

Description

ELECTRODEIONIZATION APPARATUS FOR PRODUCING DEIONIZED WATER

Technical Field

5 [0001]

The present invention relates to an electrodeionization apparatus for producing deionized water.

Background Art

[0002]

10 In recent years, an electrodeionization apparatus for producing deionized water (hereinafter this apparatus may be referred to as "EDI apparatus") that does not require regeneration by chemicals has been developed and put into practical use. An EDI apparatus is an apparatus in which electrophoresis and electro dialysis are combined. The basic configuration of a general EDI apparatus is as follows. That is, the EDI apparatus includes a deionization chamber, a pair of concentration chambers adjacent to both
15 sides of the deionization chamber, an anode (positive electrode) chamber disposed on the outside of one concentration chamber, and a cathode (negative electrode) chamber disposed on the outside of the other concentration chamber. The deionization chamber includes an anion exchange membrane and a cation exchange membrane arranged opposite to each other, and an ion exchanger (anion exchanger or/and cation exchanger) packed between these ion exchange membranes. Anion components and cation
20 components, which are present in water to be treated, move from the deionization chamber to the concentration chambers through the anion exchange membrane and the cation exchange membrane, respectively, and treated water, i.e., deionized water, is obtained from the deionization chamber, and concentrated water is obtained from the concentration chambers.

[0003]

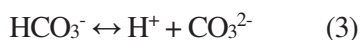
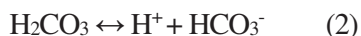
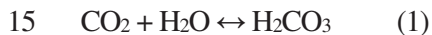
25 In order to produce deionized water, the water to be treated is passed into the deionization chamber while DC voltage is applied between electrodes that are arranged in the anode chamber and the cathode chamber, respectively. In the deionization chamber, the anion components (such as Cl^- , CO_3^{2-} , HCO_3^- , SiO_2) are captured by the anion exchanger, and the cation components (such as Na^+ , Ca^{2+} , Mg^{2+}) are captured by the cation exchanger. Simultaneously, a dissociation reaction of water (water splitting
30 reaction) occurs at the interface between the anion exchanger and the cation exchanger, for example, to generate hydrogen ions and hydroxide ions ($\text{H}_2\text{O} \rightarrow \text{H}^+ + \text{OH}^-$). The ion components, which have been captured by the ion exchangers, are replaced with the hydrogen ions and hydroxide ions, and then released from the ion exchangers. The released ion components are electrophoresed through the ion exchangers to the ion exchange membranes (anion exchange membrane or cation exchange membrane),

and are subjected to electrodialysis at the ion exchange membrane and then move into the concentration chambers. The ion components which have moved into the concentration chambers are discharged by water flowing through the concentration chambers.

[0004]

5 In the EDI apparatus, a phenomenon occurs in which weak acid components contained in the concentrated water diffuse into the treated water through the cation exchange membrane that partitions the concentration chamber and the deionization chamber, thereby decreasing the purity of the treated water. This is because weak acid components, which typically are carbonic acid, silica (silicic acid) and boron (boric acid), partially take on the forms of non-ionized molecules (neutral molecules) depending
10 on variation of the pH or the like, and therefore, they are hardly affected by the selective permeability of the cation exchange membrane. For example, as to the carbonic acid, there is equilibrium relationship represented by formulae (1) to (3). For the carbonic acid, the form of the non-ionized molecules (neutral molecules) is CO₂ as well as H₂CO₃, which can easily pass through the cation exchange membrane.

[0005]



[0006]

20 Patent Literature 1 discloses an EDI apparatus capable of suppressing contamination of treated water by weak acid components which have diffused from a concentration chamber into a deionization chamber. In this apparatus, a deionization chamber is partitioned into a first small deionization chamber and a second small deionization chamber by an ion exchange membrane. The first small deionization chamber is filled with an anion exchanger. The second small deionization chamber is filled with an
25 anion exchanger and a cation exchanger in a sequence such that the final ion exchanger, through which water to be treated finally passes, becomes an anion exchanger.

[0007]

Patent Literature 1 discloses that the second small deionization chamber is filled with an anion exchanger, that a bipolar membrane is disposed on the cathode side of the anion exchanger, and that the
30 surface made of an anion exchange membrane of the bipolar membrane faces the anion exchanger, in order to accelerate the water dissociation reaction and to realize suitable distribution of the current density.

[0008]

Patent Literatures 2 and 3 also disclose the use of a bipolar membrane in an EDI apparatus.

Patent Literatures 4 and 5 and Non-Patent Literature 1 disclose bipolar membranes.

Prior Art Literature

Patent Literature

5 [0009]

Patent Literature 1: JP 2012-161758 A

Patent Literature 2: WO 2013/018818

Patent Literature 3: WO 2011/152226

Patent Literature 4: JP H07-11021 A

10 Patent Literature 5: JP 2010-132829 A

Non-Patent Literature

[0010]

15 Non-Patent Literature 1: Yoshinobu Tanaka, "Ion Exchange Membranes Fundamentals and Applications", Maruzen Publishing, 2016, p. 15-18

Summary of Invention

Problems to be solved by the Invention

[0011]

20 In the EDI apparatus, it is very important how efficiently the weak acid components, which have diffused from the concentration chamber into the water to be treated contained in the deionization chamber, can be removed from the water to be treated.

[0012]

25 An object of the present invention is to provide an EDI apparatus having a novel configuration capable of efficiently removing a weak acid component, which has diffused from a concentration chamber into water to be treated contained in a deionization chamber, from the water to be treated.

Means for solving the Problems

[0013]

30 An aspect of the present invention provides an electrodeionization apparatus for producing deionized water comprising at least one deionization treatment unit provided between a cathode and an anode that are opposite to each other,

the deionization treatment unit comprising a deionization chamber filled with at least an anion exchanger and a pair of concentration chambers adjacent to both sides of the deionization chamber,

the deionization chamber being adjacent to one concentration chamber from among the pair of concentration chambers via a cation exchange membrane, said one concentration chamber being located on the cathode side, and

the deionization chamber being adjacent to the other concentration chamber from among the pair of concentration chambers via a first anion exchange membrane, said other concentration chamber being located on the anode side, wherein

a second anion exchange membrane is layered on a partial region of a deionization-chamber-side surface of the cation exchange membrane, as a separate body from the cation exchange membrane, and

the anion exchanger is in contact with at least a part of a deionization-chamber-side surface of the second anion exchange membrane.

Effects of the Invention

[0014]

The present invention provides an EDI apparatus having a novel configuration capable of efficiently removing a weak acid component, which has diffused from a concentration chamber into water to be treated contained in a deionization chamber, from the water to be treated.

Brief Description of the Drawings

[0015]

Figure 1 is a schematic cross-sectional view showing a schematic configuration of an embodiment of the EDI apparatus of the present invention;

Figure 2 is a schematic cross-sectional view showing a schematic configuration of an example in which the number of repetitions N is 2 in the apparatus shown in FIG. 1;

Figure 3 is a schematic sectional view showing a schematic configuration of another embodiment of the EDI apparatus of the present invention.

Figure 4 is a schematic sectional view showing a schematic configuration of yet another embodiment of the EDI apparatus of the present invention.

Figure 5 is a schematic sectional view showing a schematic configuration of yet another embodiment of the EDI apparatus of the present invention.

Figure 6 is a schematic sectional view showing a schematic configuration of yet another embodiment of the EDI apparatus of the present invention.

Figure 7 is a conceptual diagram for explaining the mechanism of the present invention.

Figure 8 is another conceptual diagram for explaining the water dissociation mechanism at the

interface where a cation exchange membrane and an anion exchange membrane are layered.

Figure 9 is a conceptual diagram for explaining the water dissociation mechanism in a bipolar membrane.

Figure 10 is a conceptual diagram for explaining a situation in which anions and cations are discharged from an interface where two membranes are layered.

