flow path plate 222, the auxiliary flow path plate 223, the auxiliary plates 224, the auxiliary plate 225, and the auxiliary plate 226. For the other description of the condenser 202, the description of FIG. 7 to FIG. 18 can be referred to as required.

[0087] The humidifier 201 illustrated in FIG. 19 has an auxiliary flow path plate 211, an auxiliary flow path plate 212, an auxiliary flow path plate 213, humidifying membranes 214, an auxiliary plate 215, and an auxiliary plate 216. For the other description of the humidifier 201, the description of the humidifier 201 illustrated in FIG. 1 can be referred to as required.

[0088] FIG. 20, FIG. 21, and FIG. 22 are each a schematic view illustrating an example structure of the auxiliary flow path plate 211. FIG. 20 is a schematic X-Y plan view of the auxiliary flow path plate 211 when viewed from above. FIG. 21 is a schematic X-Z sectional view of the auxiliary flow path plate 211. FIG. 22 is a schematic X-Y plan view of the auxiliary flow path plate 211 when viewed from below.

[0089] The auxiliary flow path plate 211 is a cathode auxiliary flow path plate having a flow path 217. The flow path 217 is a cathode auxiliary flow path, and is connected to the flow path 227 and connected via the flow path 227 to the cathode flow path defined by the cathode chamber 140. The auxiliary flow path plate 211 may be disposed to extend from a side surface of the auxiliary flow path plate 221, for example.

[0090] FIG. 23, FIG. 24, and FIG. 25 are each a schematic view illustrating an example structure of the auxiliary flow path plate 212. FIG. 23 is a schematic X-Y plan view of the auxiliary flow path plate 212 when viewed from above. FIG. 24 is a schematic X-Z sectional view of the auxiliary flow path plate 212. FIG. 25 is a schematic X-Y plan view of the auxiliary flow path plate 212 when viewed from below.

[0091] The auxiliary flow path plate 212 is an anode auxiliary flow path plate having a flow path 218. The flow path 218 is an anode auxiliary flow path, and is connected to the flow path 228 and connected via the flow path 228 to the anode flow path defined by the anode chamber 150. The auxiliary flow path plate 212 may be disposed to extend from a side surface of the auxiliary flow path plate 222, for example.

[0092] FIG. 26, FIG. 27, and FIG. 28 are each a schematic view illustrating an example structure of the auxiliary flow path plate 213. FIG. 26 is a schematic X-Y plan view of the auxiliary flow path plate 213 when viewed from above. FIG. 27 is a schematic X-Z sectional view of the auxiliary flow path plate 213. FIG. 28 is a schematic X-Y plan view of the auxiliary flow path plate 213 when viewed from below.

[0093] The auxiliary flow path plate 213 is an inter-cell auxiliary flow path plate provided between the auxiliary flow path plate 211 and the auxiliary flow path plate 212, for example. The auxiliary flow path plate 213 has the flow path 217 and the flow path 218. The flow path 217 is the cathode auxiliary flow path, and is connected to the flow path 227 of the auxiliary flow path plate 223 and connected via the flow path 227 to the cathode flow path defined by the cathode chamber 140 of the flow path plate 18. The flow path 218 is the anode auxiliary flow path, and is connected to the flow path 228 of the auxiliary flow path plate 223 and connected via the flow path 228 to the anode flow path defined by the anode chamber 150 of the flow path plate 18. The auxiliary flow path plate 213 may be disposed to extend from a side surface of the auxiliary flow path plate 223, for example.

[0094] The humidifying membrane 214 is provided between the auxiliary flow path plate 211 and the auxiliary flow path plate 213 or between the auxiliary flow path plate 212 and the auxiliary flow path plate 213. FIG. 19 illustrates a plurality of the humidifying membranes 214 provided between the auxiliary flow path plate 211 and the auxiliary flow path plate 213 and between the auxiliary flow path plate 212 and the auxiliary flow path plate 213. The humidifying membranes 214 may each be disposed to extend from a side surface of each of the auxiliary plates 224, for example. Examples of each of the humidifying membranes 214 include a water repellent porous membrane. The water repellent porous membrane may have a contact angle of not less than 45 degrees nor more than 90 degrees to water, for example.

[0095] The flow path 217 and the flow path 218 face on each other with the humidifying membrane 214 therebetween, and an auxiliary flow path is formed so that shapes of these flow paths fit each other. This causes water in the anode supply fluid flowing through the flow path 218 to be supplied to the cathode supply fluid flowing through the flow path 217 via the humidifying membrane 214, which allowing the third region to function as the humidifier 201.

[0096] The auxiliary plate 215 is provided across the auxiliary flow path plate 211 from the auxiliary flow path plate 213, for example. The auxiliary plate 215 is provided on an end portion of the humidifier 201. The auxiliary plate 215 may be disposed to extend from a side surface of the auxiliary plate 225, for example.

[0097] The auxiliary plate 216 is provided across the auxiliary flow path plate 212 from the auxiliary flow path plate 213, for example. The auxiliary plate 216 is provided on an end portion of the humidifier 201. The auxiliary plate 216 may be disposed to extend from a side surface of the auxiliary plate 226, for example.

[0098] The elements of the humidifier 201 are preferably formed using at least one material having high heat conductivity. This promotes heat conduction in the third region, which allows accurate regulation of a temperature in the region functioning as the humidifier 201.

[0099] A thickness of the auxiliary flow path plate 211 is preferably the same as each of the thickness of the flow path plate 14 and the thickness of the auxiliary flow path plate 221. A thickness of the auxiliary flow path plate 212 is preferably the same as each of the thickness of the flow path plate 15 and the thickness of the auxiliary flow path plate 222. A thickness of the auxiliary flow path plate 213 is preferably the same as each of the thickness of the flow path plate 18 and the thickness of the auxiliary flow path plate 223. A thickness of the auxiliary plate 215 is preferably the same as each of the thickness of the current collector 16 and the thickness of the auxiliary plate 225. A thickness of the auxiliary plate 216 is preferably the same as each of the thickness of the current collector 17 and the thickness of the auxiliary plate 226. Further, compression ratios among the members when they are fastened by a pair of non-illustrated support plates are also further preferably almost the same. The humidifying membrane 214, the auxiliary plate 224 and the auxiliary flow path plate MEA may differ in the compression ratio, but a thickness of the humidifying membrane 214 when it is fastened by a pair of the non-illustrated support plates is preferably the same as each of the thickness of the membrane electrode assembly MEA and the thickness of the auxiliary plate 224 when they are fastened by a pair of the non-illustrated support plates. The auxiliary flow path plate 211 may be made to adhere to the auxiliary flow path plate 221 in advance. The auxiliary flow path plate 212 may be made to adhere to the auxiliary flow path plate 222 in advance. The auxiliary flow path plate 213 may be made to adhere to the auxiliary flow path plate 223 in advance. The auxiliary plate 215 may be made to adhere to the auxiliary plate 225 in advance. The auxiliary plate 216 may be made to adhere to the auxiliary plate 226 in advance.

[0100] FIG. 19 demonstrates a method of using the anode supply fluid flowing through the flow path 218 as a humidifying water vapor source, and a sub-flow path may be formed in the auxiliary flow path plate 212 or the auxiliary flow path plate 213 to make liquid mainly composed of other water flow through the sub-flow path, resulting in that the liquid serves as the humidifying water vapor source.

[0101] FIG. 29 is a schematic view illustrating the other example structure of the auxiliary flow path plate 212. FIG. 29 is a schematic X-Y plan view of the auxiliary flow path plate 212 when viewed from above.

[0102] FIG. 30 is a schematic view illustrating the other example structure of the auxiliary flow path plate 213. FIG. 30 is a schematic X-Y plan view of the auxiliary flow path plate 213 when viewed from above.

[0103] As illustrated in FIG. 29 and FIG. 30, the auxiliary flow path plate 212 and the auxiliary flow path plate

213 may each have a sub-flow path 219. When the sub-flow path 219 is provided, the sub-flow path 219 is preferably not connected to the flow path 217 and the flow path 218. The sub-flow path 219 is formed on a surface on which the flow path 218 of the auxiliary flow path plate 212 is formed, or a surface on which the flow path 218 of the auxiliary flow path plate 213 is formed (a surface of the auxiliary flow path plate 213 across the auxiliary flow path plate 213 from the flow path 217), for example. The sub-flow path 219 is designed to fit the facing flow path 217 with the humidifier 214 sandwiched in a flow path shape as much as possible. Using cooling water used inside the electrochemical reaction device as the humidifying water vapor source, or the like results in making the device simpler, but due to the need for allowing the independent temperature regulation between the first region, the second region, and the third region, the cooling water in the second region is preferably not used as the humidifying water vapor source in the third region.

