

Description

Title of Invention: WATER TREATMENT APPARATUS AND WATER TREATMENT METHOD

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Technical Field

[0001]

The present invention relates to a water treatment apparatus and a water treatment method, and particularly to a water treatment apparatus and a water treatment method which use an electric deionized water production apparatus.

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Background Art

[0002]

A deionized water production apparatus has been known in which water to be treated flows through ion exchangers, such as ion exchange resins, and is deionized through an ion exchange reaction. Such an apparatus requires a process of regenerating the ion exchangers (a regeneration process) by means of an acid or alkali chemical agent when ion exchange groups of the ion exchangers are saturated and the demineralizing performance deteriorates. The regeneration process is a process in which positive (cation) ions and negative (anion) ions that are adsorbed to the ion exchangers are replaced by hydrogen ions (H^+) and hydroxide ions (OH^-) deriving from acid or alkali, whereby the demineralizing performance of the ion exchangers is recovered. A deionized water production apparatus that requires a regeneration process using a chemical agent is problematic in that the apparatus cannot operate continuously, and additionally, in that it takes time to replenish a chemical agent for the regeneration process.

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[0003]

As a solution to this problem, an electric deionized water production apparatus (also referred to as an EDI (Electro Deionization) apparatus), which does not require regeneration by a chemical agent, has recently been developed and put into practical use.

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An EDI apparatus is an apparatus in which electrophoresis and electrodialysis are combined. An EDI apparatus includes, between an anion exchange membrane that allows only anions to pass therethrough and a cation exchange membrane that allows

only cations to pass therethrough, a demineralization chamber that is filled with ion exchangers (anion exchangers and/or cation exchangers). In the EDI apparatus, concentration chambers are disposed on the outer side of the anion exchange membrane and on the outer side of the cation exchange membrane, respectively, when viewed from the demineralization chamber. And, the demineralization chamber and each concentration chamber are disposed between a positive electrode chamber having a positive electrode and a negative electrode chamber having a negative electrode. In the demineralization chamber, the anion exchange membrane is disposed on the side closer to the positive electrode and the cation exchange membrane is disposed on the side closer to the negative electrode. The concentration chamber that is adjacent to the demineralization chamber via the anion exchange membrane is adjacent to the positive electrode chamber via a cation exchange membrane. The concentration chamber that is adjacent to the demineralization chamber via the cation exchange membrane is adjacent to the negative electrode chamber via an anion exchange membrane.

[0004]

In order to produce deionized water (treated water) from water to be treated by means of the EDI apparatus, the water to be treated is supplied to the demineralization chamber when a DC voltage is applied between the positive electrode and the negative electrode. Then, ion components in the water to be treated are adsorbed to ion exchangers in the demineralization chamber so that a deionization (demineralizing) treatment is performed, and deionized water flows out of the demineralization chamber. At this time, water dissociation reaction, expressed by the following formula, is caused by the applied voltage in the demineralization chamber at interfaces between different types of ion exchangeable substances, such as an interface between an anion exchanger and a cation exchanger, an interface between an anion exchanger and the cation exchange membrane and an interface between the anion exchange membrane and a cation exchanger, whereby hydrogen ions and hydroxide ions are generated.



[0005]

The hydrogen ions and hydroxide ions cause ion components that have previously been adsorbed to the ion exchanger in the demineralization chamber to be ion-exchanged and to be liberated from the ion exchangers. Out of the liberated ion components, anions move to the anion exchange membrane by electrophoresis, undergo electrodialysis at the anion exchange membrane, and are discharged to

concentrated water that flows through the concentration chamber on the side of the positive electrode viewed from the demineralization chamber. Similarly, out of the liberated ion components, cations move to the cation exchange membrane by electrophoresis, undergo electrodialysis at the cation exchange membrane, and are discharged to concentrated water that flows through the concentration chamber on the side of the negative electrode viewed from the demineralization chamber. In conclusion, the ion components in the water to be treated that is supplied to the demineralization chamber move to the concentration chambers and are discharged from the chambers, and at the same time, the ion exchangers in the demineralization chamber are regenerated.