Description of Embodiments

[0016]

In an EDI apparatus whose deionization chamber is filled with an anion exchanger, weak acid components, which have diffused from the concentration chamber into the deionization chamber, can be captured by the anion exchanger and removed from the treated water. However, a part of the weak acid components, which have diffused from the concentration chamber into a region of the deionization chamber near the outlet thereof, is easily discharged from the deionization chamber before being captured and removed by the anion exchanger contained in the deionization chamber, and is easily mixed into the treated water. This phenomenon occurs probably because the weak acid components, which have diffused from the concentration chamber, do not sufficiently come into contact with the anion exchanger and leak into the treated water.

[0017]

FIG. 7(a) conceptually shows the vicinity of the boundary between deionization chamber 23 and concentration chamber 24, which is located on the cathode side of deionization chamber 23, in an example of a conventional EDI apparatus. In this EDI apparatus, cation exchange membrane 33 partitions deionization chamber 23 and concentration chamber 24 which is located on the cathode side of deionization chamber 23. Deionization chamber 23 is filled with anion exchange resin 51 as an anion exchanger, and anion exchange resin 51 is in contact with the surface of cation exchange membrane 33 on the side of the deionization chamber. In such an apparatus, the weak acid components, which have diffused from concentration chamber 24 through cation exchange membrane 33, can be ionized by an ion exchange reaction and captured in anion exchange resin 51 with respect to the portion where cation exchange membrane 33 and anion exchange resin 51 are in contact with each other. For example, carbonic acid (H_2CO_3) is converted into bicarbonate ions (HCO_3^-) or carbonate ions (CO_3^{2-}) and captured by anion exchange resin 51. The captured anions can move through anion exchange resin 51 to the opposite (anode-side) concentration chamber. On the other hand, in the portion where cation exchange membrane 33 is not in contact with anion exchange resin 51, it is considered that the weak acid components are released from cation exchange membrane 33 to the liquid phase contained in deionization chamber 23, and that a part of the weak acid components is mixed into the treated water.

[0018]

The inventors have found that there is a possibility that the above-mentioned object of the invention is achieved by a configuration in which cation exchange membrane 33 partitions deionization chamber 23 and concentration chamber 24, and in which anion exchange membrane 40 is layered on the surface of cation exchange membrane 33 on the side of the deionization chamber, as shown in FIG. 7(b). According to this configuration, the weak acid components, which have diffused to the deionization chamber through cation exchange membrane 33, permeate through anion exchange membrane 40. At this time, the weak acid components are converted from neutral molecules to anions by ion exchange in anion exchange membrane 40, and thus become ionic forms which are easily captured by anion exchange resin 51 contained in deionization chamber 23.

[0019]

In order to realize the configuration as shown in FIG. 7(b), the inventors have studied the use of a bipolar membrane instead of cation exchange membrane 33 which is shown in FIG. 7(a). A bipolar membrane is a membrane in which a cation exchange membrane and an anion exchange membrane are integrated into a single body, and usually has a structure in which a cation exchange membrane and an anion exchange membrane are adhered to each other. The bipolar membrane has a structure in which the adhesion interface between the cation exchange membrane and the anion exchange membrane is optimized for the dissociation reaction of water, and is configured so that the dissociation reaction of water easily proceeds. For this purpose, in general, a substance having a catalytic function for water dissociation is introduced into the adhesion interface. As the catalyst component, for example, a catalyst component such as a metal, a heavy metal ion in particular, or a tertiary amine, as disclosed in Non-Patent Literature 1, is used.

[0020]

FIG. 9 shows a configuration in which a bipolar membrane is used as described above. Bipolar membrane 50 has cation exchange membrane portion 50c and anion exchange membrane portion 50a. At the adhesion interface between cation exchange membrane portion 50c and anion exchange membrane portion 50a, H_2O is converted into H^+ and OH^- by the water dissociation reaction and consumed. Therefore, water needs to be efficiently supplied to the adhesion interface. This water must be supplied by moisture that penetrates respective membrane portions 50a and 50c to the adhesion interface in the thickness direction of the membrane. Therefore, at least one of cation exchange membrane portion 50c and anion exchange membrane portion 50a of bipolar membrane 50 needs to be thin so that the supply of water can be smoothly performed. However, the thickness of the cation exchange membrane portion and the anion exchange membrane portion may not be reduced from the viewpoint of strength or due to manufacturing problems.

[0021]

On the other hand, in the configuration shown in FIG. 7(b), it is considered that thicker anion exchange membrane 40 is suitable for more reliably ionizing the weak acid components, which have diffused from the concentration chamber, in anion exchange membrane 40. Thus, it has been found that realizing the configuration as shown in FIG. 7(b) without using a bipolar membrane is desirable. Further, a bipolar membrane having an adhered structure of an anion exchange membrane and a cation exchange membrane is more expensive than an anion exchange membrane or a cation exchange membrane which is formed of a single ion exchanger. Therefore, also from the viewpoint of cost, it is desirable not to use a bipolar membrane.

10 [0022]

In this regard, the inventors have found that water can be smoothly supplied to the interface between cation exchange membrane 33 and anion exchange membrane 40 by providing cation exchange membrane 33 and anion exchange membrane 40 as separate bodies, and by layering anion exchange membrane 40 on a partial region, not the whole region, of the surface of cation exchange membrane 33 on the side of the deionization chamber. According to this configuration, when determining the thickness of each ion exchange membrane, it is not necessary to consider the supply of water to the interface of these ion exchange membranes. Therefore, the degree of design flexibility is high, and it is easy to use thick anion exchange membrane 40.

[0023]

20 This configuration is conceptually shown in FIG. 8. It should be noted that anion exchange resin 51 is not shown in FIG. 8. Also, it should be noted that cation exchange membrane 33 and anion exchange membrane 40 appear to be apart from each other in FIG. 8, but these membranes may be in contact with each other.

[0024]

25 When the water dissociation reaction proceeds at the interface between cation exchange membrane 33 and anion exchange membrane 40 and thus H_2O is consumed, water contained in deionization chamber 23 is supplied from between cation exchange membrane 33 and the end portion(s) of anion exchange membrane 40 (the end portion(s) in the vertical direction of the drawing in FIG. 8). OH^- ions pass through anion exchange membrane 40 and are supplied to deionization chamber 23, and H^+ ions pass through cation exchange membrane 33 and are supplied to concentration chamber 24.

[0025]

The inventors have studied and found that, in the case where a bipolar membrane is used in place of anion exchange membrane 40 in the configuration shown in FIG. 8 (see Comparative Example 3 described later), a phenomenon may occur in which electric current concentratedly flows through the

bipolar membrane. This is probably because the water dissociation reaction is remarkably enhanced by the bipolar membrane.

[0026]

On the other hand, in the configuration shown in FIG. 8, the ion exchange membranes are
5 separate bodies from each other, and overlap with each other to form the interface therebetween. The voltage at which the water dissociation reaction proceeds at this interface is close to a voltage at which the water dissociation reaction proceeds at a usual contact point between an ion exchange resin and an ion exchange membrane (for example, the contact point between cation exchange membrane 33 and anion exchange resin 51 in FIG. 7(a)). Therefore, according to the configuration shown in FIG. 8, it is
10 easier to suppress the phenomenon that the current concentratedly flows as compared with the case where the bipolar membrane, which has the catalytic function at a portion where the water dissociation reaction proceeds, is used.

[0027]

The present invention has been achieved based on the above-mentioned findings. According to
15 the present invention, weak acid components, which have diffused from a concentration chamber, can be efficiently treated, and treated water of high purity can be obtained. Furthermore, the current concentration, which is generated when the bipolar membrane is used as described above, can be reduced, and as a result, treated water of higher purity can be obtained.

[0028]

20 Hereinafter, embodiments of the present invention will be described in detail with reference to the drawings, but the present invention is not limited thereto.

[0029]

FIG. 1 shows a basic embodiment of an EDI apparatus according to the present invention. In the EDI apparatus, at least one deionization treatment unit is provided between cathode 12 and anode 11
25 which are opposite to each other. The deionization treatment unit has deionization chamber 23 and a pair of concentration chambers 22 and 24 which are adjacent to both sides of deionization chamber 23, respectively, and also has anion exchange membrane (AEM) 32, which is a first anion exchange membrane, and cation exchange membrane (CEM) 33.