[0104] FIG. 31 is a schematic diagram illustrating another example configuration of the electrochemical reaction device of the arrangement. The electrochemical reaction device 1 may have a liquid removal unit 203 connected to the flow path P1 and provided in the previous stage of the humidifier 201, as illustrated in FIG. 31. The liquid removal unit 203 can remove liquid contained in the cathode supply fluid supplied to the humidifier 201. The liquid removal unit 203 may have a bottle which traps the liquid from the cathode supply fluid flowing through the flow path P1, for example, and trap the liquid in the bottle by, for example, gravity by providing the bottle under flow path P1. The liquid removal unit 203 may have a gas/liquid separator in the middle of the flow path P1. The liquid removal unit 203 may be provided in another position as long as it is connected to the flow path P1 in the cathode supply part 21. When the cathode supply fluid in the previous stage of the humidifier 201 forms a gas-liquid two-phase flow for the reason of connecting the electrochemical reaction device to another device, or the like, providing the liquid removal unit 203 allows the cathode supply fluid supplied to the humidifier 201 to be subjected to a removal of the liquid therefrom and to have only the gas phase, which facilitates control of the water vapor content in the humidified cathode supply fluid. The liquid removal unit 203 may be provided on the connection between the humidifier 201 and the condenser 202 or in the subsequent stage of the condenser 202. This allows the cathode supply fluid supplied to the electrolytic unit 10 to be subjected to the removal of the liquid therefrom and to have only the gas phase when, for example, mixing of unintended liquid water occurs due to trouble of the humidifier 201 or the condenser 202.

[0105] The cathode supply part 21 may have a liquid supply unit 204. This means that the condenser 202 can be used with a conventionally-known method of supplying a rinse material from an external system. The liquid supply unit 204 is connected to the flow path P1, and for example, provided in the subsequent stage of the condenser 202. The liquid supply unit 204 has a syringe pump, for example. The condenser 202 cannot produce a larger amount of liquid water than an amount of water vapor mixed by the humidifier 201. Accordingly, for example, mixing the liquid water into the cathode supply fluid from the external system by using the liquid supply unit 204 allows supply of a large amount of the liquid water.

[0106] The liquid supply method of using the condenser 202 is suitable for continuously supplying the liquid water little by little. Accordingly, the method of using the condenser 202 is well suited to such purposes as prevention of the salt precipitation and inhibition of growth of salt by removing the salt while the produced salt is small in size. On the other hand, the supply of liquid from the external system by using the liquid supply unit 204 is suitable for supplying a large amount of the liquid water at a time. For the purpose of removing large-grown salt in a short time, the mixing of the liquid water from the external system by using the liquid supply unit 204 is well suited.

[0107] The electrochemical reaction device of the arrangement may have at least one detector and a controller. Examples of the detector include a thermometer, a pressure gauge, a dew-point meter, an ammeter, a voltmeter, a gas flowmeter, a gas composition analyzer, and so on, but these detectors are not limited. FIG. 32 is a schematic diagram illustrating the other example configuration of the electrochemical reaction device of the arrangement. The electrochemical reaction device 1 may further have a detector D1, a detector D2, a detector D3, and a controller 30, as illustrated in FIG. 32.

[0108] The detector D1 is in the middle of the flow path P1, and is provided, for example, between the humidifier 201 and the condenser 202. The detector D 1 can detect at least one parameter of the humidified cathode supply fluid from the humidifier 201, for example. Examples of at least one parameter include a temperature, a pressure, a dew point, a current, a voltage, a flow rate, composition, and so on. Examples of the detector D 1 include the thermometer, the pressure gauge, the dew-point meter, the ammeter, the voltmeter, the gas flowmeter, the gas composition analyzer, and so on, but these detectors are not limited.

[0109] The detector D2 is in the middle of the flow path P1, and is provided, for example, between the condenser 202 and the electrolytic unit 10. The detector D2 can detect at least one parameter of the cathode supply fluid containing the condensed water from the condenser 202, for example. Examples of at least one parameter include a temperature, a pressure, a dew point, a current, a voltage, a flow rate, composition, and so on. Examples of the detector D2 include the thermometer, the pressure gauge, the dew-point meter, the ammeter, the voltmeter, the gas flowmeter, the gas composition analyzer, and so on, but these detectors are not limited.

[0110] The detector D3 is in the middle of the flow path P3, and is provided, for example, in the subsequent stage of the electrolytic unit 10. The detector D3 can detect at least one parameter of the cathode discharge fluid from the electrolytic unit 10, for example. Examples of at least one parameter include a temperature, a pressure, a dew point, a current, a voltage, a flow rate, composition, and so on. Examples of the detector D3 include the thermometer, the pressure gauge, the dew-point meter, the ammeter, the voltmeter, a flowmeter, a composition analyzer, and so on, but these detectors are not limited.

[0111] The electrochemical reaction device 1 may have the detector in at least one of the humidifier 201, the condenser 202, and the electrolytic unit 10 or in the middle of the flow path P2 or the flow path P4. These detectors can detect at least one parameter related to operating conditions of at least one of the humidifier 201, the condenser 202, and the electrolytic unit 10 and at least one parameter related to states of the cathode supply fluid, the cathode discharge fluid, the anode supply fluid, and the anode discharge fluid flowing through any of the above-described components, for example. Examples of at least one parameter of these include a temperature, a pressure, a dew point, a current, a voltage, a flow rate, composition, and so on. Examples of these detectors include the thermometer, the pressure gauge, the dew-point meter, the ammeter, the voltmeter, the flowmeter, the composition analyzer, and so on, but these detectors are not limited. These parameters are each sent to a receiving unit 31 as a detection signal (data signal).

[0112] The controller 30 includes the receiving unit 31 which receives the detection signal from at least one detector provided in at least one of the detector D1, the detector D2, the detector D3, the humidifier 201, the condenser 202, and the electrolytic unit 10, a processing unit 32 which performs arithmetic processing based on the detection signal, and a controlling unit 33 which generates control signals to control operations of the humidifier 201 and the condenser 202 based on results of the arithmetic processing. The controller 30 may be configured using hardware using a processor or the like, for example. Note that each operation may be stored as an operation program in a computer-readable storage medium such as a memory, and executed by appropriately reading the operation program stored in the storage medium by the hardware.

[0113] As previously described, the effects in which mixing the liquid water in the cathode supply fluid inhibits the precipitation of salt in the cathode chamber 140, the cathode catalyst layer, the cathode gas diffusion layer, and the like of the cathode 11 of the electrolytic unit 10, and prevents the growth of salt by removing the precipitated salt can be promising. On the other hand, the liquid water prevents the gas which is the reactant from being supplied to the reaction field in the cathode catalyst layer to cause the increase in cell resistance or the decrease in product selectivity for the objective product (flooding). Accordingly, the amount of the condensed water produced using the condenser 202, for example, the amount of substance and the volume per unit time, or the total production amount obtained by integrating these with the time during which the condensed water is produced is preferably determined in consideration of a balance between the salt-precipitation inhibition effect and the salt removal effect, and, performance degradation due to the flooding. Consequently, the control of the humidifier 201 and the condenser 202 are preferably performed based on the result of monitoring a salt-precipitate state and a performance index of the electrolytic unit 10 during operation using the controller 30.

[0114] The receiving unit 31 receives the detection signal from at least one detector provided in at least one of the detectors D 1, D2, and D3, the humidifier 201, the condenser 202, and the electrolytic unit 10 to transmit it to the processing unit 32. The processing unit 32 includes, for example, the computer implemented with calculation algorithm. The processing unit 32 performs the arithmetic processing (calculation) based on information on the received detection signal, and determines how the humidifier 201 and the condenser 202 are operated. Then, determination results thereof are transmitted to the controlling unit 33. The controlling unit 33 transmits control signals to the humidifier 201 and the condenser 202 based on the determination results (arithmetic results) received from the processing unit 32 to control them to be in desired operating conditions.

[0115] A humidification amount in the humidifier 201 can be controlled based on information on a temperature and a pressure inside the humidifier 201 or dew points in front of and behind the humidifier 201. A production amount of the condensed water in the condenser 202 can be controlled based on information on a temperature and a pressure inside the condenser 202 or dew points in front of and behind the condenser 202. As an index for examining the salt-precipitation inhibition effect and the salt removal effect, for example, a pressure loss of a cathode system including the cathode 11 and the cathode chamber 140 can be used. The pressure loss is defined as a difference between fluid pressures measured at an inlet and an outlet of the electrolysis cell 100. The precipitation of salt in the cathode flow path, the cathode catalyst layer, the cathode gas diffusion layer, and the like increases the pressure loss of the cathode system. By monitoring the pressure loss, a state of salt inside the cell stack can be indirectly grasped.