[0006]

As described above, in an EDI apparatus, hydrogen ions and hydroxides ion that are generated by the applied DC voltage continuously act as acid and alkali regenerating agents for regenerating the ion exchangers. For this reason, an EDI apparatus basically does not require any regeneration process by a chemical agent that is supplied from outside, and can continuously operate without regenerating ion exchangers by means of a chemical agent.

[0007]

JP2001-191080 discloses an electric deionizing apparatus having two EDI apparatuses, wherein demineralization chambers of these apparatuses communicate in series. In the electric deionizing apparatus disclosed in this patent literature, the first stage demineralization chamber is filled with only anion exchangers or a mixture of anion exchangers and cation exchangers, and the second demineralization chamber is filled with a mixture of anion exchangers and cation exchangers.

Summary of Invention

[0008]

Currently, there is a need for reducing boron concentration in treated water (deionized water), and water treatment technology to meet such a need is in demand.

An object of the present invention is to provide a water treatment apparatus and a water treatment method that can reduce boron concentration in treated water.

[0009]

According to the present invention, a water treatment apparatus includes a plurality of electric deionized water production apparatuses. Each electric deionized

water production apparatus has a demineralization chamber between a positive electrode and a negative electrode. The demineralization chamber is defined by an anion exchange membrane that is positioned on a side of the positive electrode and a cation exchange membrane that is positioned on a side of the negative electrode and that is filled with ion exchangers. The demineralization chambers of the plurality of electric deionized water production apparatuses communicate in series. The plurality of demineralization chambers which communicate in series allows water to be treated to flow therethrough and allows treated water to flow out therefrom. The farthest upstream part of a first stage demineralization chamber into which the water to be treated flows first and the farthest downstream part of a final stage demineralization chamber from which the treated water flows out are only filled with anion exchangers. A portion which is a part of the plurality of demineralization chambers and which is located between the farthest upstream part of the first stage demineralization chamber and the farthest downstream part of the final stage demineralization chamber is filled with at least cation exchangers.

[0010]

According to the present invention, a water treatment method uses a water treatment apparatus including a plurality of electric deionized water production apparatuses each having a demineralization chamber between a positive electrode and a negative electrode, wherein the demineralization chamber is defined by an anion exchange membrane that is positioned on a side of the positive electrode and a cation exchange membrane that is positioned on a side of the negative electrode and that is filled with ion exchangers, wherein the demineralization chambers of the plurality of electric deionized water production apparatuses communicate in series, the plurality of demineralization chambers which communicate in series allows water to be treated to flow therethrough and allows treated water to flow out therefrom, the farthest upstream part of a first stage demineralization chamber into which the water to be treated flows first and the farthest downstream part of a final stage demineralization chamber from which the treated water flows out are only filled with anion exchangers, and a portion which is a part of the plurality of demineralization chambers and which is located between the farthest upstream part of the first stage demineralization chamber and the farthest downstream part of the final stage demineralization chamber is filled with at least cation exchangers. The water to be treated flows through the plurality of demineralization chambers which communicate in series when a DC voltage is applied

between the positive electrode and the negative electrode, whereby the water to be treated is treated and flows out.

[0011]

According to the present invention, the demineralization chambers of the plurality of electric deionized water production apparatuses communicate in series. Out of the demineralization chambers that communicate in series, the farthest upstream part of the first stage demineralization chamber into which the water to be treated flows first and the farthest downstream part of the final stage demineralization chamber from which the treated water flows out are only filled with anion exchangers, and a portion therebetween is filled with at least cation exchangers. Thus, as will be clear from the embodiments described later, boron concentration in the treated water can be reduced, as compared to a water treatment apparatus in which the first stage demineralization chamber is filled with a mixture of anion exchangers and cation exchangers or a water treatment apparatus in which the farthest downstream part of the final stage demineralization chamber is filled with a mixture of anion exchangers and cation exchangers.