[0030]

30 Deionization chamber 23 is adjacent to concentration chamber 24 from among the pair of concentration chambers 22 and 24 via cation exchange membrane 33, this concentration chamber 24 being located on the cathode side. Also, deionization chamber 23 is adjacent to concentration chamber 22 from among the pair of concentration chambers 22 and 24 via the anion exchange membrane 32, this concentration chamber 22 being located on the anode side. The deionization chamber 23 is thus

partitioned by anion exchange membrane 32 which is located on the side facing anode 11 and by cation exchange membrane 33 which is located on the side facing cathode 12.

[0031]

In the EDI apparatus shown in FIG. 1, concentration chamber 22, deionization chamber 23 and concentration chamber 24 are provided, in this order from the anode chamber 21 side, between anode chamber 21 equipped with anode 11 and cathode chamber 25 equipped with cathode 12. Anode chamber 21 and concentration chamber 22 are adjacent to each other with cation exchange membrane 31 therebetween. Concentration chamber 24 and cathode chamber 25 are adjacent to each other with anion exchange membrane 34 therebetween.

10 [0032]

Deionization chamber 23 is filled with at least an anion exchanger. In the example shown in FIG. 1, deionization chamber 23 is filled with an anion exchanger and a cation exchanger, which form a mixed bed (MB). However, this is not limiting, and deionization chamber 23 may be filled with only an anion exchanger. Alternatively, one or more anion exchanger beds (beds consisting of an anion exchanger) and one or more cation exchanger beds (beds consisting of a cation exchanger) may be provided in deionization chamber 23. In this case, it is preferable that the deionization chamber is filled with the anion exchanger bed(s) and the cation exchanger bed(s) in a sequence such that the final ion exchanger, through which water to be treated finally passes, becomes the anion exchanger.

[0033]

20 Further, in this EDI apparatus, anode chamber 21 is filled with a cation exchanger, and concentration chambers 22 and 24 and cathode chamber 25 are filled with an anion exchanger. However, anode chamber 21, concentration chambers 22 and 24 and cathode chamber 25 need not be filled with an ion exchanger (anion exchanger nor cation exchanger).

[0034]

25 However, the effect of the present invention is particularly remarkable when concentration chambers 22 and 24 are filled with an anion exchanger. This is because the diffusion phenomenon of the weak acid components from the concentration chamber to the deionization chamber tends to be more significant when concentration chambers 22 and 24 are filled with the anion exchanger.

[0035]

30 An anion exchange resin (AER), for example, is used as the anion exchanger, and a cation exchange resin (CER), for example, is used as the cation exchanger. An ion exchange resin is synthetic resin in which a functional group (ion exchange group) is introduced into a polymer matrix having a three-dimensional network structure. The ion exchange resin is usually in the form of spherical particles having a particle diameter of about 0.4 to 0.8 mm. Examples of the polymer matrix of the ion exchange

resin include a styrene-divinylbenzene copolymer (styrene resin) and an acrylic acid-divinylbenzene copolymer (acrylic resin).

[0036]

5 The ion exchange resin can be roughly classified into a cation exchange resin in which the functional group is acidic and an anion exchange resin in which the functional group is basic, and further can be classified, depending on the type of the ion exchange group introduced, into a strongly acidic cation exchange resin, a weakly acidic cation exchange resin, a strongly basic anion exchange resin, a weakly basic anion exchange resin, and the like. Examples of the strongly basic anion exchange resin include resins having a quaternary ammonium group as a functional group (ion exchange group), and
10 examples of the weakly basic anion exchange resin include resins having a primary, secondary or tertiary amine as a functional group. Examples of the strongly acidic cation exchange resin include resins having a sulfonic acid group as a functional group, and examples of the weakly acidic cation exchange resin include resins having a carboxyl group as a functional group.

[0037]

15 Next, the production of deionized water (treated water) by using the EDI apparatus shown in FIG. 1 will be described. Supply water is fed to anode chamber 21, concentration chambers 22 and 24 and cathode chamber 25, and the water to be treated is passed through deionization chamber 23, in a state where a DC voltage is applied between anode 11 and cathode 12. Then, ion components in the water to be treated are adsorbed to the ion exchanger in deionization chamber 23, the deionization
20 (demineralization) process is performed, and the deionized water flows out from deionization chamber 23 as the treated water. At this time, in deionization chamber 23, a dissociation reaction of water occurs mainly at the interface between different types of ion exchangers (which may be ion exchange membranes) due to the applied voltage, and hydrogen ions and hydroxide ions are generated. Then, the ion components which have been previously adsorbed to the ion exchanger in deionization chamber 23
25 undergo ion exchange with the hydrogen ions and hydroxide ions, and are released from the ion exchanger. From among the released ion components, anions move to concentration chamber 22, which is located on the anode side, via anion exchange membrane 32, and are discharged in concentrated water from concentration chamber 22. From among the released ion components, cations move to concentration chamber 24, which is located on the cathode side, via cation exchange membrane 33, and
30 are discharged in concentrated water from concentration chamber 24. As a result, the ion components in the water to be treated, which has been supplied to deionization chamber 23, move to concentration chambers 22 and 24, and are discharged. Simultaneously, the ion exchanger in deionization chamber 23 is regenerated. In addition, electrode water is discharged from anode chamber 21 and cathode chamber 25.

[0038]

In the EDI apparatus according to the present invention, cation exchange membrane 33 partitions deionization chamber 23 and concentration chamber 24. And, anion exchange membrane 40, which is a second anion exchange membrane, is layered on a partial region, not the whole region, of the surface of cation exchange membrane 33 on the side of deionization chamber 23. Hereinafter, a surface (of a membrane) on the side of deionization chamber 23 may be referred to as "deionization-chamber-side surface". Anion exchange membrane 40 is a separate body from cation exchange membrane 33, in other words, is not integrated with cation exchange membrane 33 into a single body.

[0039]

Cation exchange membrane 33 is provided so as to partition concentration chamber 24 and deionization chamber 23, and thus is arranged in the substantially whole region of the boundary between deionization chamber 23 and concentration chamber 24. On the other hand, as described above, anion exchange membrane 40 is layered on a partial region of the deionization-chamber-side surface of cation exchange membrane 33. Therefore, the area of anion exchange membrane 40 is smaller than the area of cation exchange membrane 33. With such a configuration, the interface between cation exchange membrane 33 and anion exchange membrane 40 can be in contact with water which is contained in deionization chamber 23. Therefore, as described with reference to FIG. 8, it is possible to supply the water in deionization chamber 23 to the interface between cation exchange membrane 33 and anion exchange membrane 40 from between cation exchange membrane 33 and the end portion(s) of anion exchange membrane 40 (the end portion(s) in the vertical direction in FIG. 1).

[0040]

Hereinafter, the abovementioned partial region (i.e., the region, which overlaps anion exchange membrane 40, of the deionization-chamber-side surface of cation exchange membrane 33) may be referred to as "overlap region". With respect to one cation exchange membrane 33, there may be a single overlap region (see FIGS. 1 to 3 and 5 to 6), or a plurality of overlap regions may exist apart from each other (see FIG. 4). When a single overlap region exists on the deionization-chamber-side surface of cation exchange membrane 33, one anion exchange membrane 40 can be overlapped on this region. When there is a plurality of overlap regions on the deionization-chamber-side surface of cation exchange membrane 33, one anion exchange membrane 40 may be overlapped on each overlap region. When there is a plurality of overlap regions, these regions may be apart from each other along the water passing direction of the water to be treated in deionization chamber 23.

[0041]

From the viewpoint of preventing the weak acid component from contaminating the treated water, it is preferable that the overlap region includes a region of the deionization-chamber-side surface

of cation exchange membrane 33, the latter region reaching the end of cation exchange membrane 33 on the deionization chamber outlet side (the end on the treated water outlet side). That is, when there is a single overlap region, it is preferable that this overlap region reaches the end of cation exchange membrane 33 on the deionization chamber outlet side. When there is a plurality of overlap regions, it is preferable that one of these overlap regions reaches the end of cation exchange membrane 33 on the deionization chamber outlet side. In particular, when there is a plurality of overlap regions apart from each other along the water passing direction of the water to be treated in deionization chamber 23, it is preferable that the overlap region which is located at the most downstream position in the water passing direction reaches the end of cation exchange membrane 33 on the deionization chamber outlet side.