[0116] As an index of determination of the presence/absence of the flooding, a voltage of the electrolysis cell 100, product selectivity at a cathode outlet, or the like can be cited. The voltage of the electrolysis cell 100 can be measured by installing the voltmeter in the electrolysis cell 100. The product selectivity can calculated based on the result of providing the gas composition analyzer in a gas pipe and measuring composition after gas/liquid separation of the cathode discharge fluid when the product is a gas. As the gas composition analyzer, a gas chromatograph, or various-system sensors can be used. Faraday efficiency may be used as an index. The Faraday efficiency can be found from the product selectivity, the gas flow rate, and the current.

[0117] Based on the above, the control of the humidifier 201 and the condenser 202 can be performed as an example thereof as follows, for example. To avoid the flooding, first, the operation is performed in a state of producing no condensed water or a state of producing a small amount thereof in the condenser 202. Thereafter, when the pressure loss of the cathode system of the electrolysis cell 100 rises, the processing unit 32 determines a required amount of the condensed water to need to be added to the cathode supply fluid as the rinse material based on information thereon. Then, with an increase in humidification amount in the humidifier 201, the condenser 202 is controlled to produce more condensed water than condensed water previous thereto in the condenser 202. When the humidifier 201 has a method of varying the humidification amount by temperature regulation, the control signal for increasing the temperature of the humidifier 201 is sent from the controlling unit 33. When the condenser 202 has a method of varying the humidification amount by the temperature regulation, the control signal for decreasing the temperature of the condenser 202 is sent from the controlling unit 33. The cathode pressure loss is continuously monitored, and at the time of an decrease in pressure loss, the humidification amount is decreased to decrease the production amount of the condensed water. The condensed water may be completely eliminated. During this time, information on the voltage of the electrolysis cell 100 and the selectivity of the product is also acquired, and also when such a sign of the flooding as a rise in the voltage and a decrease in the selectivity is observed, the humidification amount is decreased to decrease the production amount of the condensed water. The condensed water may be completely eliminated. Even when the sign of the flooding is observed, thereafter decreasing or eliminating the condensed water allows the liquid water accumulated in the vicinity of the cathode 11 to be expelled outside the cell stack. This allows a disappearance of the flooding.

[0118] For the purpose of preventing the salt precipitation from occurring, even when such a sign of the salt precipitation as the increase in pressure loss of the cathode system is not observed, the condensed water may be regularly produced. The condensed water may be intermittently produced or may be continuously produced.

[0119] The calculation algorithm implemented in the processing unit 32 can be created based on the finding of a preliminary experiment or the like. Further, the algorithm may be updated according to stored operation data as is a machine learning model.

[0120] The components of the electrochemical reaction device described with reference to FIG. 1 to FIG. 32 can be appropriately combined.

[0121] The configurations of the arrangements are applicable in combination with each other, and parts thereof are also replaceable. While certain arrangements of the present invention have been described above, these arrangements have been presented by way of example only, and are not intended to limit the scope of the invention. Indeed the novel arrangements described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions, and changes in the form of the arrangements described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

[0122] The arrangements can be summarized into the following clauses.

(Clause 1) An electrochemical reaction device comprising:

an electrolytic unit comprising a cathode, an anode, a diaphragm between the cathode and the anode, a cathode chamber facing on the cathode, and an anode chamber facing on the anode;

a first flow path through which a first fluid flows, the first flow path being connected to an inlet of the cathode chamber, and the first fluid containing a reducible material to be supplied to the cathode chamber;

a second flow path through which a second fluid flows, the second flow path being connected to an inlet of the anode chamber, and the second fluid containing an oxidizable material to be supplied to the anode chamber;

a third flow path through which a third fluid flows, the third flow path being connected to an outlet of the cathode chamber, the third fluid being discharged from the cathode chamber, and the third fluid containing a reduction product;

a fourth flow path through which a fourth fluid flows, the fourth flow path being connected to an outlet of the anode chamber, the fourth fluid being discharged from the anode chamber, and the fourth fluid containing an oxidation product;

a humidifier provided in the middle of the first flow path and configured to humidify the first fluid; and

a condenser provided in the middle of the first flow path so as to follow the humidifier, the condenser being configured to treat the humidified first fluid and thus condense a part of water vapor in the humidified first fluid to produce a condensed water, and to control a ratio of the condensed water in the humidified first fluid.

(Clause 2) The electrochemical reaction device according to clause 1, wherein

the condenser has a temperature controller.

(Clause 3) The electrochemical reaction device according to clause 2, wherein the condenser is configured to treat the first fluid so that a temperature of the treated first fluid to be discharged from the condenser is lower than a dew point of the humidified first fluid supplied to the condenser.

(Clause 4) The electrochemical reaction device according to any one of clause 1 to clause 3, comprising a plurality of the condensers.

(Clause 5) The electrochemical reaction device according to any one of clause 1 to clause 4, wherein the electrolytic unit has the condenser.

(Clause 6) The electrochemical reaction device according to any one of clause 1 to clause 5, further including

a liquid supply unit configured to supply a liquid containing water to the first flow path.

(Clause 7) The electrochemical reaction device according to any one of clause 1 to clause 6, further comprising

a liquid removal unit configured to remove a liquid from the first fluid.

(Clause 8) The electrochemical reaction device according to any one of clause 1 to clause 7, further comprising

a controller configured to control the humidifier and the condenser.

(Clause 9) The electrochemical reaction device according to clause 8, comprising

> at least one detector configured to detect at least one parameter of at least one element selected from the consisting of the humidifier, the condenser, the electrolytic unit, the first flow path, the second flow path, the third flow path, the fourth flow path, the first fluid, the second fluid, the third fluid, and the fourth fluid, wherein
> the controller comprises:
>
> > a receiving unit configured to receive a detection signal from the at least one detector;
> > a processing unit configured to perform arithmetic processing depending on the detection signal; and
> > a controlling unit configured to control at least one of the humidifier and the condenser in response to a result of the arithmetic processing.

(Clause 10) The electrochemical reaction device according to clause 9, wherein

the at least one detector is selected from the group consisting of a thermometer, a pressure gauge, a dew-point meter, an ammeter, a voltmeter, a gas flowmeter, and a gas composition analyzer.

(Clause 11) A method of operating an electrochemical reaction device,

the device comprising:

> an electrolytic unit comprising a cathode, an anode, a diaphragm between the cathode and the anode, a cathode chamber facing on the cathode, and an anode chamber facing on the anode;
> a first flow path through which a first fluid flows, the first flow path being connected to an inlet of the cathode chamber, and the first fluid containing a reducible material to be supplied to the cathode chamber;
> a second flow path through which a second fluid flows, the second flow path connected to being an inlet of the anode chamber, and the second fluid containing an oxidizable material to be supplied to the anode chamber;
> a third flow path through which a third fluid flows, the third flow path being connected to an outlet of the cathode chamber, the third fluid being discharged from the cathode chamber, and the third fluid containing a reduction product; and
> a fourth flow path through which a fourth fluid flows, the fourth flow path connected to being an outlet of the anode chamber, the fourth fluid being discharged from the anode chamber, and the fourth fluid containing an oxidation product, and
> the method comprising:
>
> > humidifying the first fluid flowing through the first flow path; and
> > treating the humidified first fluid to condense a part of water vapor in the humidified first fluid to produce a condensed water, and controlling a ratio of the condensed water in the humidified first fluid.

(Clause 12) The method according to clause 11, wherein

the device comprises:

> a humidifier provided in the middle of the first flow path and configured to humidify the first fluid; and
> a condenser provided in the middle of the first flow path so as to follow the humidifier, configured to treat the humidified first fluid and condenses a part of the water vapor in the humidified first fluid to produce the condensed water, and thus control the ratio of the condensed water in the humidified first fluid.

(Clause 13) The method according to clause 12, wherein

the condenser has a temperature controller.

(Clause 14) The method according to clause 13, wherein

the condenser is configured to treat the first fluid so that a temperature of the treated first fluid discharged from the condenser is lower than a dew point of the humidified first fluid supplied to the condenser.

(Clause 15) The method according to clause 12, wherein

the electrolytic unit has the condenser.

(Clause 16) The method according to any one of clause 11 to clause 15, wherein

the electrochemical reaction device further comprises a liquid supply unit configured to supply a liquid containing water to the first flow path.

(Clause 17) The method according to any one of clause 11 to clause 16, wherein

the device further comprises a liquid removal unit configured to remove a liquid from the first fluid.

(Clause 18) The method according to any one of clause 11 to clause 17, wherein

the device further comprises a controller configured to control the humidifier and the condenser.

(Clause 19) The method according to clause 18, wherein:

the device further comprises at least one detector configured to detect at least one parameter of at least one element from the group consisting of the humidifier, the condenser, the electrolytic unit, the first flow path, the second flow path, the third flow path, the fourth flow path, the first fluid, the second fluid, the third fluid, and the fourth fluid, and

the controller comprises:

a receiving unit configured to receive a detection signal from the at least one detector;

a processing unit configured to perform arithmetic processing depending on the detection signal; and

a controlling unit configured to control at least one selected from the group consisting of the humidifier and the condenser in response to a result of the arithmetic processing.