Brief Description of Drawings

[0012]

Figure 1 is a diagram illustrating EDI apparatus 101 in a first form;
Figure 2 is a diagram illustrating EDI apparatus 102 in a second form;
Figure 3 is a diagram illustrating EDI apparatus 103 in a third form;
Figure 4 is a diagram illustrating EDI apparatus 104 in a fourth form;
Figure 5 is a diagram illustrating EDI apparatus 105 in a fifth form;
Figure 6 is a diagram illustrating EDI apparatus 106 in a sixth form;
Figure 7 is a diagram illustrating water treatment apparatus 201 according to a first embodiment of the present invention;
Figure 8 is a diagram illustrating water treatment apparatus 202 according to a second embodiment of the present invention;
Figure 9 is a diagram illustrating water treatment apparatus 203 according to a third embodiment of the present invention;
Figure 10 is a diagram illustrating water treatment apparatus 204 according to a fourth embodiment of the present invention;
Figure 11 is a diagram illustrating water treatment apparatus 205 according to a fifth

embodiment of the present invention;

Figure 12 is a diagram illustrating water treatment apparatus 206 according to a sixth embodiment of the present invention;

5 Figure 13 is a diagram illustrating water treatment apparatus 207 according to a seventh embodiment of the present invention;

Figure 14 is a diagram illustrating water treatment apparatus 208 according to an eighth embodiment of the present invention;

Figure 15 is a diagram illustrating EDI apparatus 301;

10 Figure 16 is a diagram illustrating a water treatment apparatus of the comparative example 1;

Figure 17 is a diagram illustrating a water treatment apparatus of the comparative example 2;

Figure 18 is a diagram illustrating a water treatment apparatus of the comparative example 3;

15 Figure 19 is a diagram illustrating a water treatment apparatus of the comparative example 4;

Figure 20 shows the measurement of boron concentration in treated water in the examples 1 to 8 and in the comparative examples 1 to 4;

20 Figure 21 shows the measurement of boron concentration in treated water in the examples 9 and 10;

Figure 22 shows the measurement of boron concentration in treated water in the examples 11 to 13; and

Figure 23 shows the measurement of boron concentration in treated water in the example 14.

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List of Reference Numerals

[0013]

- | | |
|------------------------------|---------------------------------------|
| 11 | positive electrode |
| 12 | negative electrode |
| 30 21 | positive electrode chamber |
| 22, 24 | concentration chamber |
| 23a, 23b, 23c, 23d, 23e, 23f | demineralization chamber |
| 23d-1, 23e-1, 23f-1 | first small demineralization chamber |
| 23d-2, 23e-2, 23f-2 | second small demineralization chamber |

25 negative chamber
 31, 33 cation exchange membrane
 32, 34 anion exchange membrane
 36 intermediate ion exchange membrane
 5 CER, K cation exchanger
 AER, A anion exchanger
 101 to 106 EDI apparatus
 201 to 208 water treatment apparatus

10 Description of Embodiments

[0014]

Hereinafter, embodiments of the present invention will be described with reference to the drawings. A water treatment apparatus according to the embodiments of the present invention includes a plurality of EDI apparatuses (electric deionized water
 15 production apparatuses). In the EDI apparatuses, a demineralization chamber is filled with ion exchangers, and ions that are captured in the ion exchange reaction pass along the ion exchangers and move to an ion exchange membrane. Accordingly, ions can be efficiently eliminated. Moreover, an electric current flows in the EDI apparatuses with a current density that causes water decomposition reaction. The minimum electric
 20 current that causes water decomposition reaction is called the limiting current, and an electric current that is equal to or larger than the limiting current flows in the EDI apparatuses. Thus, even when the ion concentration in water to be treated is low, hydrogen ions and hydroxide ions that are caused by the water decomposition reaction move to the ion exchange membranes along ion exchangers, and carry electric charges.
 25 It is thus possible for an EDI apparatuses to produce pure water because electricity flows even in the pure water. In contrast, an electrodialyzing (ED) apparatus cannot utilize water decomposition reaction because the demineralization chamber is not filled with ion exchangers and the electric current that flows in the apparatus is smaller than the limiting current.

30 [0015]

First, six types of EDI apparatuses 101 to 106 that are used in the embodiments of the present invention will be described. The six types of EDI apparatuses are different from each other in the arrangement of the demineralization chambers.

[0016]

<EDI apparatus 101>

Figure 1 is a diagram illustrating EDI apparatus 101.

In EDI apparatus 101, concentration chamber 22, demineralization chamber 23a and concentration chamber 24 are provided in this order from the side of positive electrode chamber 21 between positive electrode chamber 21 that includes positive electrode 11 and negative electrode chamber 25 that includes negative electrode 12.