10 [0042]

For example, anion exchange membrane 40 has the same width (the dimension in the depth direction of the drawing in FIG. 1) as cation exchange membrane 33, and has a length (the dimension in the vertical direction of the drawing in FIG. 1) shorter than cation exchange membrane 33.

[0043]

15 At least a part of the surface of anion exchange membrane 40 on the side of deionization chamber 23 is in contact with an anion exchanger. In the present embodiment, the mixed bed (MB) is in contact with the surface of anion exchange membrane 40 on the side of the deionization chamber. Therefore, the anion exchanger, in particular, the anion exchange resin, contained in the mixed bed is in contact with the surface of the anion exchange membrane 40 on the side of the deionization chamber.

20 Thus, it is easy to efficiently discharge the weak acid components, which have diffused from the concentration chamber and which have been converted from neutral molecules to anions by anion exchange membrane 40, into concentration chamber 22 through the anion exchanger packed in deionization chamber 23, and further through anion exchange membrane 32. From this viewpoint, it is preferable that an anion exchanger bed or a mixed bed be provided in the deionization chamber so as to be in contact with anion exchange membranes 40 and 32, in order to form a path for moving anions through the anion exchanger from anion exchange membrane 40 to anion exchange membrane 32.

25 [0044]

As cation exchange membrane 33 and anion exchange membrane 40, those known in the field of EDI apparatus and electrodialysis (ED) apparatus can be used.

30 [0045]

The thickness of each of cation exchange membrane 33 and anion exchange membrane 40 is generally about 100 μm to 700 μm , particularly about 200 μm to 600 μm .

[0046]

It is preferable that neither cation exchange membrane 33 nor anion exchange membrane 40

contains such a catalyst component for promoting the water dissociation reaction as contained in a bipolar membrane, from the viewpoint of preventing concentration of electric current.

[0047]

The ion exchange membrane can be roughly classified into a heterogeneous membrane and a homogeneous membrane. The heterogeneous membrane is obtained by dispersing fine powder of an ion exchange resin in an appropriate binder (polymer compound), and by heating and forming the resulting substance into the form of a membrane. On the surface of the heterogeneous membrane, there is a portion made of an inert polymer compound in which there is no ion exchange group. The heterogeneous membrane is easier to manufacture than the homogeneous membrane. On the other hand, the homogeneous membrane is an ion exchanger synthesized in a membrane form. The homogeneous membrane has a structure in which the whole of the membrane is chemically bonded with a high degree of cross-linking, and in which a large number of ion exchange groups are uniformly distributed. The homogeneous membrane is excellent in that it has lower electric resistance than the heterogeneous membrane. In general, for the purpose of improving the mechanical strength, a mesh, a nonwoven fabric or the like is integrated as a reinforcing body in both the heterogeneous membrane and the homogeneous membrane. The ion exchange membrane is classified into an anion exchange membrane and a cation exchange membrane depending on the type of the functional group introduced, similarly to the ion exchange resin.

[0048]

In the present invention, it is possible to employ either a heterogeneous membrane or a homogeneous membrane. However, it is preferable that the combination of the types of cation exchange membrane 33 and anion exchange membrane 40 is either a homogeneous membrane / homogeneous membrane, a heterogeneous membrane / homogeneous membrane, or a homogeneous membrane / heterogeneous membrane (the type of cation exchange membrane 33 is shown before the slash "/" and the type of anion exchange membrane 40 is shown after the slash "/"). That is, at least one of cation exchange membrane 33 and anion exchange membrane 40 is preferably a homogeneous membrane. This is because the heterogeneous membrane has an inactive partial region in which there is no ion exchange group, and therefore, if the combination of a heterogeneous membrane/heterogeneous membrane is used at the place where the water dissociation reaction occurs, the number of reaction points of the water dissociation may decrease and the voltage may increase.

[0049]

Cation exchange membrane 33 and anion exchange membrane 40 can be brought into contact with each other in a wet state by overlapping them together. By contacting both membranes with each other in the wet state, when water is consumed in the water dissociation reaction, water is drawn in from

the end portion(s) of the overlap, and the water can be easily supplied to between these two membranes. In addition, the contact part between the two membranes functions as a reaction portion for the water dissociation.

[0050]

5 When cation exchange membrane 33 and anion exchange membrane 40 are installed in the EDI apparatus, the respective membranes may be overlapped and installed in a dry state, and thereafter, water may be passed through the apparatus to cause these membranes to become a wet state. Alternatively, both membranes may be overlapped and installed in a wet state when they are installed in the EDI apparatus. When cation exchange membrane 33 and anion exchange membrane 40 are
10 overlapped with each other, for example, the respective membranes may be caused to be in a wet state, then their surfaces may be cleaned by using a flow of clean pure water or the like, and then they are overlapped with each other. In addition, both membranes may be fixed to each other by using appropriate means.

[0051]

15 With regard to the end portion(s) of the overlap where cation exchange membrane 33 and anion exchange membrane 40 overlap with each other, only a part of the end portion needs to be capable of supplying (drawing in) water from deionization chamber 23 to the water dissociation reaction portion (that is, only a part of the end portion(s) needs to be non-sealed, i.e., needs to be open). For example, a part of the end portion(s) of the overlap may be non-sealed and the other part may be sealed.
20 Alternatively, the whole of the end portion(s) may be open. Examples of sealing means include bonding by using an adhesive, welding in which the membrane constituent materials are melted and integrated by heating or ultrasonic vibration, and a method in which the membrane constituent materials are sandwiched and fixed by a frame.

[0052]

25 As anode 11 and cathode 12, those known in the field of EDI apparatus can be used. For example, a stainless-steel electrode is used for the cathode, and a noble metal, such as platinum, or noble metal-plated electrode is used for the anode.

[0053]

 As cation exchange membrane 31 and anion exchange membranes 32 and 34, those known in
30 the field of EDI apparatus can be used. Anode 11 and cathode 12, anode chamber 21, concentration chambers 22 and 24, deionization chamber 23, cathode chamber 25, cation exchange membranes 31 and 33, and anion exchange membranes 32, 34 and 40 may be contained in an appropriate frame body (not shown).

[0054]

As the supply water and the water to be treated, those known in the field of EDI apparatus can be used. Generally, permeated water of a reverse osmosis membrane (RO) is used, and it is more preferable to use permeated water which has been treated in two or more passes by RO membranes. In addition, a decarboxylation tower or a membrane degassing (MD) may be used to remove carbonic acid.

5 Further, in recent years, water which has been treated with EDI may be used as the supply water or the water to be treated.

[0055]

In the apparatus shown in FIG. 1, as to anode chamber 21, concentration chambers 22 and 24, and cathode chamber 25, the supply water is introduced into these chambers from below, and water
10 (electrode water or concentrated water) is discharged from above. As to deionization chamber 23, the water to be treated is supplied to this chamber from above, and the treated water is discharged from below. However, this is not limiting, and the flow directions of water can be appropriately determined. Further, instead of supplying water from the outside to anode chamber 21, the outlet water of cathode chamber 25 (electrode water) may be supplied to anode chamber 21, or the outlet water of anode
15 chamber 21 (electrode water) may be supplied to cathode chamber 25.

[0056]

The diffusion of a weak acid component from concentration chamber 24 to deionization chamber 23 is affected by the concentration of the weak acid component in concentration chamber 24, and its diffusion amount increases as its concentration increases. In concentration chamber 24, the
20 concentration ratio increases and the concentration of the weak acid component increases from the inlet to the outlet. By arranging the inlet side of concentration chamber 24 at a position adjacent to the outlet side of deionization chamber 23, it is possible to suppress much occurrence of the diffusion from concentration chamber 24 at a position close to the treated water outlet of deionization chamber 23. Therefore, it is preferable that the flow direction of water in concentration chamber 24 is a countercurrent
25 with respect to the flow direction of water in the adjacent deionization chamber (i.e., deionization chamber 23 in the embodiment shown in FIG. 1, second small deionization chamber 27 in the embodiment shown in FIG. 6).

