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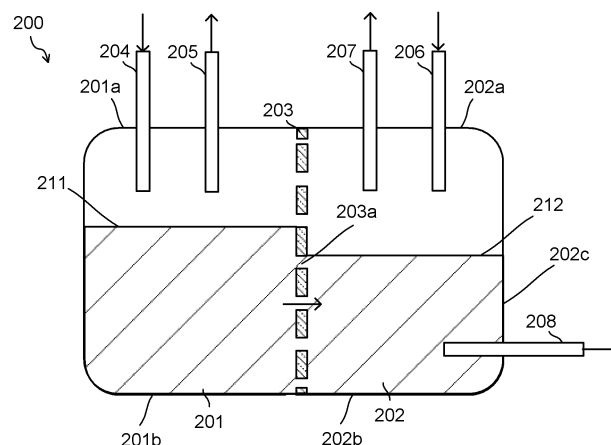
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(54) **ELECTROLYTIC DEVICE AND METHOD OF DRIVING ELECTROLYTIC DEVICE**

(57) An electrolytic device includes: an electrolysis cell including: a cathode; an anode; a cathode flow path facing the cathode; and an anode flow path facing the anode; a tank including: a first room; a second room; and an opening connecting the rooms, the rooms store a liquid containing at least one ion, the tank forms a level difference so that the first liquid level of the liquid in the

first room is higher to the bottom of the second room than the second liquid level of the liquid in the second room, and thus cause an ion in the liquid to move from the first to the second room through the opening; a first flow path connecting an outlet of the cathode flow path and the first room; and a second flow path connecting the second room and an outlet of the anode flow path.

FIG. 2



Description

FIELD

5 **[0001]** Arrangements relate to an electrolytic device and a method of driving an electrolytic device.

BACKGROUND

10 **[0002]** In recent years, from the viewpoint of both energy problems and environmental problems, it has been desired not only to convert renewable energy such as solar power into electric energy for use, but also to convert it into a form that can be stored and transported. In response to this demand, research and development of artificial photosynthesis technology that produces chemical substances using sunlight, like photosynthesis by plants, is underway. This technology has the potential to store the renewable energy as a storable fuel and is also expected to create value by producing chemical substances that can be used as industrial raw materials.

15 **[0003]** As a device that uses renewable energy to produce chemical substances, there has been known an electrochemical reaction device that includes, for example, a cathode that reduces carbon dioxide (CO₂), generated from a power plant, or waste treatment plant and an anode that oxidizes water (H₂O). At the cathode, for example, carbon dioxide is reduced to produce carbon compounds such as carbon monoxide (CO). When such an electrochemical reaction device is fabricated in a cell form (also called an electrolysis cell), it is considered to be effective to fabricate
20 the device in a form similar to a fuel cell, such as a polymer electric fuel cell (PEFC), for example. Direct supply of carbon dioxide to a catalyst layer of the cathode enables a carbon dioxide reduction reaction to proceed rapidly.

[0004] However, in such a cell form, a problem similar to that of the PEFC arises. In other words, in order to fabricate the electrolysis cell that is resistant to failure and is durable, it is necessary to keep the resistance of the electrolysis cell low.

25 RELEVANT REFERENCES

Patent Reference

30 **[0005]** Reference 1: JPA 2022-42280

BRIEF DESCRIPTION OF THE DRAWINGS

[0006]

35 FIG. 1 is a schematic view illustrating a configuration example of an electrolytic device 1;
FIG. 2 is a schematic view illustrating a structural example of a tank 200;
FIG. 3 is a schematic view illustrating another structural example of the tank 200; and
FIG. 4 is a schematic view illustrating another structural example of the tank 200.

40 DETAILED DESCRIPTION

[0007] An electrolytic device according to an arrangement, including: an electrolysis cell including: a cathode; an anode; a cathode flow path facing on the cathode; and an anode flow path facing on the anode; a tank including: a first room; a second room; and an opening connecting the first room and the second room, the first room and the second
45 room being configured to store a liquid containing at least one ion, the tank being configured to form a level difference between a first liquid level and a second liquid level so that a height of the first liquid level of the liquid to be stored in the first room relative to a bottom of the second room is higher than a height of the second liquid level of the liquid to be stored in the second room relative to the bottom of the second room, and thus cause an ion contained in the liquid to move from the first room to the second room through the opening; a first flow path connecting an outlet of the cathode
50 flow path and the first room; and a second flow path connecting the second room and an outlet of the anode flow path.

[0008] Hereinafter, there will be explained an arrangement with reference to the drawings. The drawings are schematic, and dimensions such as a thickness and a width of each component, for example, are sometimes different from actual ones. Further, in the arrangement, substantially the same components are denoted by the same reference numerals and symbols, and their explanation is sometimes partially omitted.

55 **[0009]** In this specification, "connection" includes not only direct connection but also indirect connection, unless otherwise specified.

[0010] FIG. 1 is a schematic view illustrating a configuration example of an electrolytic device. The electrolytic device illustrated in FIG. 1 is a carbon dioxide electrolytic device.

[0011] An electrolytic device 1 illustrated in FIG. 1 includes an electrolysis cell 100, a power supply 150, a tank 200, a cathode supply part 301, and an anode supply part 401.

[0012] The electrolysis cell 100 includes an anode 111, an anode flow path 112, an anode current collector 113, a cathode 121, a cathode flow path 122, a cathode current collector 123, and a separator 131. In the electrolysis cell 100, these members are sandwiched between a pair of not-illustrated support plates and further tightened with bolts or other means.

[0013] The anode 111 is provided between the separator 131 and the anode flow path 112 to be in contact with them. The anode 111 is an electrode for oxidizing water (H_2O) in an anode solution to produce oxygen (O_2) and hydrogen ions (H^+), or an electrode for oxidizing hydroxide ions (OH^-) produced by a reduction reaction of carbon dioxide at the cathode 121 to produce oxygen and water.

[0014] The anode 111 preferably contains a catalyst material capable of reducing an overvoltage in the above-described oxidation reaction (anode catalyst material). Examples of such a catalyst material include metals such as platinum (Pt), palladium (Pd), and nickel (Ni), alloys containing those metals, intermetallic compounds, binary metal oxides such as manganese oxide (Mn-O), iridium oxide (Ir-O), nickel oxide (Ni-O), cobalt oxide (Co-O), iron oxide (Fe-O), tin oxide (Sn-O), indium oxide (In-O), ruthenium oxide (Ru-O), lithium oxide (Li-O), and lanthanum oxide (La-O), ternary metal oxides such as Ni-Co-O, Ni-Fe-O, La-Co-O, Ni-La-O, and Sr-Fe-O, quaternary metal oxides such as Pb-Ru-Ir-O and La-Sr-Co-O, and metal complexes such as a Ru complex and a Fe complex.