[0017]

Positive electrode chamber 21 is adjacent to concentration chamber 22 via cation exchange membrane 31, concentration chamber 22 is adjacent to demineralization chamber 23a via anion exchange membrane 32, demineralization chamber 23a is adjacent to concentration chamber 24 via cation exchange membrane 33, and concentration chamber 24 is adjacent to negative electrode chamber 25 via anion exchange membrane 34. Concentration chamber 24 is an example of the first concentration chamber, and concentration chamber 22 is an example of the second concentration chamber.

[0018]

Demineralization chamber 23a is defined by anion exchange membrane 32 and cation exchange membrane 33. The inside of demineralization chamber 23a is filled with anion exchangers AER in a single bed form. For example, anion exchange resins are used as anion exchangers AER. Water to be treated flows through demineralization chamber 23a.

[0019]

Supply water flows through each of concentration chambers 22, 24, positive electrode chamber 21 and negative electrode chamber 25. Pure water, water to be treated or the like are used as the supply water.

[0020]

The supply water flows through concentration chambers 22 and 24 in the direction opposite to the direction in which water to be treated flows through demineralization chamber 23a. The supply water flows through positive electrode chamber 21 and negative electrode chamber 25 in the direction opposite to the direction in which water to be treated flows through demineralization chamber 23a. It should be noted that the relationships between the directions in which these waters flow may be changed, as needed. The electrode water that is discharged from negative electrode chamber 25 flows into positive electrode chamber 21 as supply water. Alternatively, the

electrode water that is discharged from positive electrode chamber 21 may flow into negative electrode chamber 25 as supply water.

[0021]

<EDI apparatus 102>

5 Figure 2 is a diagram illustrating EDI apparatus 102. As compared to EDI apparatus 101 illustrated in Figure 1, the demineralization chamber of EDI apparatus 102 is filled with different ion exchangers. In demineralization chamber 23b of EDI apparatus 102, the portion on the side of inlet 23b1 of water to be treated is only filled with anion exchangers AER, and the portion on the side of outlet 23b2 is only filled with
10 cation exchangers CER. For example, cation exchange resins are used as cation exchangers CER.

[0022]

<EDI apparatus 103>

15 Figure 3 is a diagram illustrating EDI apparatus 103. As compared to EDI apparatus 102 illustrated in Figure 2, anion exchangers AER and cation exchangers CER are charged in the reversed portions. Specifically, in demineralization chamber 23c of EDI apparatus 103, the portion on the side of inlet 23b1 of water to be treated is only filled with cation exchangers CER, and the portion on the side of outlet 23b2 is only filled with anion exchangers AER. For example, cation exchange resins are used as
20 cation exchangers CER.

[0023]

<EDI apparatus 104>

Figure 4 is a diagram illustrating EDI apparatus 104.

25 In demineralization chamber 23d of EDI apparatus 104, intermediate ion exchange membrane 36 is provided between anion exchange membrane 32 and cation exchange membrane 33, and demineralization chamber 23d is divided into small demineralization chamber 23d-1 and small demineralization chamber 23d-2 by intermediate ion exchange membrane 36. As intermediate ion exchange membrane 36, any one of the membranes selected from an anion exchange membrane, a cation
30 exchange membrane and a composite membrane, such as a bipolar membrane, may be used. In EDI apparatus 104, an anion exchange membrane is used as intermediate ion exchange membrane 36. Small demineralization chamber 23d-1 on the side of the positive electrode is an example of the first small demineralization chamber, and small demineralization chamber 23d-2 on the side of the negative electrode is an example of

the second small demineralization chamber.

[0024]

Small demineralization chamber 23d-1 is filled with anion exchangers AER in a single bed form, and small demineralization chamber 23d-2 is filled with cation exchangers CER in a single bed form. Small demineralization chamber 23d-1 and small demineralization chamber 23d-2 communicate with each other in series such that water to be treated flows through small demineralization chamber 23d-1 and the water that flows out of small demineralization chamber 23d-1 flows into small demineralization chamber 23d-2 (see arrows 104a, 104b, 104c).