(Clause 20) The method according to clause 19, wherein

the at least one detector is selected from the group consisting of a thermometer, a pressure gauge, a dew-point meter, an ammeter, a voltmeter, a gas flowmeter, and a gas composition analyzer.

Claims

1. An electrochemical reaction device comprising:

an electrolytic unit comprising a cathode, an anode, a diaphragm between the cathode and the anode, a cathode chamber facing on the cathode, and an anode chamber facing on the anode;

a first flow path through which a first fluid flows, the first flow path being connected to an inlet of the cathode chamber, and the first fluid containing a reducible material to be supplied to the cathode chamber;

a second flow path through which a second fluid flows, the second flow path being connected to an inlet of the anode chamber, and the second fluid containing an oxidizable material to be supplied to the anode chamber;

a third flow path through which a third fluid flows, the third flow path being connected to an outlet of the cathode chamber, the third fluid being discharged from the cathode chamber, and the third fluid containing a reduction product;

a fourth flow path through which a fourth fluid flows, the fourth flow path being connected to an outlet of the anode chamber, the fourth fluid being discharged from the anode chamber, and the fourth fluid containing an oxidation product;

a humidifier provided in the middle of the first flow path and configured to humidify the first fluid; and

a condenser provided in the middle of the first flow path so as to follow the humidifier, the condenser being configured to treat the humidified first fluid and thus condense a part of water vapor in the humidified first fluid to produce a condensed water, and to control a ratio of the condensed water in the humidified first fluid.

2. The device according to claim 1, wherein
the condenser has a temperature controller.

3. The device according to claim 2, wherein
the condenser is configured to treat the first fluid so that a temperature of the treated first fluid to be discharged from the condenser is lower than a dew point of the humidified first fluid supplied to the condenser.

4. The device according to any one of claim 1 to claim 3, comprising a plurality of the condensers.

5. The device according to one of claim 1 to claim 4, wherein the electrolytic unit has the condenser.

6. The device according to one of claim 1 to claim 5, further comprising
a liquid supply unit configured to supply a liquid containing water to the first flow path.

7. The device according to one of claim 1 to claim 6, further comprising a liquid removal unit configured to remove a liquid from the first fluid.

8. The device according to one of claim 1 to claim 7, further comprising a controller configured to control the humidifier and the condenser.

9. The device according to claim 8, further comprising

at least one detector configured to detect at least one parameter of at least one element selected from the consisting of the humidifier, the condenser, the electrolytic unit, the first flow path, the second flow path, the third flow path, the fourth flow path, the first fluid, the second fluid, the third fluid, and the fourth fluid, wherein
the controller comprises:

a receiving unit configured to receive a detection signal from the at least one detector;
a processing unit configured to perform arithmetic processing depending on the detection signal; and
a controlling unit configured to control at least one of the humidifier and the condenser in response to a result of the arithmetic processing.

10. The device according to claim 9, wherein
the at least one detector is selected from the group consisting of a thermometer, a pressure gauge, a dew-point meter, an ammeter, a voltmeter, a gas flowmeter, and a gas composition analyzer.

11. A method of operating an electrochemical reaction device,
the device comprising:

an electrolytic unit comprising a cathode, an anode, a diaphragm between the cathode and the anode, a cathode chamber facing on the cathode, and an anode chamber facing on the anode;
a first flow path through which a first fluid flows, the first flow path being connected to an inlet of the cathode chamber, and the first fluid containing a reducible material to be supplied to the cathode chamber;
a second flow path through which a second fluid flows, the second flow path connected to being an inlet of the anode chamber, and the second fluid containing an oxidizable material to be supplied to the anode chamber;
a third flow path through which a third fluid flows, the third flow path being connected to an outlet of the cathode chamber, the third fluid being discharged from the cathode chamber, and the third fluid containing a reduction product; and
a fourth flow path through which a fourth fluid flows, the fourth flow path connected to being an outlet of the anode chamber, the fourth fluid being discharged from the anode chamber, and the fourth fluid containing an oxidation product, and
the method comprising:

humidifying the first fluid flowing through the first flow path; and
treating the humidified first fluid to condense a part of water vapor in the humidified first fluid to produce a condensed water, and controlling a ratio of the condensed water in the humidified first fluid.

12. The method according to claim 11, wherein
the device comprises:

a humidifier provided in the middle of the first flow path and configured to humidify the first fluid; and
a condenser provided in the middle of the first flow path so as to follow the humidifier, configured to treat the humidified first fluid and condenses a part of the water vapor in the humidified first fluid to produce the condensed water, and thus control the ratio of the condensed water in the humidified first fluid.

13. The method according to claim 12, wherein the condenser has a temperature controller.

14. The method according to claim 13, wherein
the condenser is configured to treat the first fluid so that a temperature of the treated first fluid discharged from the condenser is lower than a dew point of the humidified first fluid supplied to the condenser.

15. The method according to claim 12, wherein
the electrolytic unit has the condenser.

FIG. 1

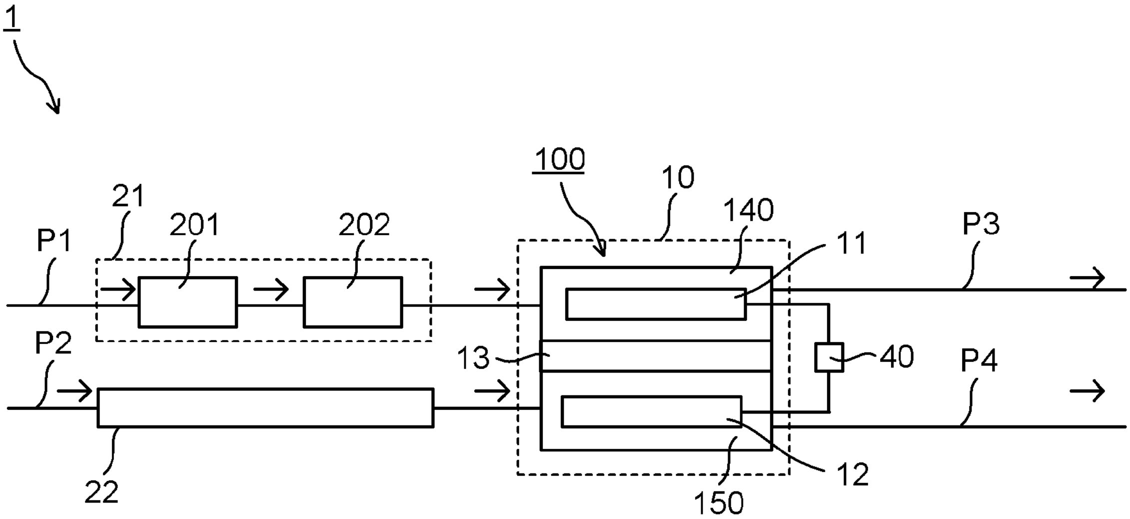
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FIG. 2

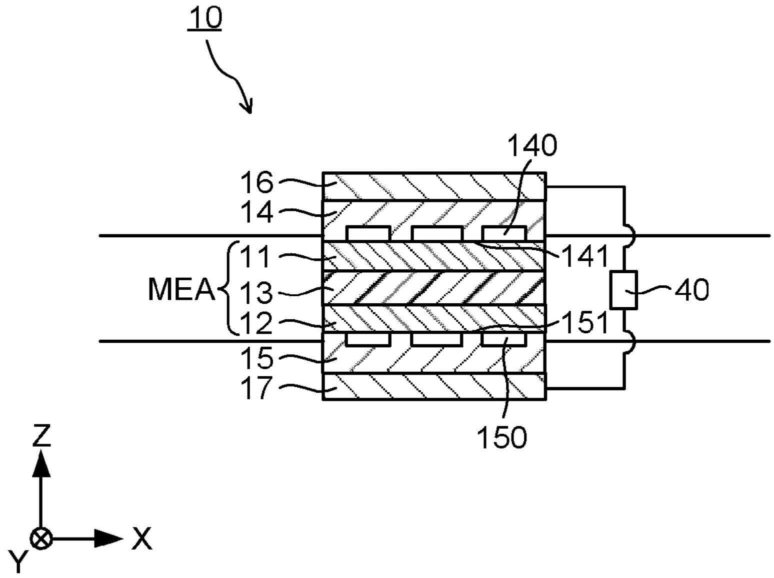
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FIG. 3