[0015] The anode 111 includes a base material having a structure capable of making a liquid or ions move between the separator 131 and the anode flow path 112, which is, for example, a porous structure such as a mesh material, a punching material, a porous body, or a metal fiber sintered body. The base material may be formed of a metal such as titanium (Ti), nickel (Ni), or iron (Fe), or a metal material such as an alloy containing at least one of these metals (for example, SUS), or may be formed of the above-described anode catalyst material. When an oxide is used as the anode catalyst material, it is preferable to form a catalyst layer by attaching or stacking the anode catalyst material to or on a surface of the base material made of the above-described metal material. The anode catalyst material preferably has nanoparticles, a nanostructure, a nanowire, or the like for increasing the oxidation reaction. The nanostructure is a structure with nanoscale irregularities formed on the surface of the catalyst material. Further, the oxidation catalyst does not necessarily have to be provided on the anode 111. The oxidation catalyst layer provided other than on the anode 111 may be electrically connected to the anode 111.

[0016] The cathode 121 is in contact with the separator 131. To the cathode 121, an anode solution and ions are supplied from the separator 131, and a carbon dioxide gas is supplied from the cathode flow path 122. The cathode 121 is an electrode that causes a reduction reaction of carbon dioxide or a reduction reaction of a reduction product to produce carbon compounds (reduction electrode). Examples of the carbon compound include carbon monoxide (CO), methane (CH_4), ethane (C_2H_6), and so on. The reduction reaction at the cathode 121 may include a side reaction that causes a reduction reaction of water to produce hydrogen (H_2), along with the reduction reaction of carbon dioxide.

[0017] The cathode 121 includes a gas diffusion layer and a cathode catalyst layer provided on the gas diffusion layer. A porous layer denser than the gas diffusion layer may be arranged between the gas diffusion layer and the cathode catalyst layer. The gas diffusion layer is arranged on the cathode flow path 122 side, and the cathode catalyst layer is arranged on the separator 131 side. The cathode catalyst layer may enter the gas diffusion layer. The cathode catalyst layer preferably has catalyst nanoparticles, a catalyst nanostructure, or the like. The gas diffusion layer is formed of, for example, a carbon paper, a carbon cloth, or the like, and may be subjected to a water repellent treatment. The porous layer is formed of a porous body with a smaller pore size than the carbon paper or the carbon cloth.

[0018] With the application of a moderate water repellent treatment to the gas diffusion layer, a carbon dioxide gas reaches the cathode catalyst layer mainly by gas diffusion. The reduction reaction of carbon dioxide or the reduction reaction of the carbon compound produced by the reduction reaction occur near the boundary between the gas diffusion layer and the cathode catalyst layer, or near the cathode catalyst layer that has entered the gas diffusion layer.

[0019] The cathode catalyst layer is preferably formed of a catalyst material capable of reducing an overvoltage in the above-described reduction reaction (cathode catalyst material). Examples of such a material include metals 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), and tin (Sn), metal materials such as alloys containing at least one of these metals and intermetallic compounds, carbon materials such as carbon (C), graphene, CNT (carbon nanotube), fullerene, and ketjen black, and metal complexes such as a Ru complex and a Re complex. The cathode catalyst layer can employ various shapes such as a plate shape, a mesh shape, a wire shape, a particle shape, a porous shape, a thin film shape, and an island shape.

[0020] The cathode catalyst material forming the cathode catalyst layer preferably has nanoparticles of the above-described metal material, a nanostructure of the metal material, a nanowire of the metal material, or a composite body in which nanoparticles of the above-described metal material are supported on a carbon material such as carbon particles, a carbon nanotube, or graphene. Applying catalyst nanoparticles, a catalyst nanostructure, a catalyst nanowire, a catalyst nano-support structure, or the like as the cathode catalyst material makes it possible to increase the reaction efficiency

of the reduction reaction of carbon dioxide at the cathode 121.

[0021] The anode 111 and the cathode 121 can be connected to the power supply 150. Examples of the power supply 150 are not limited to ordinary system power supplies or batteries, but may include a power source that supplies power generated by renewable energy such as solar cells or wind power generation. The use of renewable energy is also environmentally preferable in terms of effective use of carbon dioxide. The power supply 150 may further include a power controller that controls a voltage between the anode 111 and the cathode 121 by adjusting output of the above-described power supply. The power supply 150 may be provided outside the electrolytic device 1.

[0022] The anode flow path 112 faces the anode 111. The anode flow path 112 has a function of supplying an anode solution to the anode 111.

[0023] The anode solution preferably contains at least water (H_2O). The liquid may contain carbon dioxide (CO_2). The liquid does not need to contain carbon dioxide (CO_2) because carbon dioxide (CO_2) is supplied from the cathode flow path 122.

[0024] As the anode solution, an aqueous solution containing metal ions (electrolytic solution) can be used. Examples of the aqueous solution include aqueous solutions containing phosphate ions (PO_4^{2-}), borate ions (BO_3^{3-}), sodium ions (Na^+), potassium ions (K^+), calcium ions (Ca^{2+}), lithium ions (Li^+), cesium ions (Cs^+), magnesium ions (Mg^{2+}), chloride ions (Cl^-), hydrogen carbonate ions (HCO_3^-), and so on. Besides, aqueous solutions containing $LiHCO_3$, $NaHCO_3$, $KHCO_3$, $CsHCO_3$, phosphoric acid, boric acid, and so on may also be used.

[0025] The anode flow path 112 is provided on a surface of a flow path plate 114. The flow path plate 114 is to supply the anode solution, which is an electrolytic solution, to the anode 111, and has a groove (recessed portion) in its surface in which the anode flow path 112 is formed. As the material of the flow path plate 114, it is preferable to use a material having low chemical reactivity and high conductivity. Examples of such a material include metal materials such as Ti and SUS, carbon, and so on. The anode flow path 112 may be provided at the anode current collector 113. Further, the material of the flow path plate 114 contains a material having low chemical reactivity and no conductivity, for example. Examples of such a material include insulating resin materials such as an acrylic resin, polyether ether ketone (PEEK), and a fluorocarbon resin. The flow path plate 114 has an inlet port and an outlet port of the anode flow path 112 and screw holes for tightening, which are not illustrated.

[0026] The flow path plate 114 is mainly formed of one member, but may be formed of different members to be formed by stacking them. Further, a surface treatment may be applied to a portion or all of the surface, to thereby provide a hydrophilic or water-repellent function.

[0027] The anode flow path 112 has an inlet and an outlet, and the anode solution is supplied from the anode supply part 401 through the inlet, and the anode solution is discharged through the outlet. The anode solution flows through inside the anode flow path 112 so as to be in contact with the anode 111.

[0028] The anode current collector 113 is electrically connected to the anode 111. The anode current collector 113 is in contact with the surface of the flow path plate 114 on the side opposite to the anode flow path 112. The anode current collector 113 preferably contains a material having low chemical reactivity and high conductivity. Examples of such a material include metal materials such as Ti and SUS, carbon, and so on.