[0057]

A configuration in which the concentration chamber also serves as an electrode chamber is
30 included in the scope of the present invention. For example, concentration chamber 24 shown in FIG. 1 may be provided with a cathode, and cathode chamber 25 may be omitted. Even in this case, the deionization treatment unit composed of the deionization chamber and the pair of concentration chambers is disposed between the cathode and the anode.

[0058]

The EDI apparatus may include a plurality of deionization treatment units. For this purpose, a plurality of basic configurations (i.e. cell sets), each of which consists of [concentration chamber | first anion exchange membrane (AEM) | deionization chamber | cation exchange membrane (CEM) (on which second anion exchange membrane is layered) | concentration chamber], can be juxtaposed
5 between the anode and the cathode. In this case, neighboring concentration chambers can be shared between adjacent cell sets. Therefore, assuming that one cell set is constituted by anion exchange membrane 32, deionization chamber 23, cation exchange membrane 33 (on which anion exchange membrane 40 is layered), and concentration chamber 24, a plurality of the cell sets can be arranged between cathode chamber 25 and concentration chamber 22 which is the closest concentration chamber
10 to anode chamber 21. In FIG. 1, "N" means the number of cell sets, and N is an integer of 1 or more.
[0059]

Although a basic configuration of the EDI apparatus according to the present invention has been described above, the present invention is widely applicable to EDI apparatus of various configurations. Examples of the configurations of the EDI apparatus to which the present invention can
15 be applied will be described below.
[0060]

Referring to FIG. 2, an EDI apparatus having two deionization treatment units will be described. This EDI apparatus has a configuration of the apparatus shown in FIG. 1 in which two cell sets are arranged in between cathode chamber 25 and concentration chamber 22 which is the closest
20 concentration chamber to anode chamber 21. In FIG. 2, a character " ' (dash)" is put after a reference sign indicating a component constituting the cell set closer to cathode chamber 25.
[0061]

Anode chamber 21 is filled with a cation exchange resin (CER), and concentration chamber 22 and cathode chamber 25 are filled with an anion exchange resin (AER). Concentration chambers 24 and
25 24' are each filled with an anion exchange resin AER. Deionization chambers 23 and 23' are each filled with a mixed bed of an anion exchange resin and a cation exchange resin.
[0062]

Anode chamber 21 and concentration chamber 22 are partitioned by cation exchange membrane 31. Concentration chamber 22 and deionization chamber 23 are partitioned by anion
30 exchange membrane 32. Deionization chamber 23 and concentration chamber 24 are partitioned by cation exchange membrane 33. Concentration chamber 24 and deionization chamber 23' are partitioned by anion exchange membrane 32'. Deionization chamber 23' and concentration chamber 24' are partitioned by cation exchange membrane 33'. Concentration chamber 24' and cathode chamber 25 are partitioned by anion exchange membrane 34.

[0063]

Anion exchange membrane 40 is layered on cation exchange membrane 33. Anion exchange membrane 40' is layered on cation exchange membrane 33'.

[0064]

5 The configurations of anion exchange membranes 32' and 40', deionization chamber 23', cation exchange membrane 33', and concentration chamber 24' may be the same as or different from the configurations of anion exchange membranes 32 and 40, deionization chamber 23, cation exchange membrane 33, and concentration chamber 24, respectively.

[0065]

10 Also in this embodiment, the same effect as the embodiment shown in FIG. 1 can be achieved.

[0066]

 Anions, such as CO_3^{2-} and HCO_3^- , derived from weak acids move from deionization chamber 23' to concentration chamber 24 through anion exchange membrane 32'. Therefore, in addition to the weak acid components which have been originally contained in the supply water, weak acid components
15 which have moved through anion exchange membrane 32' are also contained in concentration chamber 24. Accordingly, the concentrations of the weak acid components in the concentration chamber 24 become relatively higher, and the diffusion phenomenon of the weak acid components from concentration chamber 24 to deionization chamber 23 tends to become significant. Therefore, the present invention is particularly effective in an EDI apparatus including a plurality of deionization
20 treatment units.

[0067]

 FIG. 3 shows another embodiment of an EDI apparatus according to the present invention. This EDI apparatus is similar to that shown in FIG. 1 except that a cation exchange resin (CER) is arranged in the inlet side region of deionization chamber 23 and an anion exchange resin (AER) is
25 arranged in the outlet side region. In other words, in deionization chamber 23, a bed made of a cation exchange resin (a cation exchange resin bed, and thus a cation exchanger bed) and a bed made of an anion exchange resin (an anion exchange resin bed, and thus an anion exchanger bed) are stacked one by one in the water passing direction of the water to be treated. That is, the deionization chamber is filled with the anion exchanger bed and the cation exchanger bed in a sequence such that the final ion
30 exchanger, through which the water to be treated finally passes, becomes the anion exchanger. Anion exchange membrane 40 is disposed on the cathode side of the anion exchange bed contained in deionization chamber 23, that is, between the anion exchange bed and cation exchange membrane 33. Anion exchange membrane 40 is not arranged on the cathode side of the cation exchanger bed contained in deionization chamber 23.

[0068]

As shown in FIG. 3, the lengths of beds contained in deionization chamber 23 in the water passing direction (the length in the vertical direction of the drawing in FIG. 3) may be the same as each other, but may be different from each other.

5 [0069]

As a matter of course, also in this embodiment, assuming that one cell set is constituted by anion exchange membrane 32, deionization chamber 23, cation exchange membrane 33 on which anion exchange membrane 40 is layered, and concentration chamber 24, N (N is an integer of 1 or more) cell sets can be arranged between cathode chamber 25 and concentration chamber 22 which is the closest
10 concentration chamber to anode chamber 21.

[0070]

The EDI apparatus shown in FIG. 4 is the same as that shown in FIG. 3, except that deionization chamber 23 is divided into four regions along the water passing direction of the water to be treated, and an ion exchange resin is arranged in each region such that the first cation exchanger bed, the
15 first anion exchanger bed, the second cation exchanger bed, and the second anion exchanger bed are aligned in this order from the inlet side of the water to be treated. Anion exchange membrane 40, which is layered on cation exchange membrane 33, is disposed on the cathode side of each of the first anion exchanger bed and the second anion exchanger bed. Anion exchange membrane 40 is not disposed on the cathode side of the first cation exchanger bed nor on the cathode side of the second cation exchanger
20 bed. In this apparatus, there are two overlap regions (i.e., regions of the deionization-chamber-side surface of cation exchange membrane 33, where anion exchange membrane 40 is layered) apart from each other along the water passing direction of the water to be treated in the deionization chamber 23. One of the two overlap regions, this overlap region being located at the most downstream side in the water passing direction, reaches the end portion of cation exchange membrane 33 on the outlet side of the
25 deionization chamber.

[0071]

As shown in FIG. 4, the length of beds contained in deionization chamber 23 in the water passing direction may be the same as each other, but may be different from each other. Also, although the number of the beds is four in FIG. 4, the number may be five, six or more, as far as they can be
30 actually manufactured.

[0072]

The EDI apparatus shown in FIG. 5 is the same as that shown in FIG. 1, except that in deionization chamber 23, an anion exchanger bed is provided instead of a mixed bed MB on anion exchange membrane 40 on the side of the deionization chamber. In the region of deionization chamber

23 in which anion exchange membrane 40 does not exist in the water passing direction of the water to be treated, a mixed bed is provided similarly to the embodiment shown in FIG. 1.

[0073]

That is, in this embodiment, the mixed bed (MB) of an anion exchange resin and a cation exchange resin is arranged in the inlet side region of deionization chamber 23, and an anion exchanger bed (bed of AER) is arranged in the outlet side region. That is, a mixed bed and an anion exchanger bed are stacked one by one in the water passing direction in deionization chamber 23.