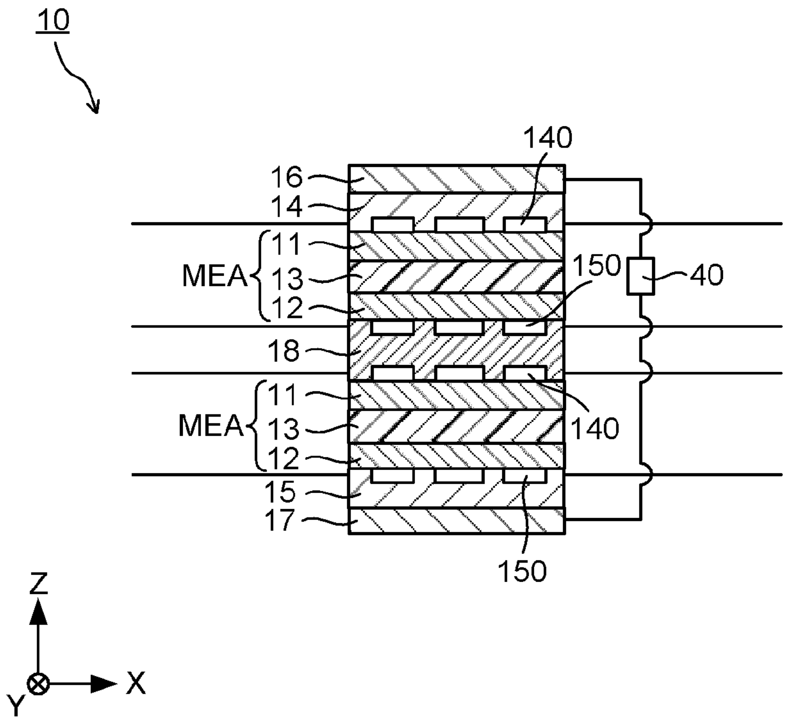
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FIG. 4

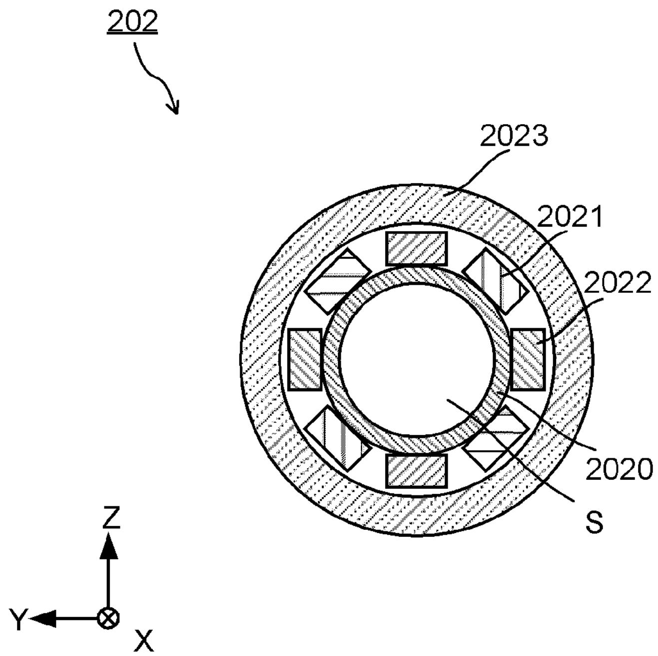
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FIG. 5

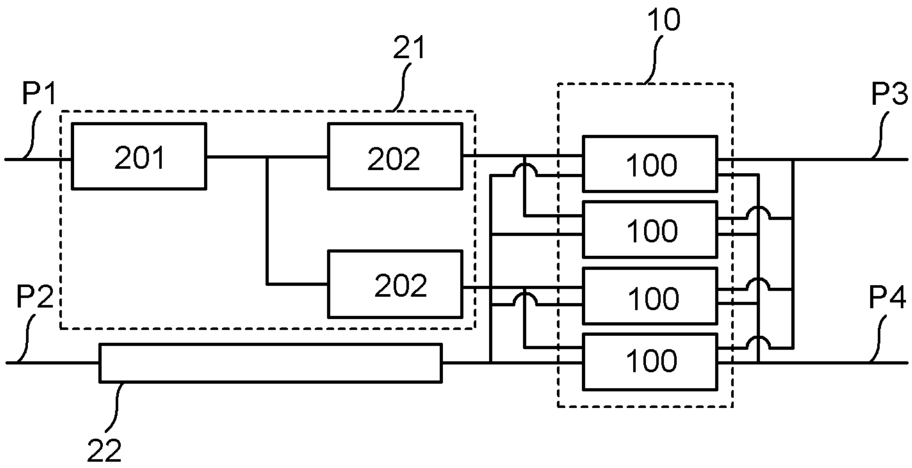
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FIG. 6

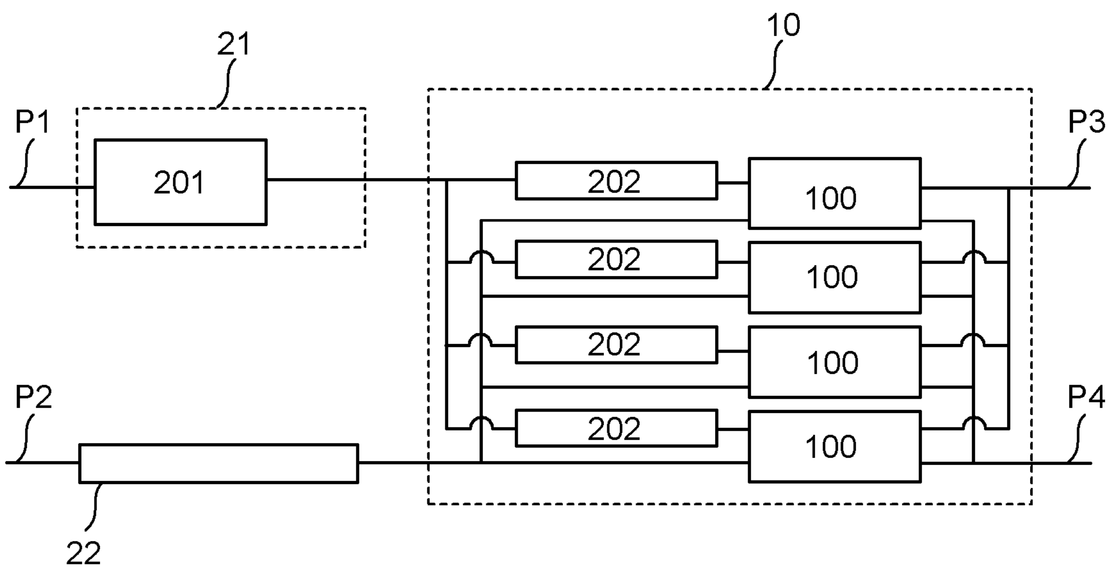
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FIG. 7

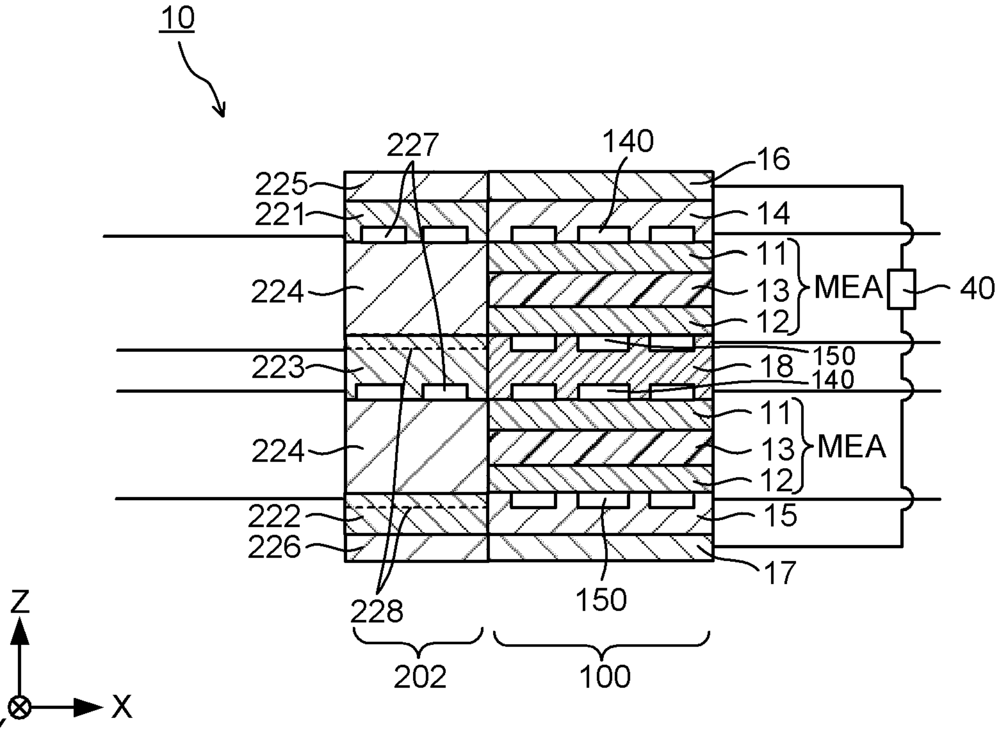
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FIG. 8