[0029] The cathode flow path 122 faces the cathode 121. The cathode flow path 122 has a function of supplying a fluid containing carbon dioxide (cathode gas) to the cathode 121. The fluid containing carbon dioxide may contain steam by being humidified. The compound produced by the reduction reaction is mainly discharged from the cathode flow path 122. The compound produced by the reduction reaction varies depending on the type of reduction catalyst, or other factors. Along with such a gas product, vapor or moisture obtained by dew condensation of steam contained in the humidified carbon dioxide gas is discharged from the cathode flow path 122.

[0030] The cathode flow path 122 is provided on a surface of a flow path plate 124. The flow path plate 124 has a groove (recessed portion) in its surface in which the cathode flow path 122 is formed. As the material of the flow path plate 124, it is preferable to use a material having low chemical reactivity and high conductivity. Examples of such a material include metal materials such as Ti and SUS, carbon, and so on. Further, the material of the flow path plate 124 contains a material having low chemical reactivity and no conductivity, for example. Examples of such a material include insulating resin materials such as an acrylic resin, polyether ether ketone (PEEK), and a fluorocarbon resin. The flow path plate 124 has not-illustrated screw holes for tightening. Further, a not-illustrated packing is sandwiched at the front and the back of each of the flow path plates as necessary. The cathode flow path 122 may be provided at the cathode current collector 123.

[0031] The cathode flow path 122 has an inlet and an outlet, and the cathode gas such as carbon dioxide is supplied from the cathode supply part 301 through the inlet, and the fluid containing the cathode gas is discharged through the outlet. The cathode gas flows through inside the cathode flow path 122 so as to be in contact with the cathode 121.

[0032] The cathode flow path 122 may have a land in contact with the cathode 121 for electrical connection with the cathode 121. The shape of the cathode flow path 122 is not particularly limited as long as it is continuously connected, and examples of the shape include a serpentine structure with a bent elongated flow path, and so on. As a result, the cathode gas flows uniformly on the surface of the cathode 121, so that a uniform reaction can be performed at the

cathode 121, which is preferable.

[0033] The cathode gas may be supplied in a dry state. When the cathode gas is a carbon dioxide gas, the concentration of carbon dioxide in the cathode gas supplied from the cathode supply part 301 to the cathode flow path 122 does not have to be 100%. The gas containing carbon dioxide discharged from various facilities can also be used as the cathode gas.

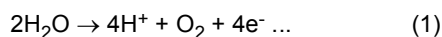
[0034] The flow path plate 124 is mainly formed of a single member, but may be formed of different members to be formed by stacking them. Further, a surface treatment may be applied to a portion or all of the surface, to thereby provide a hydrophilic or water-repellent function.

[0035] The cathode current collector 123 is electrically connected to the cathode 121 of the electrolysis cell 100. The cathode current collector 123 preferably contains a material having low chemical reactivity and high conductivity. Examples of such a material include metal materials such as Ti and SUS, carbon, and so on.

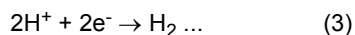
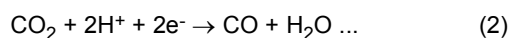
[0036] The separator 131 is arranged so as to separate the anode 111 and the cathode 121. The separator 131 includes an ion exchange membrane capable of making ions move between the anode 111 and the cathode 121 and separating the anode 111 and the cathode 121. As an example of the ion exchange membrane, for example, cation exchange membranes such as Nafion and Flemion, and anion exchange membranes such as Neosepta, Selemion, and Sustainion can be used. When an alkaline solution is used as the electrolytic solution and moving of OH⁻ is mainly assumed, the separator 131 is preferably formed of the anion exchange membrane. Further, the ion exchange membrane may be formed by using a membrane having a hydrocarbon basic structure or a membrane having an amine group. However, besides the ion exchange membrane, a salt bridge, a glass filter, a porous polymer membrane, a porous insulating material, or the like may be applied to the separator 131 as long as the material is capable of making ions move between the anode 111 and the cathode 121. However, when gas distribution occurs between the anode 111 and the cathode 121, a circular reaction due to reoxidation of a reduction product sometimes occurs. Therefore, it is preferable to have less gas exchange between the anode 111 and the cathode 121. Therefore, care should be taken when using a porous thin membrane as the separator 131.

[0037] Next, an example of a method of driving the electrolysis cell 100 is explained. Here, the case of producing carbon monoxide as the carbon compound, is mainly explained but the carbon compound as a reduction product of carbon dioxide is not limited to carbon monoxide.

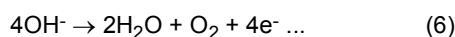
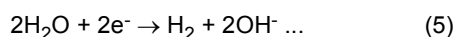
[0038] First, a reaction process in the case of mainly oxidizing water (H₂O) to produce hydrogen ions (H⁺) is explained. When the current is supplied between the anode 111 and the cathode 121 from the power supply 150, the oxidation reaction of water (H₂O) occurs at the anode 111 in contact with the anode solution. Specifically, as illustrated in Expression (1) below, H₂O contained in the anode solution is oxidized to produce oxygen (O₂) and hydrogen ions (H⁺).



[0039] H⁺ produced at the anode 111 moves through the electrolytic solution present in the anode flow path 112 and the separator 131 to reach near the cathode 121. Electrons (e⁻) based on the current supplied to the cathode 121 from the power supply 150 and H⁺ that has moved near the cathode 121 cause the reduction reaction of carbon dioxide. Specifically, as illustrated in Expression (2) below, carbon dioxide supplied to the cathode 121 from the cathode flow path 122 is reduced to produce carbon monoxide. Further, hydrogen is produced by hydrogen ions receiving electrons, as illustrated in Expression (3) below. At this time, hydrogen may be produced simultaneously with carbon monoxide.



[0040] Next, a reaction process in the case of mainly reducing carbon dioxide (CO₂) to produce hydroxide ions (OH⁻) is explained. When the current is supplied between the anode 111 and the cathode 121 from the power supply 150, water (H₂O) and carbon dioxide (CO₂) are reduced near the cathode 121 to produce carbon monoxide (CO) and hydroxide ions (OH⁻), as illustrated in Expression (4) below. Further, hydrogen is produced by water receiving electrons as illustrated in Expression (5) below. At this time, hydrogen may be produced simultaneously with carbon monoxide. The hydroxide ions (OH⁻) produced by these reactions diffuse near the anode 111, and as illustrated in Expression (6) below, the hydroxide ions (OH⁻) are oxidized to produce oxygen (O₂).



[0041] The electrolysis cell 100 can not only specialize in the reduction of carbon dioxide, but can also produce reduction products and hydrogen at an arbitrary ratio where, for example, carbon monoxide and hydrogen are produced at a ratio of 1 : 2, to produce methanol by a subsequent chemical reaction.