[0074]

In the EDI apparatus according to the present invention, an intermediate ion exchange membrane (IIEM) may be provided between the anion exchange membrane on the anode side and the cation exchange membrane on the cathode side in each deionization chamber, and each deionization chamber may be partitioned into a first small deionization chamber and a second small deionization chamber by the intermediate ion exchange membrane. The first and second small deionization chambers may be arranged so as to communicate with each other, so that the water to be treated is supplied to one of the first and second small deionization chambers, and the water flowing out of this small deionization chamber flows into the other small deionization chamber. As the intermediate ion exchange membrane, either an anion exchange membrane or a cation exchange membrane can be used. The small deionization chamber on the anode side is the first small deionization chamber, and the small deionization chamber on the cathode side is the second small deionization chamber. For example, the first small deionization chamber is filled with at least an anion exchanger, and the second small deionization chamber is filled with at least a cation exchanger.

[0075]

FIG. 6 shows an example of an EDI apparatus in which the deionization chamber is partitioned into two small deionization chambers by an intermediate ion exchange membrane. This EDI apparatus has a configuration in which each deionization chamber 23 in the EDI apparatus shown in FIG. 1 is partitioned into a first small deionization chamber 26 on the anode 11 side and a second small deionization chamber 27 on the cathode 12 side by intermediate ion exchange membrane 36 which is positioned between anion exchange membrane 32 and cation exchange membrane 33. First small deionization chamber 26 is located between anion exchange membrane 32 and intermediate ion exchange membrane 36, and second small deionization chamber 27 is located between cation exchange membrane 33 and intermediate ion exchange membrane 36. First small deionization chamber 26 and second small deionization chamber 27 communicate with each other so that the water to be treated is supplied to first small deionization chamber 26 and the water flowing out of first small deionization chamber 26 flows into second small deionization chamber 27.

[0076]

First small deionization chamber 26 is filled with an anion exchange resin. A cation exchange resin is disposed in the inlet side region of second small deionization chamber 27, and an anion exchange resin is disposed in the outlet side region. That is, second small deionization chamber 27 is provided
5 with a cation exchanger bed and an anion exchanger bed in this order along the water passing direction of the water to be treated. The water to be treated is supplied to first small deionization chamber 26, the outlet water of first small deionization chamber 26 is sent to second small deionization chamber 27, and deionized water is obtained from second small deionization chamber 27 as treated water. Therefore, deionization chamber 23 is filled with an anion exchanger bed and a cation exchanger bed in a sequence
10 such that the final ion exchanger, through which the water to be treated finally passes, becomes the anion exchanger.

[0077]

Anion exchange membrane 40, which is layered on cation exchange membrane 33, is arranged on the cathode side of the anion exchanger bed contained in second small deionization chamber 27.
15 Anion exchange membrane 40 is not disposed on the cathode side of the cation exchanger bed contained in second small deionization chamber 27. There is one above-mentioned overlap region (i.e., a region of the deionization-chamber-side surface of cation exchange membrane 33, where anion exchange membrane 40 is layered). This overlap region reaches the end portion of cation exchange membrane 33 on the outlet side of the deionization chamber. Here, the deionization chamber outlet is an outlet of the
20 treated water, and in this apparatus, it is an outlet of second small deionization chamber 27.

[0078]

As shown in FIG. 6, the lengths of beds contained in second small deionization chamber 27 in the water passing direction may be the same as each other, but may be different from each other.

[0079]

25 As intermediate ion exchange membrane 36, for example, an anion exchange membrane is used.

[0080]

In the apparatus shown in FIG. 6, the flow of water in first small deionization chamber 26 and the flow of water in second small deionization chamber 27 form a counter-flow with each other.
30 However, this is not limiting, and these flows may be parallel-flows.

[0081]

The water to be treated is supplied to first small deionization chamber 26. The anion components in the supplied water to be treated is captured when they pass through first small deionization chamber 26. The anion components, which have been captured in first small deionization

chamber 26, move to concentration chamber 22, which is adjacent to first small deionization chamber 26, via anion exchange membrane 32, and is discharged to the outside together with the concentrated water passing through concentration chamber 22.

[0082]

5 Next, the water to be treated, which has passed through first small deionization chamber 26, is supplied to second small deionization chamber 27. The water, which has been supplied to second small deionization chamber 27, first passes through the cation exchanger bed and then passes through the anion exchanger bed. At this time, cation components contained in the water to be treated are captured when the water passes through the cation exchanger bed. Specifically, the cation components, which have
10 been captured by the cation exchanger contained in second small deionization chamber 27, move to concentration chamber 24, which is adjacent to second small deionization chamber 27, via cation exchange membrane 33, and is discharged from concentration chamber 24 to the outside together with the concentrated water.

[0083]

15 Further, the water to be treated, which has passed through the cation exchanger bed contained in second small deionization chamber 27, passes through the downstream anion exchanger bed. At this time, the anion components in the water to be treated are captured again. Specifically, the anion components, which have been captured by the anion exchanger contained in second small deionization chamber 27, move to first small deionization chamber 26, which is adjacent to second small deionization
20 chamber 27, via intermediate ion exchange membrane 36. The anion components, which have moved to first small deionization chamber 26, move to concentration chamber 22, which is adjacent to first small deionization chamber 26, via anion exchange membrane 32, and is discharged to the outside together with the concentrated water passing through concentration chamber 22.

[0084]

25 Here, it is assumed that the diffusion phenomenon occurs, in which weak acid components (bicarbonate, silica or boron) contained in the concentrated water in concentration chamber 24 pass through cation exchange membrane 33 in the form of neutral molecules and move to second small deionization chamber 27.

[0085]

30 The weak acid components, which have moved from concentration chamber 24 to second small deionization chamber 27, uniformly diffuse on the anode side surface of cation exchange membrane 33. That is, the weak acid components diffuse not only on a region of the surface of cation exchange membrane 33, this region being in contact with anion exchange membrane 40, but also on a region of the surface of cation exchange membrane 33, this region being in contact with the cation

exchanger bed contained in second small deionization chamber 27. Since the weak acid components are not captured by the cation exchanger, the weak acid components which have diffused on the region of the anode side surface of cation exchange membrane 33, this region being in contact with the cation exchanger bed, pass through the cation exchanger bed together with the water to be treated. However, in
5 second small deionization chamber 27, the cation exchanger bed and the anion exchanger bed are stacked along the water passing direction of the water to be treated. Therefore, the weak acid components, which have passed through the cation exchanger bed, are ionized again and captured in the downstream anion exchanger bed, and move to first small deionization chamber 26. The weak acid components, which have moved to first small deionization chamber 26, pass through anion exchange
10 membrane 32, move to concentration chamber 22, and are discharged to outside together with the concentrated water passing through concentration chamber 22.

[0086]

As described above, in this embodiment, even if the weak acid components pass through cation exchange membrane 33, the weak acid components are easily discharged from concentration chamber 22
15 because the downstream anion exchanger bed is present, and as a result, it is easy to suppress a decrease in the purity of the treated water. Of course, also in this embodiment, the weak acid components which have diffused on a region of the surface of cation exchange membrane 33, this region being in contact with anion exchange membrane 40, can be efficiently removed from the water to be treated by anion exchange membrane 40.

20 [0087]

From the above description, it is understood that the downstream-most bed of the stack of ion exchanger beds provided in the deionization chamber, in particular in second small deionization chamber 27, preferably is an anion exchanger bed. There are no particular limitations on the type, stacking order, and number of ion exchanger beds with respect to the bed(s) upstream of the downstream-most bed.

25 [0088]

In the EDI apparatus according to the present embodiment, first small deionization chamber 26, to which the water to be treated is first supplied, is filled with an anion exchanger, and second small deionization chamber 27, to which the water to be treated is then supplied, includes a cation exchanger bed and an anion exchanger bed which are stacked in this order. Thus, the water to be treated first passes
30 through an anion exchanger bed. As a result, anion components are removed from the water to be treated, and the pH of the water to be treated rises.