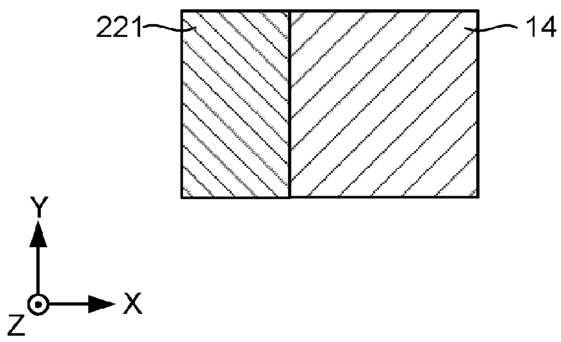


FIG. 9

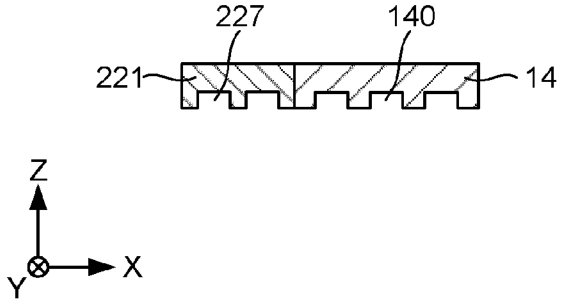


FIG. 10

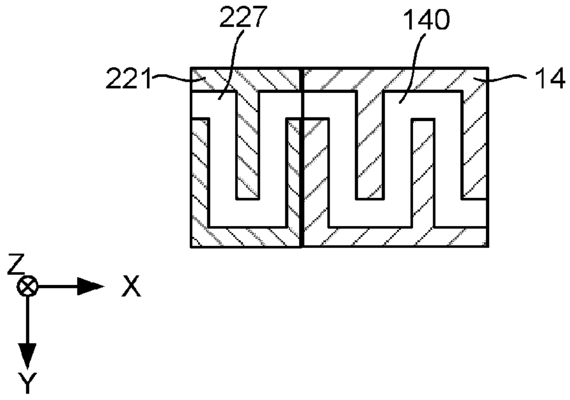


FIG. 11

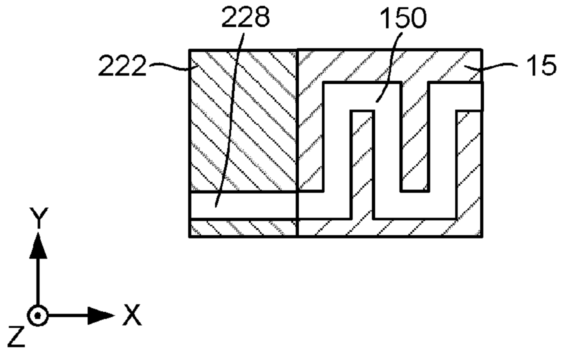


FIG. 12

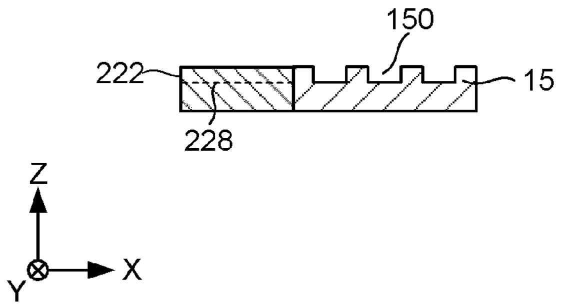


FIG. 13

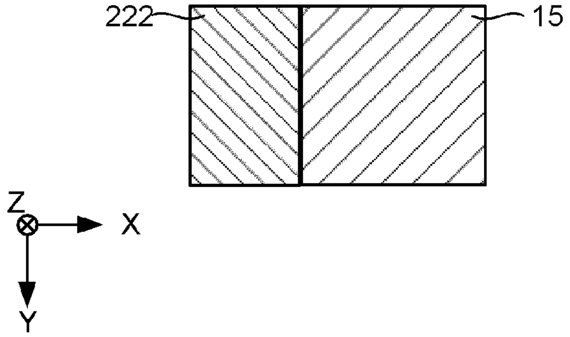


FIG. 14

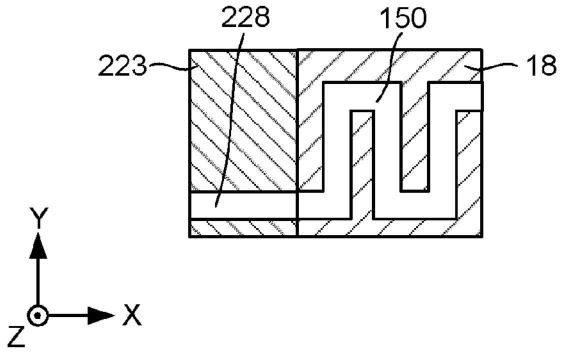


FIG. 15

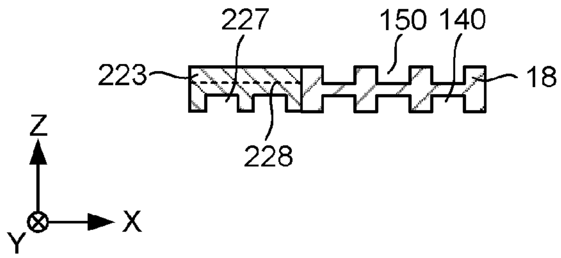


FIG. 16

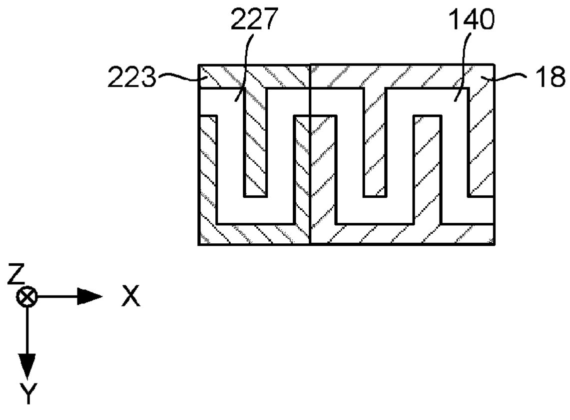


FIG. 17

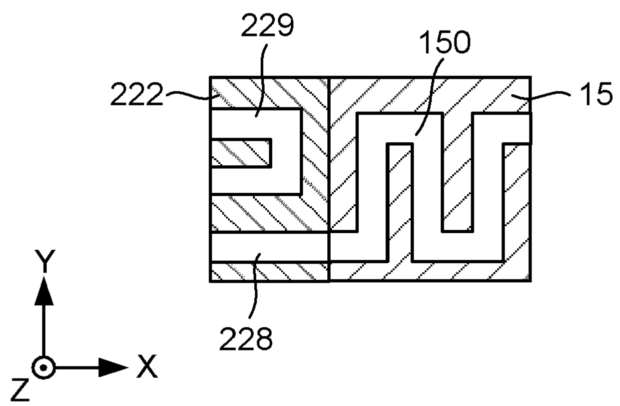


FIG. 18

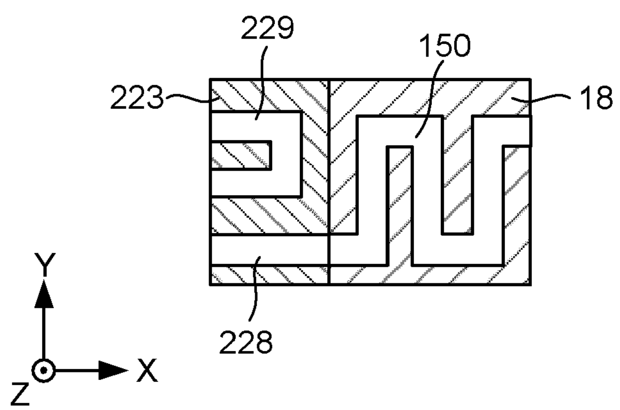
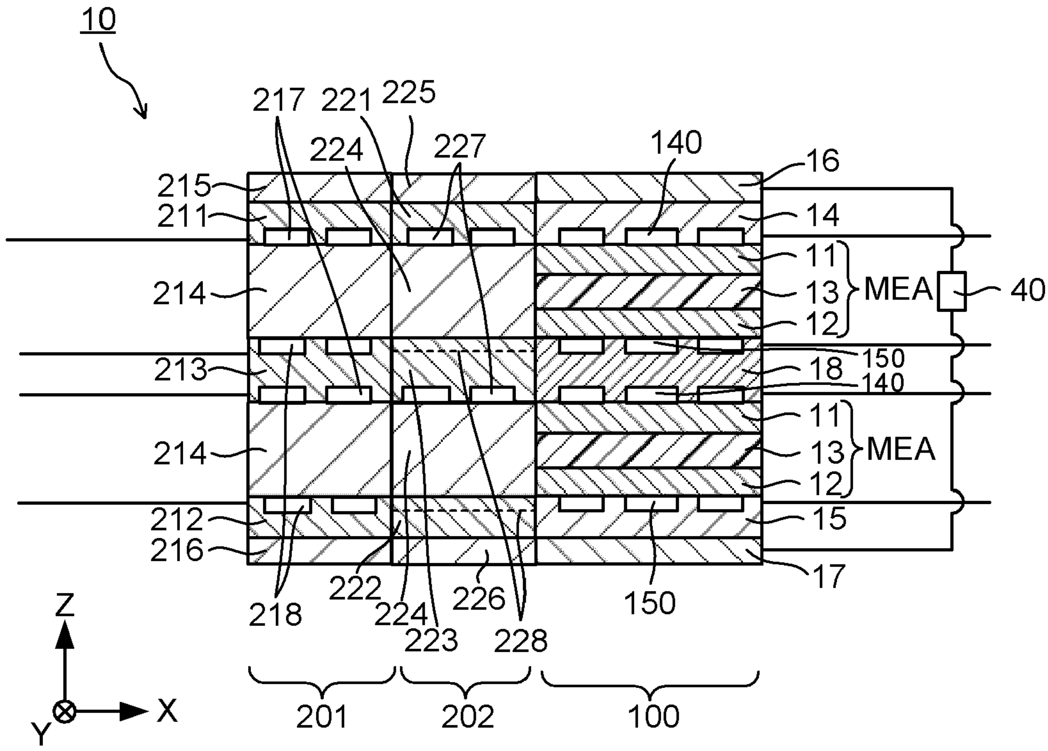


FIG. 19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150
218
224
223
228
Z
X
Y
201
202
100