[0042] Since hydrogen is an inexpensive and readily available raw material from water electrolysis and fossil fuels, the ratio of hydrogen does not need to be large. From these viewpoints, the ratio of carbon monoxide to hydrogen is at least 1 or more, and preferably 1.5 or more, which is preferable from economic and environmental aspects.

[0043] The electrolytic device in the arrangement is not limited to the carbon dioxide electrolytic device, and may be a nitrogen electrolytic device, for example. In the case of the nitrogen electrolytic device, the cathode 121 can reduce a nitrogen (N_2) gas to produce ammonia. For the other configuration of the nitrogen electrolytic device, the configuration of the carbon dioxide electrolytic device can be used as appropriate.

[0044] In the electrolysis cell 100, there has been known a phenomenon in which potassium (K^+) ions in the electrolytic solution circulating on the anode flow path 112 side move to the cathode flow path 122 side, and the K^+ ions flow out to the outside of the cell together with vapor, moisture generated at the cathode 121, or the like from the outlet of the cathode flow path 122, causing a decrease in the concentration of the electrolytic solution. When the concentration of the electrolytic solution circulating on the anode 111 side decreases, the resistance of the electrolysis cell 100 increases, causing problems such as degradation of the performance of the electrolysis cell 100 during a long continuous operation. In contrast to this, it is conceivable to use a pump to return the liquid that has collected in a cathode discharge liquid recovery bottle, called a trap, located on the outlet side of the cathode flow path 122, to an electrolytic solution tank that stores the electrolytic solution, which is connected to the anode flow path 112. This makes it possible to return the K^+ ions contained in the cathode discharge liquid to the electrolytic solution having a decreased concentration, and thus, the decrease in the concentration of the electrolytic solution can be hindered.

[0045] However, when the trap is used, the trap, the pump for moving the liquid from the trap to the electrolytic solution tank, and the like are required, the system around the electrolysis cell 100 becomes complicated, and power for driving the pump is also required. Further, the discharge rate of the liquid to be discharged from the cathode flow path 122 is slower than an electrolytic solution circulation rate on the anode flow path 112 side, and thus, the timing of transferring the liquid that has collected in the trap to the electrolytic solution tank becomes intermittent. In addition, it has been known that the concentration of K^+ ions in the cathode discharge liquid is higher than the concentration of K^+ ions in the electrolytic solution. Therefore, a high-concentration K^+ ion-containing liquid is intermittently dropped into the electrolytic solution tank. As a result, in this case, it takes time for the K^+ ions to diffuse in the electrolytic solution tank to make the concentration of K^+ ions uniform. It is preferable to have a more efficient mechanism that avoids such a decrease in the concentration of the electrolytic solution.

[0046] In contrast to this, the electrolytic device 1 in the arrangement includes the tank 200, and does not include any traps and any pumps for moving liquid from the trap to the electrolytic solution tank. FIG. 2 is a schematic view illustrating a structural example of the tank 200. The tank 200 includes a room 201, a room 202, a supply flow path 204, a discharge flow path 205, a supply flow path 206, a discharge flow path 207, and a discharge flow path 208.

[0047] The room 201 and the room 202 can store a liquid containing the anode solution. The container forming the room 201 and the room 202 may be made of glass, resin, metal, or the like. This container is a container having high gas and liquid airtightness. When the container is made of metal, an insulating coating is preferably applied inside in order to avoid leakage currents due to electrical conduction through the anode solution. The insulating coating may be resin, glass, or rubber, and is preferably highly durable. The container may be provided with water level sensors for measuring the heights of the liquid level of the liquid stored at one or several places in the container. Further, the container may be provided with sensors for measuring the ion concentration or conductivity of the liquid at one or several places in the container. Further, the container may be provided with sensors for measuring the pressure or temperature in the container at one or several places. The operation of the electrolytic device 1 may be controlled by a controller or the like with reference to the values detected by these sensors.

[0048] The volume of the container is preferably large enough to hold the anode solution for operating the electrolytic device 1 and the condensed water, and may be, for example, a volume of 1 L to 100 L, but the volume is not limited to this range. The shape of the container is not particularly limited, but may be spherical, cylindrical, or rectangular, for example.

[0049] At least one room may be further provided between the room 201 and the room 202. It is preferable that the heights of the bottoms of these rooms should be lowered gradually. It is further preferable that the anode solution should be always present in all of these rooms.

[0050] Further, a pipe for recovering gas may be connected to each of the tops of a plurality of the rooms. Thereby, even if the total amount of liquid in the container decreases or increases for some reason, the gas from the cathode flow path 122 and the gas from the anode flow path 112 do not mix easily, and gas products can be recovered while maintaining a safe state.

[0051] A partition 203 is provided between the room 201 and the room 202, and separates the room 201 from the

room 202. The partition 203 includes at least one opening 203a connecting the room 201 and the room 202. Any pumps are not formed in the middle of the opening 203a. The material of the partition 203 may be a semipermeable membrane, a polymer membrane, a liquid junction, or a porous material that allows liquid to pass therethrough but does not allow gas to pass therethrough, and may be, for example, a glass filter impregnated with liquid. Further, an ion exchange membrane may be used, and for example, a cation exchange membrane such as Nafion or Flemion can be used. The liquid junction may be, for example, a sintered glass layer, a cellulose layer, pulp, absorbent cotton, an animal semipermeable membrane such as fish skin, an ion exchange membrane, agar, a solution having a coagulated crystal structure, such as gelatin, or the like. A plurality of the openings 203 a may be provided.

[0052] The opening 203a allows liquid to pass therethrough but does not allow gas to pass therethrough. This makes it possible to spatially separate the gas component (for example, CO, CO₂, or hydrogen (H₂) gas) that comes out with the fluid discharged from the outlet of the cathode flow path 122 and the gas component (for example, oxygen (O₂) or CO₂ gas) that comes out with the electrolytic solution discharged from the outlet of the anode flow path 112. Thereby, valuable products (for example, CO or H₂ gas), which are products of a carbon dioxide electrolysis cell, can be recovered separately from the liquid, and further, the H₂ gas and the O₂ gas described above do not mix, and thus it is effective for safety.

[0053] The room 201 and the room 202 may be asymmetrical in shape with the partition 203 as a boundary. The two spaces created by the wall provided inside the container may have the same shape and volume, but may have different shapes and volumes. The volume of the room 201 is preferably smaller than the volume of the room 202, and further, an top 201a of the room 201 may be higher in height relative to a bottom 202b of the room 202 than an top 202a of the room 202. Further, a bottom 201b of the room 201 may be inclined so as to be lowered toward the room 202 in order to promote the movement of liquid from the room 201 to the room 202.

[0054] The supply flow path 204 connects the room 201 and the outlet of the cathode flow path 122. The electrolytic device 1 can supply the fluid containing the cathode gas supplied from the cathode flow path 122 to the room 201 via the supply flow path 204. The supply flow path 204 is preferably provided at a position closer to the top 201a than the bottom 201b of the room 201. As a result, the liquid from the cathode flow path 122 collects in the bottom of the container, and the gas product from the cathode flow path 122 collects in the top of the container. FIG. 2 illustrates, as one example, the supply flow path 204 provided in the top 201a.