[0089]

Further, the water to be treated, which has passed through first small deionization chamber 26, is supplied to second small deionization chamber 27 in which the cation exchanger bed and the anion

exchanger bed are stacked in this order. That is, the water to be treated, which has passed through an anion exchanger bed in first small deionization chamber 26, passes through a cation exchanger bed, and then again passes through an anion exchanger bed. In short, according to the configuration of the present embodiment, the water to be treated passes through the alternate anion and cation exchanger beds.

5 [0090]

Here, the anion component capturing ability of the anion exchanger increases when the pH of the water to be treated is lower, and the cation component capturing ability of the cation exchanger increases when the pH of the water to be treated is higher. In the present embodiment, the water to be treated first passes through the anion exchanger bed, and thereafter passes through the alternative cation and anion exchanger beds. Therefore, according to the configuration of this embodiment, the pH of the water to be treated is increased because the anion components are removed by the passing through the anion exchanger, and successively, the water passes through the cation exchanger bed. Therefore, reactions of the cation exchanger to remove cations are facilitated to a greater degree than is usually the case.

15 [0091]

Further, the pH of the water to be treated is decreased because the cation components are removed by the passing through the cation exchanger bed, and successively, the water passes through the anion exchanger bed. Therefore, reactions of the anion exchanger to remove anions are facilitated to a greater degree than is usually the case. Accordingly, not only the ability to remove anion components which include carbonic acid, silica and boron is further improved, but also the ability to remove cation components is improved. As a result, the purity of the treated water is further improved.

[0092]

As described above, it is preferable to use alternative cation and anion exchanger beds in a sequence such that the final ion exchanger, through which the water to be treated finally passes, becomes the anion exchanger. This is true not only for the configuration shown in FIG. 6, but also for the configurations shown in FIGS. 3 and 4.

Examples

[0093]

30 [Example 1]

Water to be treated was treated by using the EDI apparatus having the configuration shown in FIG. 6 to obtain treated water (deionized water). Specifications and test conditions of the EDI apparatus are shown below.

[0094]

The specifications and conditions of concentration chambers 22 and 24 are common to each other, and the specifications and conditions of the concentrate water obtained from these chambers are common to each other. Anode chamber 21 and a part (inlet side region) of second small deionization chamber 27 are filled with a common cation exchange resin (CER). Cathode chamber 25, concentration chambers 22 and 24, first small deionization chamber 26, and the remaining part (outlet side region) of second small deionization chamber 27 are filled with a common anion exchange resin (AER). Cation exchange membranes 31 and 33 are common to each other, and anion exchange membranes 32 and 34 and intermediate ion exchange membrane 36 are common to each other.

[0095]

10 In the following description, the expression "length" relates to the vertical direction (direction along the flow direction of water) in the drawing, and the expression "width" relates to the depth direction in the drawing.

- Number of cell sets (N): 1
- Anode chamber 21: 100 mm in length × 100 mm in width × 10 mm in thickness, filled with CER
- 15 • Cathode chamber 25: 100 mm in length × 100 mm in width × 10 mm in thickness, filled with AER
- Concentration chambers 22 and 24: 100 mm in length × 100 mm in width × 10 mm in thickness, filled with AER
- First small deionization chamber 26: 100 mm in length × 100 mm in width × 10 mm in thickness, filled with AER
- 20 • Second small deionization chamber 27: 100 mm in length × 100 mm in width × 10 mm in thickness, filled with CER (a half region on the inlet side) and AER (a half region on the outlet side)
- CER: Strong acid cation exchange resin
- AER: Strong base anion exchange resin
- Cation exchange membranes 31 and 33: homogeneous membrane, 100 mm in length × 100 mm in
- 25 width, 290 μm in thickness (current-flowing section effective membrane size)
- Anion exchange membranes 32 and 34 and intermediate ion exchange membrane 36: homogeneous membrane, 100 mm in length × 100 mm in width, 220 μm in thickness (current-flowing section effective membrane size)
- Anion Exchange Membrane 40: homogeneous membrane, 50 mm in length × 100 mm in width, 220
- 30 μm in thickness (current-flowing section effective membrane size)
- Supply water and water to be treated: two-pass RO (reverse osmosis membrane) permeate water, conductivity of 2.0 to 2.5 μS/cm
- Flow rate of treated water (deionized water): 25 L/h
- Flow rate of concentrated water: 6 L/h

- Flow rate of electrode water: 5 L/h (common to anode and cathode)
- Applied DC current: 0.5 A.

[0096]

5 Second anion exchange membrane 40 was disposed on the cathode side of the anion exchange resin bed which was formed in the half region on the outlet side of second small deionization chamber 27. At this time, the position of the end of cation exchange membrane 33 on the deionization chamber outlet side (the upper end in the vertical direction in the drawing) and the position of the end of anion exchange membrane 40 on the deionization chamber outlet side were aligned. Further, the position of cation exchange membrane 33 in the lateral direction (the depth direction in the drawing) and the
10 position of anion exchange membrane 40 in the lateral direction were aligned.

[0097]

[Comparative Example 1]

Anion exchange membrane 40 was not used. That is, only cation exchange membrane 33 was used between second small deionization chamber 27 and concentration chamber 24. Except for this, the
15 water to be treated was treated in the same manner as in Example 1 to obtain treated water.

[0098]

[Comparative Example 2]

Instead of second anion exchange membrane 40, a cation exchange membrane was used. This cation exchange membrane was a membrane of the same material and thickness as those of cation
20 exchange membranes 31 and 33 which were used in Example 1, and its length, width and position were the same as those of second anion exchange membrane 40 which was used in Example 1. Except for this, the water to be treated was treated in the same manner as in Example 1 to obtain treated water.

[0099]

[Evaluation 1]

25 For each of Example 1 and Comparative Examples 1 and 2, after the continuous operation was performed for about 500 hours, the concentration of total carbonic acid in the treated water (the sum of the concentrations of CO_2 , H_2CO_3 , HCO_3^- and CO_3^{2-}) was measured, and the resistivity of the treated water was measured. The results are shown in Table 1. The concentration of total carbonic acid is used as an index indicating the concentration of carbonic acid that has diffused from the concentration
30 chamber to the deionization chamber and then leaked into the treated water without being removed. The value of the resistivity is used as an index of the purity of the treated water in which not only carbonic acid but also other ions are taken into account.

[0100]

In Example 1, as compared with Comparative Examples 1 and 2, the leakage of carbonic acid

was small and the purity of the treated water was high.

[0101]

Table 1

	Example 1	Comparative Example 1	Comparative Example 2
Total carbonic acid [$\mu\text{gCO}_2/\text{L}$]	< 0.5	56.8	35.2
Resistivity [$\text{M}\Omega \cdot \text{cm}$]	17.7	8.0	8.3

5 [0102]

[Example 2]

The water to be treated was treated in the same manner as in Example 1 except that the conditions were changed as described below to obtain treated water.

- Supply water and water to be treated: two-pass RO (reverse osmosis membrane) permeate water, conductivity of 4.0 to 4.5 $\mu\text{S}/\text{cm}$
- Applied DC current: 1.0A.

[0103]

[Example 3]

- 15 A heterogeneous anion exchange membrane was used as second anion exchange membrane 40. The length, width and position of the anion exchange membrane (heterogeneous) were the same as those of the second anion exchange membrane 40 which was used in Example 2. The thickness of the anion exchange membrane (heterogeneous) was 580 μm . Except for this, the water to be treated was treated in the same manner as in Example 2 to obtain treated water.

[0104]

20 [Comparative Example 3]

- Instead of second anion exchange membrane 40, a bipolar membrane was used. The length, width and position of the bipolar membrane were the same as those of second anion exchange membrane 40 which was used in Example 2. The bipolar membrane was arranged so that the anion exchange membrane portion thereof faces second small deionization chamber 27. The bipolar membrane had a total thickness of 220 μm including the anion exchange membrane portion and the cation exchange membrane portion. Except for this, the water to be treated was treated in the same manner as in Example 2 to obtain treated water.