FIG. 20

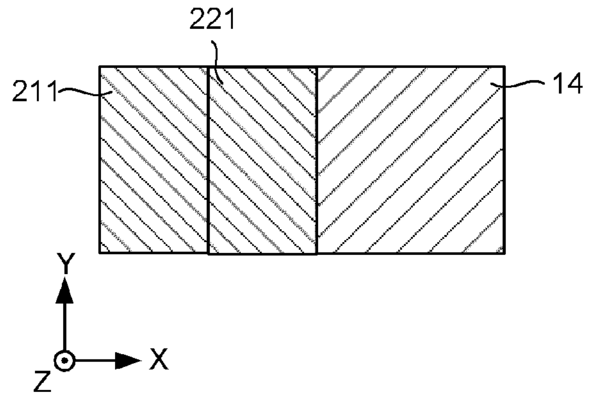


FIG. 21

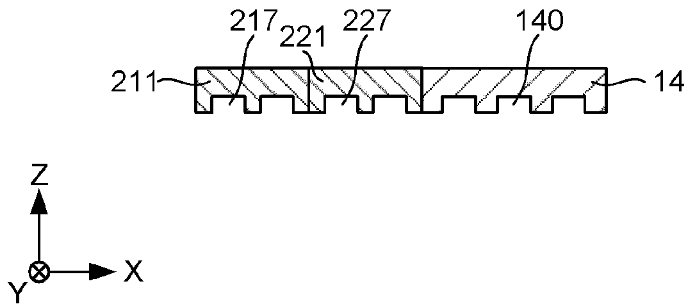


FIG. 22

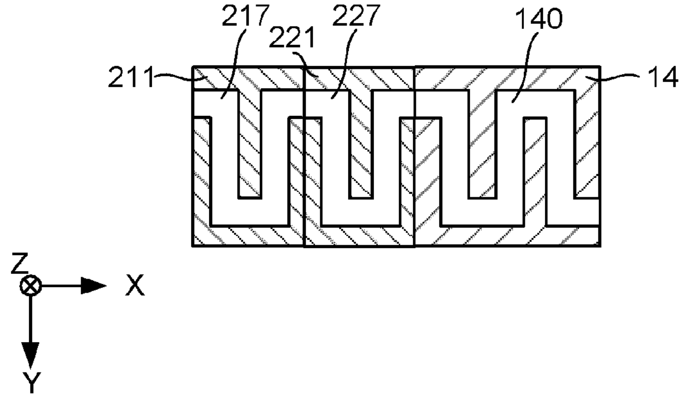


FIG. 23

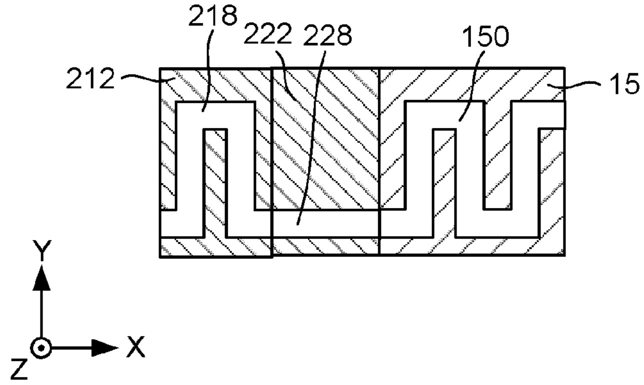


FIG. 24

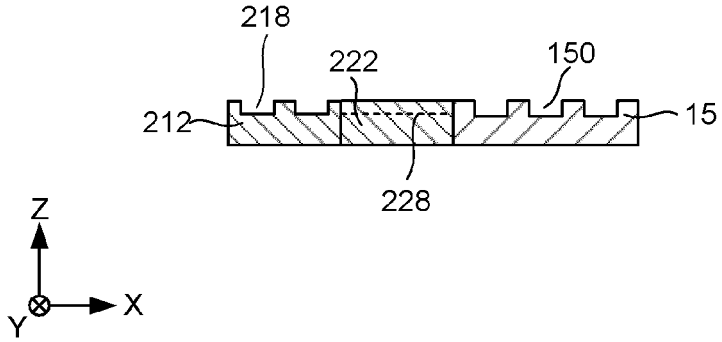


FIG. 25

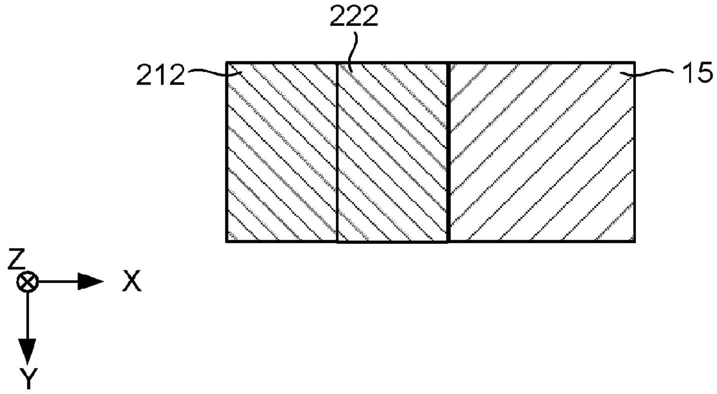


FIG. 26

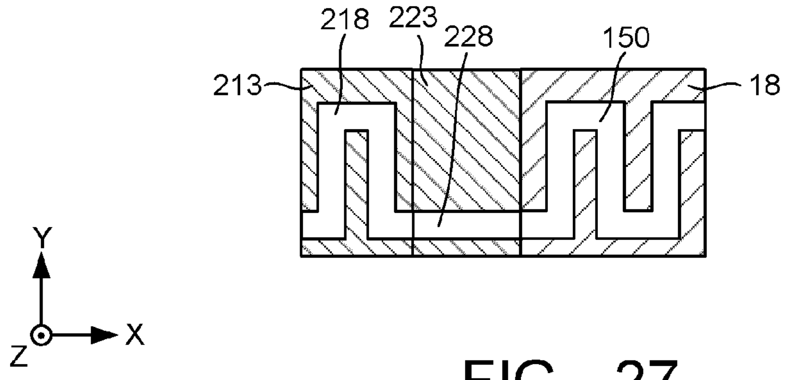


FIG. 27

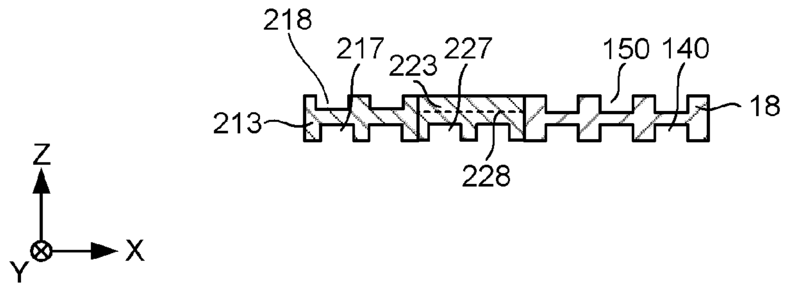


FIG. 28

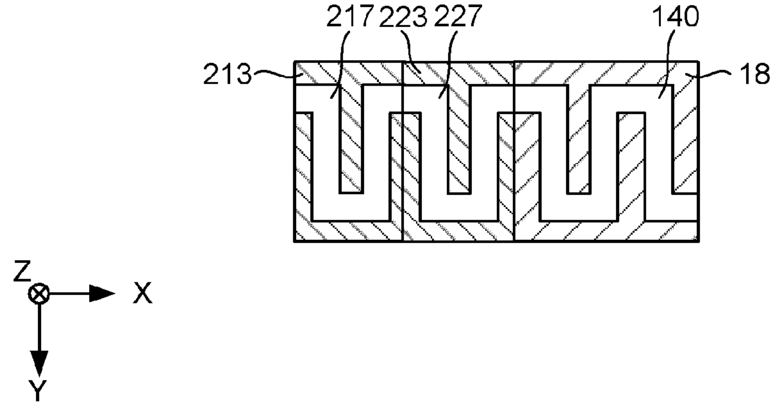