[0055] The discharge flow path 205 is connected to the room 201. The electrolytic device 1 can discharge gaseous reduction products in the room 201 from the room 201 via the discharge flow path 205. The discharge flow path 205 is preferably provided at a position closer to the top 201a than the bottom 201b of the room 201. FIG. 2 illustrates, as one example, the discharge flow path 205 provided in the top 201a.

[0056] The supply flow path 206 connects the room 202 and the outlet of the anode flow path 112. The electrolytic device 1 can supply the fluid containing the anode solution supplied from the anode flow path 112 to the room 202 via the supply flow path 206. The supply flow path 206 may be provided at a position closer to the top 202a than the bottom 202b of the room 202, or may be provided at a position closer to the bottom 202b than the top 202a of the room 202. FIG. 2 illustrates, as one example, the supply flow path 206 provided in the top 202a.

[0057] The discharge flow path 207 is connected to the room 202. The electrolytic device 1 can discharge gaseous oxidation products supplied into the room 202 from the room 202 via the discharge flow path 207. The discharge flow path 207 may be provided at a position closer to the top 202a than the bottom 202b of the room 202, or may be provided at a position closer to the bottom 202b than the top 202a of the room 202. FIG. 2 illustrates, as one example, the discharge flow path 207 provided in the top 202a.

[0058] The discharge flow path 208 connects the room 202 and the anode supply part 401. The electrolytic device 1 can discharge the liquid containing the anode solution in the room 202 from the room 202 to the anode supply part 401 via the discharge flow path 208. The discharge flow path 208 is preferably provided at a position closer to the bottom 202b than the top 202a of the room 202. FIG. 2 illustrates, as one example, the discharge flow path 208 provided in a side portion 202c of the room 202.

[0059] The supply flow path 204, the discharge flow path 205, the supply flow path 206, the discharge flow path 207, and the discharge flow path 208 each are a pipe. The pipe is formed by using a material applicable to the container, for example.

[0060] The cathode supply part 301 is connected to the inlet of the cathode flow path 122. The cathode supply part 301 can supply the cathode gas to the cathode flow path 122. In the case of the carbon dioxide electrolytic device, the cathode supply part 301 can supply a cathode gas containing a carbon dioxide gas to the cathode flow path 122. In the case of the nitrogen electrolytic device, the cathode supply part 301 can supply a cathode gas containing nitrogen to the cathode flow path 122. The cathode supply part 301 includes, for example, a tank that stores the cathode gas, a mass flow controller that adjusts the flow rate of the cathode gas to be supplied from the tank to the cathode flow path 122, and so on. The supply of the cathode gas by the cathode supply part 301 may be controlled by a controller or the like according to a detection signal from water level sensors, pressure sensors, temperature sensors, sensors that measure the ion concentration or conductivity of a liquid, or the like provided in the container forming the room 201 and

the room 202.

[0061] The anode supply part 401 connects the discharge flow path 208 and the inlet of the anode flow path 112. The anode supply part 401 can supply the fluid containing the anode solution discharged from the discharge flow path 208 to the anode flow path 112. This allows the anode solution to circulate. The anode supply part 401 includes, for example,

a pump. The flow rate of the liquid containing the anode solution to be supplied to the anode 111 can be adjusted by the pump. The supply of the liquid by the anode supply part 401 may be controlled by a controller or the like according to a detection signal from water level sensors, pressure sensors, temperature sensors, sensors that measure the ion concentration or conductivity of a liquid, or the like provided in the container forming the room 201 and the room 202.

[0062] Next, an example of a method of driving the tank 200 is explained. When the electrolytic solution that has moved to the cathode flow path 122 side is supplied from the supply flow path 204 together with the cathode gas, the fluid containing the liquid and the gas generated on the cathode 121 side is pushed by the pressure of a raw material gas supplied to the cathode 121 side to the room 201. In the room 201, gas-liquid separation occurs due to the effect of gravity or the like. The separated liquid generated on the cathode 121 side containing metal ions is stored in the bottom of the room 201. On the other hand, a liquid having a substantially constant water level is present in the room 202. The electrolytic device 1 is driven in a manner that when the fluid containing the anode solution is supplied to the room 202 from the supply flow path 206 and the electrolytic solution that has moved to the cathode flow path 122 side is supplied to the room 201 from the supply flow path 204 together with the cathode gas, a level difference between a liquid level 211 and a liquid level 212 is formed so that the height of the liquid level 211 of the liquid stored in the room 201 relative to the bottom 202b of the room 202 is higher than the height of the liquid level 212 of the liquid stored in the room 202 relative to the bottom 202b of the room 202. This causes ions such as K^+ ions contained in the electrolytic solution to move from the room 201 to the room 202 through the opening 203a.

[0063] This allows, for example, the liquid having a high K^+ ion concentration discharged from the outlet of the cathode flow path 122 and the electrolytic solution circulating on the anode flow path 112 side to mix together through the opening 203a. Thereby, the K^+ ions diffuse in the electrolytic solution, and thus, a large concentration gradient does not occur, the time until the concentration of the K^+ ions becomes uniform can be significantly shortened, and the state where the electrolytic solution in the room 202 has a high concentration can be maintained. Further, the device configuration can be simplified, and thus, the installation area of the device can be made smaller. Further, the configuration of the tank 200 does not require the trap or the pump for moving liquid from the trap to the electrolytic solution tank, so that it is possible to reduce the amount of power required to operate the pump.

[0064] The structure of the tank 200 is not limited to the structural example illustrated in FIG. 2. FIG. 3 and FIG. 4 are schematic views illustrating another structural example of the tank 200.

[0065] A tank 200 illustrated in FIG. 3 is different from the tank 200 illustrated in FIG. 2 in that the opening 203a is formed by using a pipe 231. The pipe 231 connects the room 201 and the room 202. The pipe 231 may be formed by using a material applicable to the container, for example.

[0066] A valve controlled by an external signal may be provided in the middle of the pipe 231. The opening and closing of the valve is controlled by a controller or the like according to a detection signal from water level sensors, pressure sensors, temperature sensors, sensors that measure the ion concentration or conductivity of a liquid, or the like provided in the container.

[0067] Further, the tank 200 illustrated in FIG. 3 is different from the tank 200 illustrated in FIG. 2 in that the level difference between the liquid level 211 and the liquid level 212 is formed by making the bottom 201b higher in height relative to the bottom 202b than the bottom 202b.