[0025]

The supply water flows through concentration chambers 22 and 24 in the direction opposite to the direction in which water to be treated flows through small demineralization chambers 23d-1 and 23d-2. The supply water flows through positive electrode chamber 21 and negative electrode chamber 25 in the direction opposite to the direction in which water to be treated flows through small demineralization chambers 23d-1, 23d-2. It should be noted that the relationships between the directions in which these waters flow may be changed, as needed. The electrode water that is discharged from negative electrode chamber 25 flows into positive electrode chamber 21 as supply water. It should be noted that the electrode water that is discharged from positive electrode chamber 21 may flow into negative electrode chamber 25 as supply water.

[0026]

<EDI apparatus 105>

Figure 5 is a diagram illustrating EDI apparatus 105.

As compared to EDI apparatus 104 illustrated in Figure 4, the water to be treated flows through the first small demineralization chamber and the second small demineralization chamber in the reversed order. In EDI apparatus 105, small demineralization chamber 23e-1 and small demineralization chamber 23e-2 communicate with each other in series such that water to be treated is supplied to small demineralization chamber 23d-2 and the water that flows out of small demineralization chamber 23d-2 flows into small demineralization chamber 23d-1 (see arrows 105a, 105b, 105c).

[0027]

The supply water flows through concentration chambers 22 and 24 in the direction opposite to the direction in which water to be treated flows through small

demineralization chambers 23e-1, 23e-2. The supply water flows through positive electrode chamber 21 and negative electrode chamber 25 in the direction opposite to the direction in which water to be treated flows through small demineralization chambers 23e-1, 23e-2. It should be noted that the relationships between the directions in which these waters flow may be changed, as needed. The electrode water that is discharged from negative electrode chamber 25 flows into positive electrode chamber 21 as supply water. It should be noted that the electrode water that is discharged from positive electrode chamber 21 may flow into negative electrode chamber 25 as supply water.

[0028]

<EDI apparatus 106>

Figure 6 is a diagram illustrating EDI apparatus 106.

As compared to EDI apparatus 104 illustrated in Figure 4, the small demineralization chamber on the side of the negative electrode is filled with different ion exchangers. In small demineralization chamber 23f-2, the portion on side of inlet 23f-21 of water that flows out of small demineralization chamber 23f-1 is only filled with cation exchangers CER, and the portion on the side of outlet 23f-22 is only filled with anion exchangers AER. In EDI apparatus 106, small demineralization chamber 23f-1 and small demineralization chamber 23f-2 communicate with each other in series such that water to be treated is supplied to small demineralization chamber 23f-1 and the water that flows out of small demineralization chamber 23f-1 flows into small demineralization chamber 23f-2 (see arrows 106a, 106b, 106c). The water to be treated flows through small demineralization chamber 23f-1 in the direction opposite to the direction in which water to be treated flows through small demineralization chamber 23f-2. An anion exchange membrane is used as intermediate ion exchange membrane 36.

[0029]

The supply water flows through concentration chambers 22 and 24 in the direction opposite to the direction in which water to be treated flows through demineralization chamber 23f-2. The supply water flows through positive electrode chamber 21 and negative electrode chamber 25 in the direction opposite to the direction in which water to be treated flows through demineralization chamber 23f-2. It should be noted that the relationships between the directions in which these waters flow may be changed, as needed. The electrode water that is discharged from negative electrode chamber 25 flows into positive electrode chamber 21 as supply water. It should be

noted that the electrode water that is discharged from positive electrode chamber 21 may flow into negative electrode chamber 25 as supply water.

[0030]

<First embodiment>

5 Figure 7 is a diagram illustrating water treatment apparatus 201 according to a first embodiment of the present invention.

Water treatment apparatus 201 includes EDI apparatus 102 and EDI apparatus 103. Demineralization chamber 23b of EDI apparatus 102 and demineralization chamber 23c of EDI apparatus 103 communicate with each other in series in this order.
10 Water that flows out from outlet 23b2 of demineralization chamber 23b flows into demineralization chamber 23c from inlet 23c1. The concentration chambers of EDI apparatus 102 and the concentration chambers of EDI apparatus 103 do not communicate with each other in series, and the supply water (pure water) is separately supplied to the concentration chambers. The supply water (pure water) is separately
15 supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 102 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 103. It should be noted that the concentration chambers of EDI apparatus 102 and the concentration chambers of EDI apparatus 103 may communicate with each other in series.
20 Alternatively, common supply water may be supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 102 and the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 103.