[0105]

[Evaluation 2]

- 30 In each of Examples 2 and 3 and Comparative Example 3, after the continuous operation was performed for about 500 hours, the concentration of total carbonic acid, the resistivity and the sodium

concentration in the treated water were measured, and the voltage (the voltage between anode 11 and cathode 12) and the current distribution ratio were measured. The results are shown in Table 2. In the table, "upper current distribution ratio" and "lower current distribution ratio" are defined as follows, respectively.

- 5 (upper current distribution ratio) = (value of the current flowing in the region where second anion exchange membrane 40 or the bipolar membrane is installed) / (total current value),
 (lower current distribution ratio) = (value of the current flowing through the region of cation exchange membrane 33 where second anion exchange membrane 40 nor the bipolar membrane does not overlap) / (total current value).

10 [0106]

The current distribution ratio was obtained by dividing the cathode plate, which was used as cathode 12, into two parts corresponding to the above-mentioned regions in the vertical direction, measuring the values of the currents flowing through the upper and lower cathode plates, respectively, by using an ammeter, and calculating the ratio of each current value to the total applied current value.

15 [0107]

In Example 2, as compared with Comparative Example 3, the difference between the upper current distribution ratio and the lower current distribution ratio was small, the sodium concentration in the treated water was low, and the resistivity of the treated water was high. That is, in Example 2, as compared with Comparative Example 3, a larger amount of current was distributed to the cation resin
 20 bed contained in the deionization chamber, better removal of cations was achieved, and the purity of the treated water was higher. In Example 3, these tendencies were further increased, the sodium concentration in the treated water was low, and the resistivity of the treated water was the highest. This is probably because, as described above, the heterogeneous membrane has an inactive partial region in which there is no ion exchange group, and therefore the water dissociation reaction hardly proceeds, and
 25 thus the concentration of the current flow on the upper part can be more suppressed.

[0108]

Table 2

	Example 2	Example 3	Comparative Example 3
Total carbonic acid [$\mu\text{gCO}_2/\text{L}$]	< 0.5	< 0.5	< 0.5
Resistivity [$\text{M}\Omega \cdot \text{cm}$]	15.0	15.7	13.6
Na [$\mu\text{g}/\text{L}$]	3.1	2.4	5.3
Voltage [V]	8.6	10.5	8.5
Upper current distribution ratio	60%	52%	70%
Lower current distribution ratio	40%	48%	30%

[0109]

In the configuration according to the present invention, when the water to be treated contained in the deionization chamber enters the interface between cation exchange membrane 33 and anion exchange membrane 40, the weak acid components contained in the water to be treated is easily removed from the interface through anion exchange membrane 40. On the other hand, in the configuration in which a bipolar membrane is used instead of anion exchange membrane 40 as in Comparative Example 3, when the water to be treated contained in the deionization chamber enters the interface between cation exchange membrane 33 and the bipolar membrane, it is difficult to remove the anion components contained in the water to be treated from the interface. This is because the movement of the anion components is obstructed by both cation exchange membrane 33 and the cation exchange membrane portion of the bipolar membrane. As a result, anions leak into the treated water, resulting in the decrease of the water quality.

[0110]

For example, as shown in FIG. 10(b), when anions and cations (referred to as " C^+A^- " in the drawing) enter the interface between cation exchange membrane 33 and anion exchange membrane 40, the anions (referred to as " A^- " in the drawing) move through anion exchange membrane 40 to deionization chamber 23 and are easily captured in the anion exchange resin inside the deionization chamber 23. Cations (referred to as " C^+ " in the drawing) are removed from the interface through cation exchange membrane 33. On the other hand, as shown in FIG. 10(a), in the configuration in which bipolar membrane 50 is used instead of anion exchange membrane 40, cations (C^+) are removed from the interface between cation exchange membrane 33 and bipolar membrane 50 through cation exchange membrane 33, but anions (A^-) cannot pass through bipolar membrane 50 nor cation exchange membrane 33. As a result, for example, anions are discharged from an end portion (upper end in the vertical direction in FIG. 10) of the interface, and leak into the treated water as they are.

Reference Signs List

[0111]

- | | |
|-------|----------------------------------|
| 11 | Anode |
| 12 | Cathode |
| 21 | Anode chamber |
| 22、24 | Concentration chamber |
| 23 | Deionization chamber |
| 25 | Cathode chamber |
| 26 | First small deionization chamber |

27	Second small deionization chamber
31, 33	Cation exchange membrane (CEM)
32	First anion exchange membrane (AEM)
34	Anion exchange membrane (AEM)
5 36	Intermediate ion exchange membrane (IEM)
40	Second anion exchange membrane (AEM)
50	Bipolar membrane
51	Anion exchange resin

Claims

1. An electrodeionization apparatus for producing deionized water comprising at least one deionization treatment unit provided between a cathode and an anode that are opposite to each other,
5 the deionization treatment unit comprising a deionization chamber filled with at least an anion exchanger and a pair of concentration chambers adjacent to both sides of the deionization chamber, the deionization chamber being adjacent to one concentration chamber from among the pair of concentration chambers via a cation exchange membrane, said one concentration chamber being located on the cathode side, and
10 the deionization chamber being adjacent to the other concentration chamber from among the pair of concentration chambers via a first anion exchange membrane, said other concentration chamber being located on the anode side, wherein a second anion exchange membrane is layered on a partial region of a deionization-chamber-side surface of the cation exchange membrane, as a separate body from the cation exchange membrane,
15 and the anion exchanger is in contact with at least a part of a deionization-chamber-side surface of the second anion exchange membrane.
2. The electrodeionization apparatus for producing deionized water according to claim 1, wherein
20 said partial region of the deionization-chamber-side surface of the cation exchange membrane comprises a region which reaches an end of the cation exchange membrane on the deionization chamber outlet side.
3. The electrodeionization apparatus for producing deionized water according to claim 1 or 2, wherein the deionization chamber comprises one or more anion exchanger beds, which are beds
25 consisting of an anion exchanger, and one or more cation exchanger beds, which are beds consisting of a cation exchanger, in a sequence such that a final ion exchanger, through which water to be treated finally passes, becomes the anion exchanger.
4. The electrodeionization apparatus for producing deionized water according to claim 3, wherein
30 the deionization chamber is provided with a first cation exchanger bed, a first anion exchanger bed, a second cation exchanger bed, and a second anion exchanger bed in this order along a passing direction of the water to be treated, the second anion exchange membrane is disposed on each of the cathode side of the first anion exchanger bed and the cathode side of the second anion exchanger bed,

the second anion exchange membrane is not disposed on the cathode side of the first cation exchanger bed nor on the cathode side of the second cation exchanger bed.

5. The electrodeionization apparatus for producing deionized water according to claim 3, wherein
5 the deionization chamber is provided with an intermediate ion exchange membrane which is an ion exchange membrane located between the first anion exchange membrane and the cation exchange membrane, and the deionization chamber is partitioned into a first small deionization chamber and a second small deionization chamber by the intermediate ion exchange membrane,
10 the first small deionization chamber is located between the first anion exchange membrane and the intermediate ion exchange membrane,
10 the second small deionization chamber is located between the cation exchange membrane and the intermediate ion exchange membrane,
15 the first small deionization chamber and the second small deionization chamber communicate with each other so that the water to be treated is supplied to the first small deionization chamber and the water flowing out of the first small deionization chamber flows into the second small deionization chamber,
15 the first small deionization chamber is provided with said anion exchanger bed,
15 the second small deionization chamber is provided with said cation exchanger bed and another said anion exchanger bed in this order along the passing direction of the water to be treated,
20 the second anion exchange membrane is disposed on the cathode side of the anion exchanger bed provided in the second small deionization chamber, and
20 the second anion exchange membrane is not disposed on the cathode side of the cation exchanger bed provided in the second small deionization chamber.
- 25 6. The electrodeionization apparatus for producing deionized water according to any one of claims 1 to 5, wherein the pair of concentration chambers is filled with at least an anion exchanger.
7. The electrodeionization apparatus for producing deionized water according to any one of claims 1 to 6, wherein the second anion exchange membrane is a heterogeneous membrane and the cation
30 exchange membrane is a homogeneous membrane.