[0068] A tank 200 illustrated in FIG. 4 is different from the tank 200 illustrated in FIG. 2 in that the opening 203a is formed in a partition 232 that does not allow liquid or gas to pass therethrough. The material of the partition 232 may be, for example, glass, resin, or metal. When the material of the partition 232 is metal, the partition 232 and the outside of the container are preferably electrically insulated. The thickness of the partition 232 is not particularly limited as long as it is strong enough to withstand the pressure difference in the internal space of the container. The thickness of the partition 232 may be, for example, 1 mm to 50 cm, but is not limited to this range.

[0069] The opening 203a illustrated in FIG. 4 is provided at a position closer to the bottom 201b of the room 201 and the bottom 202b of the room 202 than the top 201a of the room 201 and the top 202a of the room 202, respectively. The opening 203a may have a polygonal shape such as a triangle or a circle, or the shape of the opening 203a may be a combination thereof. The opening 203a preferably has a shape that does not hinder the movement of liquid, but the circumference of the opening 203a may be flat or may have a protrusion provided thereon.

[0070] The opening 203a preferably has a size that does not hinder the movement of liquid, and the size may be, for example, 1 mm to 10 cm, but is not limited to this range.

[0071] The number of openings 203a per unit area is preferably a value that does not hinder the movement of liquid, and more preferably a value that can maintain the strength of the partition 203.

[0072] The above arrangement has been presented by way of example only, and is not intended to limit the scope of the inventions. Indeed, the above arrangement may be embodied in a variety of other forms; furthermore, various

omissions, substitutions, and changes in the form of the arrangement 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.

5 (Numbered Clauses relating to the arrangements)

[0073]

- 10 1. An electrolytic device, comprising:
 - an electrolysis cell comprising: a cathode; an anode; a cathode flow path facing on the cathode; and an anode flow path facing on the anode;
 - a tank comprising: a first room; a second room; and an opening connecting the first room and the second room, the first room and the second room being configured to store a liquid containing at least one ion, the tank being configured to form a level difference between a first liquid level and a second liquid level so that a height of the first liquid level of the liquid to be stored in the first room relative to a bottom of the second room is higher than a height of the second liquid level of the liquid to be stored in the second room relative to the bottom of the second room, and thus cause an ion contained in the liquid to move from the first room to the second room through the opening;
 - 20 a first flow path connecting an outlet of the cathode flow path and the first room; and
 - a second flow path connecting the second room and an outlet of the anode flow path.
- 25 2. The device according to clause 1, wherein the tank comprises a partition provided between the first and second rooms and having the opening.
3. The device according to clause 1 or clause 2, wherein the tank comprises a pipe having the opening.
- 30 4. The device according to any one of clauses 1 to 3, wherein the tank does not comprise any pumps in the middle of the opening.
5. The device according to any one of clauses 1 to 4, wherein a bottom of the first room is higher than the bottom of the second room.
- 35 6. The device according to any one of clauses 1 to 5, wherein the cathode is configured to reduce carbon dioxide to produce a carbon compound.
7. The device according to any one of clauses 1 to 5, wherein the cathode is configured to reduce nitrogen to produce ammonia.
- 40 8. The device according to any one of clauses 1 to 7, wherein the at least one ion includes a potassium ion.
- 45 9. A method of driving an electrolytic device, the electrolytic device comprising:
 - an electrolysis cell comprising: a cathode; an anode; a cathode flow path facing on the cathode; and an anode flow path facing on the anode;
 - a tank comprising: a first room; a second room; and an opening connecting the first room and the second room, the first room and the second room being configured to store a liquid containing at least one ion;
 - 50 a first flow path connecting an outlet of the cathode flow path and the first room; and
 - a second flow path connecting the second room and an inlet of the anode flow path, the method comprising: forming a level difference between a first liquid level and a second liquid level so that a height of the first liquid level of the liquid to be stored in the first room relative to a bottom of the second room is higher than a height of the second liquid level of the liquid to be stored in the second room relative to the bottom of the second room, and thus causes an ion contained in the liquid to move from the first room to the second room through the opening.
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10. The method according to clause 9, wherein

the tank comprises a partition provided between the first and second rooms and having the opening.

11. The method according to clause 9 or clause 10, wherein the tank comprises a pipe having the opening.

12. The method according to any one of clauses 9 to 11, wherein the tank does not comprises any pumps in the middle of the opening.

13. The method according to any one of clauses 9 to 12, wherein a bottom of the first room is higher than the bottom of the second room.

14. The method according to any one of clauses 9 to 13, wherein the cathode reduces carbon dioxide to produce carbon compounds.

15. The method according to any one of clauses 9 to 13, wherein the cathode reduces nitrogen to produce ammonia.

16. The method according to any one of clauses 9 to 15, wherein the at least one ion includes a potassium ion.

Claims

1. An electrolytic device, comprising:

an electrolysis cell comprising: a cathode; an anode; a cathode flow path facing on the cathode; and an anode flow path facing on the anode;

a tank comprising: a first room; a second room; and an opening connecting the first room and the second room, the first room and the second room being configured to store a liquid containing at least one ion, the tank being configured to form a level difference between a first liquid level and a second liquid level so that a height of the first liquid level of the liquid to be stored in the first room relative to a bottom of the second room is higher than a height of the second liquid level of the liquid to be stored in the second room relative to the bottom of the second room, and thus cause an ion contained in the liquid to move from the first room to the second room through the opening;

a first flow path connecting an outlet of the cathode flow path and the first room; and
a second flow path connecting the second room and an outlet of the anode flow path.

2. The device according to claim 1, wherein the tank comprises a partition provided between the first and second rooms and having the opening.

3. The device according to claim 1 or claim 2, wherein the tank comprises a pipe having the opening.

4. The device according to any one of claims 1 to 3, wherein the tank does not comprise any pumps in the middle of the opening.

5. The device according to any one of claims 1 to 4, wherein a bottom of the first room is higher than the bottom of the second room.

6. The device according to any one of claims 1 to 5, wherein the at least one ion includes a potassium ion.

7. A method of driving an electrolytic device, the electrolytic device comprising:

an electrolysis cell comprising: a cathode; an anode; a cathode flow path facing on the cathode; and an anode flow path facing on the anode;

a tank comprising: a first room; a second room; and an opening connecting the first room and the second room,

the first room and the second room being configured to store a liquid containing at least one ion;
a first flow path connecting an outlet of the cathode flow path and the first room; and
a second flow path connecting the second room and an inlet of the anode flow path, the method comprising:
forming a level difference between a first liquid level and a second liquid level so that a height of the first liquid
level of the liquid to be stored in the first room relative to a bottom of the second room is higher than a height
of the second liquid level of the liquid to be stored in the second room relative to the bottom of the second room,
and thus causes an ion contained in the liquid to move from the first room to the second room through the opening.