FIG. 29

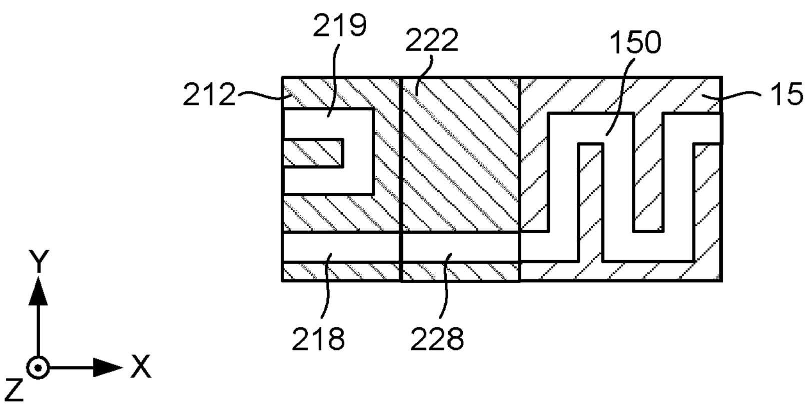


FIG. 30

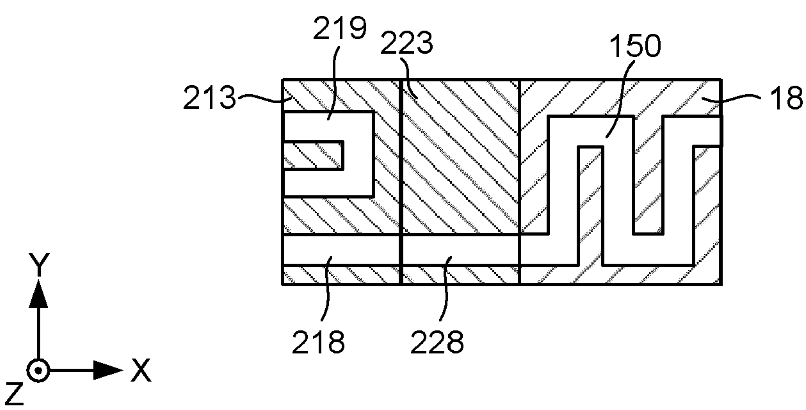


FIG. 31

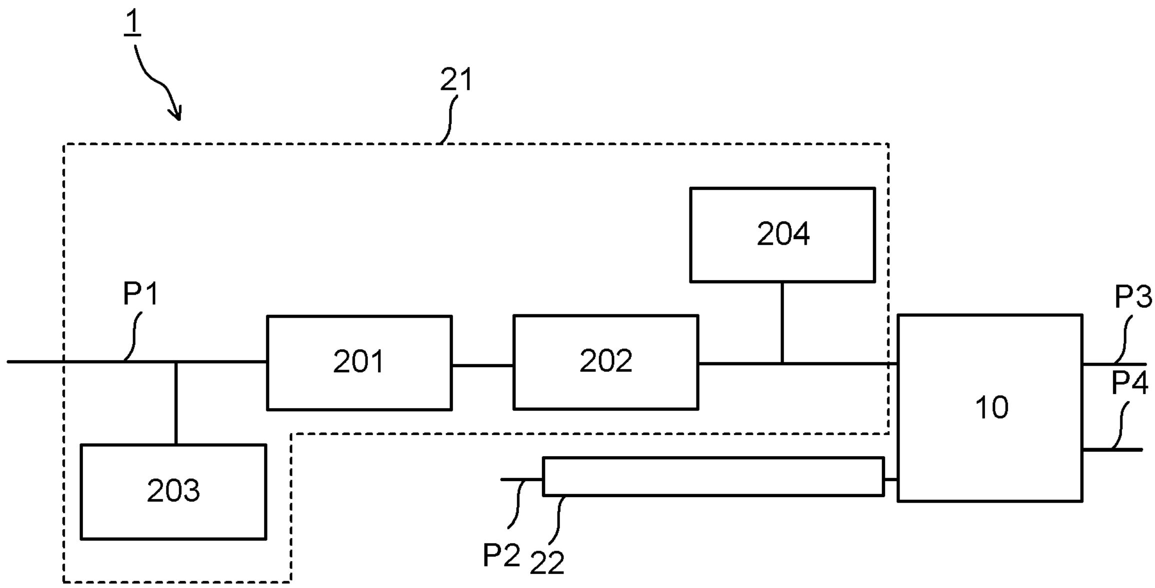
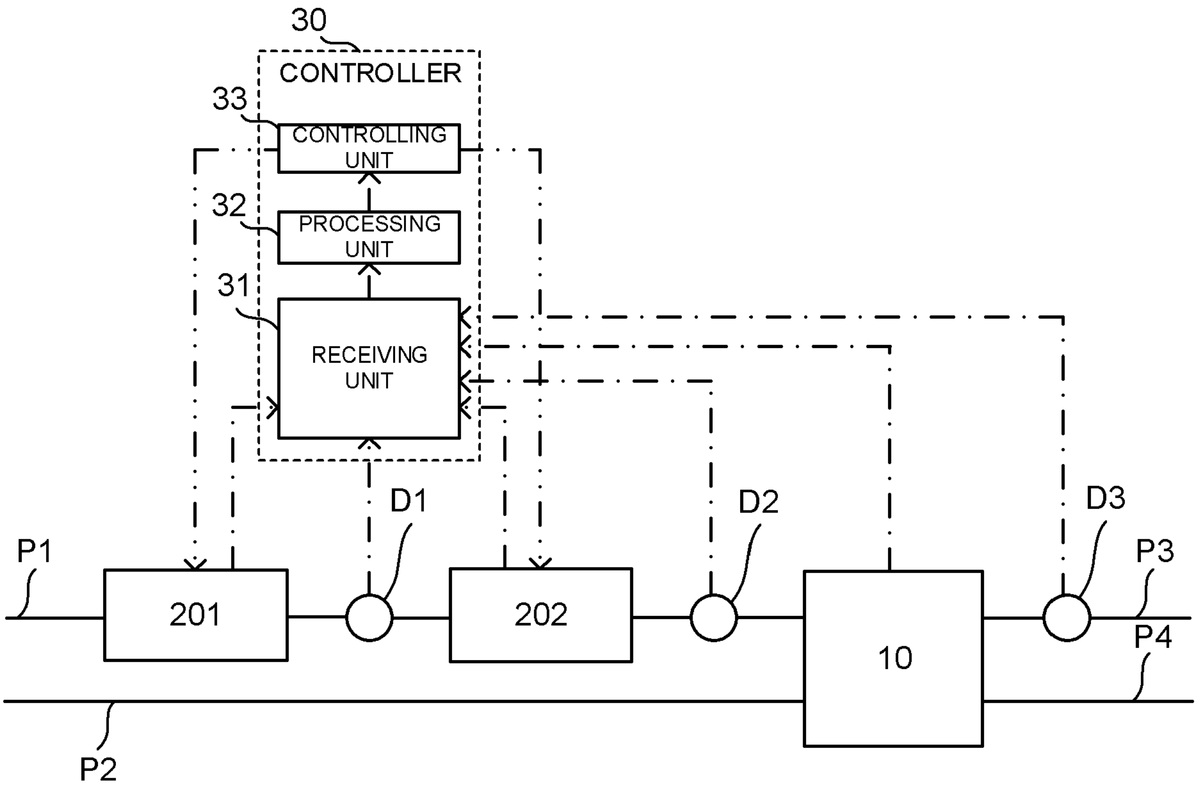


FIG. 32


30
CONTROLLER
33
CONTROLLING UNIT
32
PROCESSING UNIT
31
RECEIVING UNIT
D1
D2
D3
P1
P2
P3
P4
201
202
10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2022141239 A **[0006]**

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