8. The method according to claim 7, wherein
the tank comprises a partition provided between the first and second rooms and having the opening.
9. The method according to claim 7 or claim 8, wherein
the tank comprises a pipe having the opening.
10. The method according to any one of claims 7 to 9, wherein
the tank does not comprises any pumps in the middle of the opening.
11. The method according to any one of claims 7 to 10, wherein
a bottom of the first room is higher than the bottom of the second room.
12. The method according to any one of claims 7 to 11, wherein
the cathode reduces carbon dioxide to produce carbon compounds.
13. The method according to any one of claims 7 to 11, wherein
the cathode reduces nitrogen to produce ammonia.
14. The method according to any one of claims 7 to 13, wherein
the at least one ion includes a potassium ion.

FIG. 1

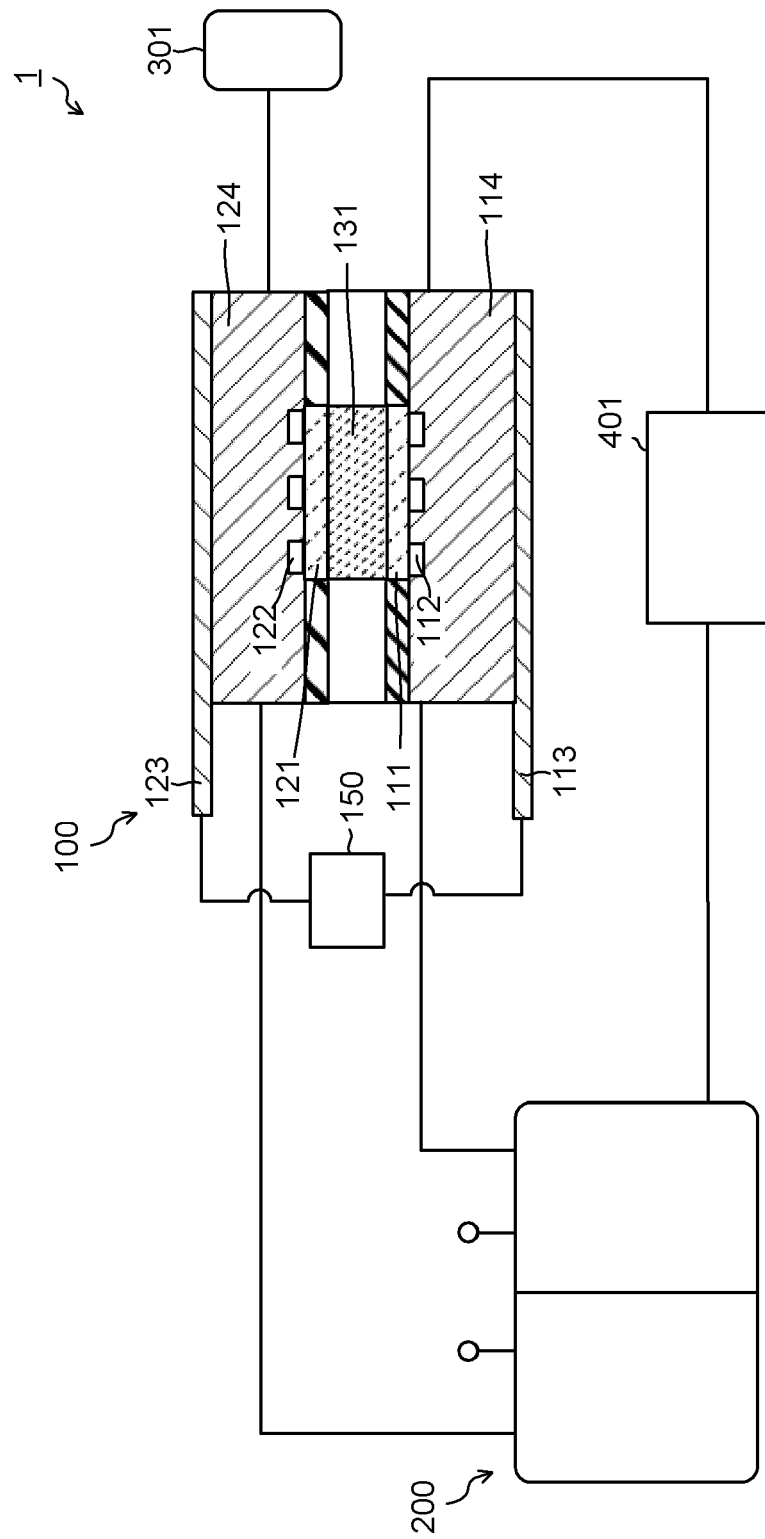


FIG. 2

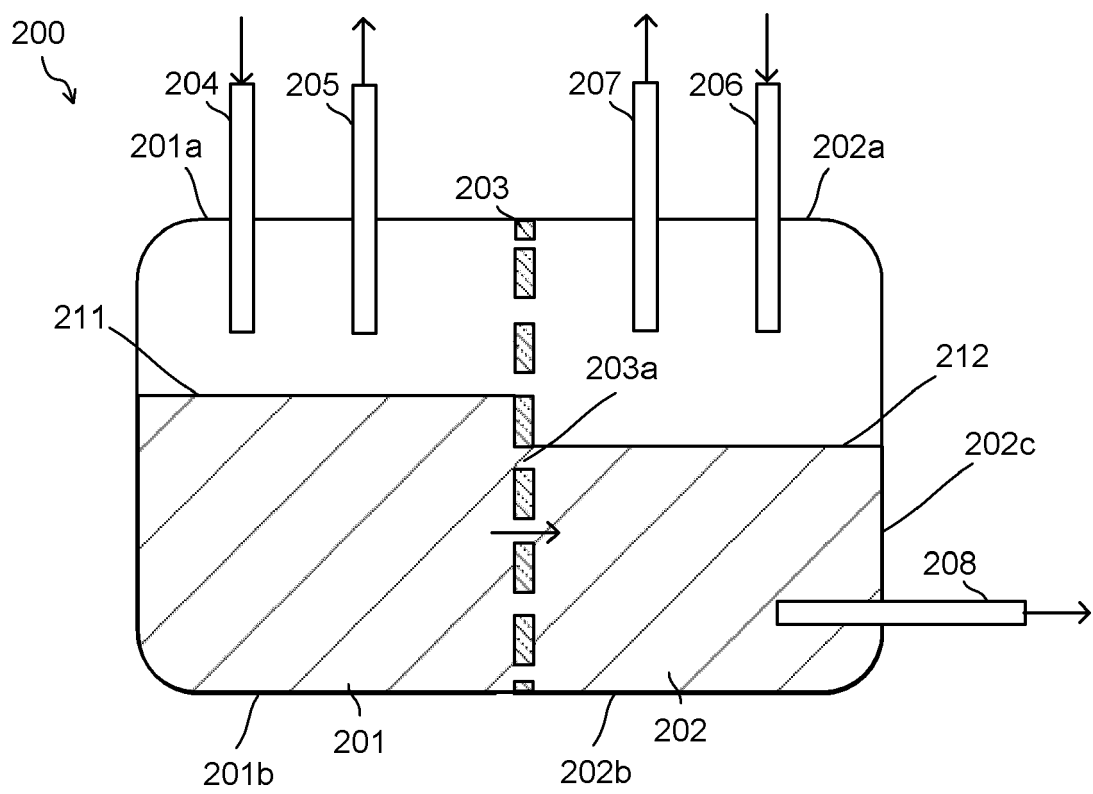


FIG. 3

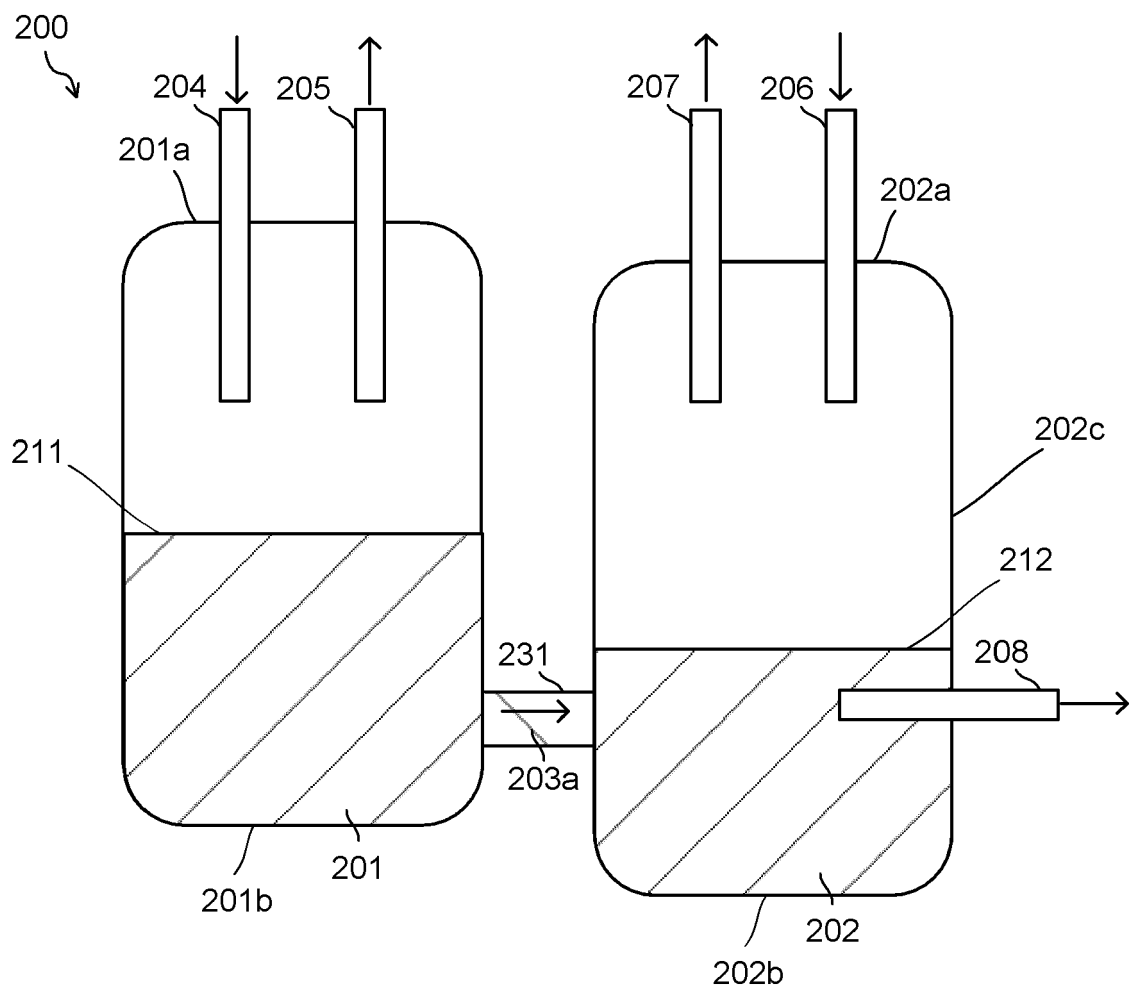
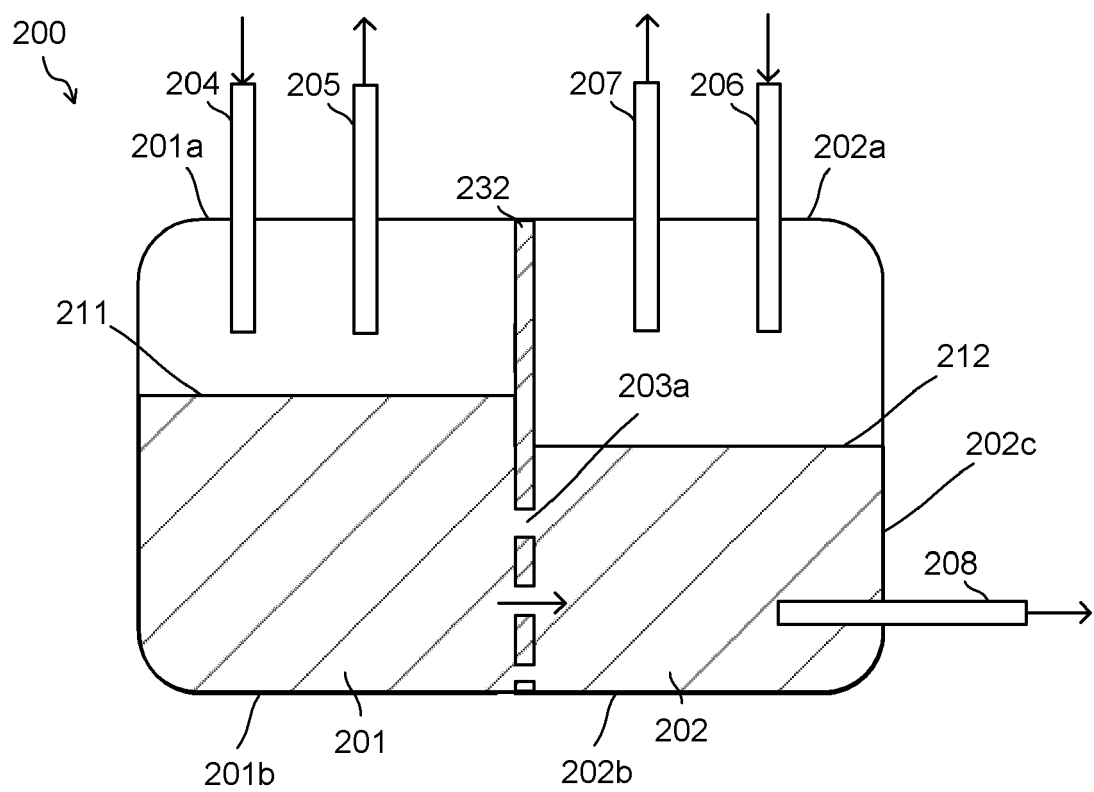


FIG. 4





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