[0031]

25 In the water treatment apparatuses according to the present embodiment and embodiments described later, reverse osmosis membrane device 111 is preferably provided upstream of the upstream-side EDI apparatus with regard to the flow direction of water to be treated, or, upstream of the demineralization chamber of the first stage EDI apparatus, into which water to be treated flows first, with regard to the flow direction
30 of water to be treated. Reverse osmosis membrane device 111 can reduce silica concentration in the water to be treated, for example, to 100 $\mu\text{g SiO}_2/\text{L}$ or less and reduce boron concentration in the water to be treated, for example, to 100 $\mu\text{g B/L}$ or less. More preferably, two reverse osmosis membrane devices 111 are provided in series, although not illustrated. Furthermore, decarboxylation membrane device 112 is

preferably provided upstream of the upstream-side EDI apparatus with regard to the flow direction of water to be treated, or, upstream of the demineralization chamber of the first stage EDI apparatus, into which water to be treated flows first, with regard to the flow direction of water to be treated. Decarboxylation membrane device 112 can reduce carbonic acid concentration in the water to be treated, for example, to 5 mg CO₂/L or less. Either reverse osmosis membrane device 111 or decarboxylation membrane device 112 may be provided on the upstream side with regard to the flow direction of the water to be treated.

[0032]

Next, water treatment that is performed in demineralization chambers 23b and 23c of water treatment apparatus 201 will be described.

[0033]

In EDI apparatuses 102 and 103, water to be treated flows from inlet 23b1 of demineralization chamber 23b of EDI apparatus 102 when the supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC voltage is applied between positive electrode 11 and negative electrode 12.

[0034]

In EDI apparatus 102, the water to be treated is assumed to be treated in the manner described below.

When boron in the water to be treated comes into contact with anion exchangers AER that fill the portion of demineralization chamber 23b on the side of inlet 23b1, the boron dissociates in the form of anion and is adsorbed to anion exchangers AER. A part of boron in the water to be treated stays in the water to be treated without being adsorbed to anion exchangers AER. The water to be treated that contains the remaining boron flows into an area (a portion) of demineralization chamber 23b that is filled with cation exchangers CER.

[0035]

At this time, water dissociation reaction is caused in demineralization chamber 23b due to the voltage applied between positive electrode 11 and negative electrode 12, and hydrogen ions and hydroxide ions are generated. Then, an anion (boron) that has been adsorbed to anion exchangers AER in demineralization chamber 23b is ion-exchanged with a hydroxide ion, and is liberated from anion exchangers AER. The liberated anion is moved to concentration chamber 22 through anion exchange

membrane 32 and is discharged from concentration chamber 2 as concentrated water.

[0036]

When the water to be treated flows into the area of demineralization chamber 23b that is filled with cation exchangers CER after passing through the area of demineralization chamber 23b that is filled with anion exchangers AER, a cation that is contained in the water to be treated is adsorbed to cation exchangers CER. Then, the cation that is adsorbed to cation exchangers CER is ion-exchanged with a hydrogen ion that is generated by water dissociation reaction, and then dissociates from cation exchangers CER. The liberated cation is moved to concentration chamber 24 through cation exchange membrane 33, and is discharged from concentration chamber 24 as concentrated water.

[0037]

Hydroxide ions in the water to be treated are moved to concentration chamber 22 through anion exchange membrane 32, and are discharged from concentration chamber 22 as concentrated water.

[0038]

Moreover, hydroxide ions in the water to be treated react with hydrogen ions, which are ion-exchanged and released from cation exchangers CER, and with hydrogen ions, which are generated by dissociation of water, and are converted into water (H_2O).

Thus, hydroxide ion concentration in the water to be treated that flows out of demineralization chamber 23b is lower than the hydroxide ion concentration that would be observed when there were no cation exchangers CER in demineralization chamber 23b. It should be noted that hydroxide ions in the water to be treated may be adsorbed to anion exchangers AER, instead of boron (an anion). For this reason, when hydroxide ion concentration in the water to be treated is excessively high, efficiency of adsorbing boron (anion) by the downstream anion exchangers AER may be worsened. Therefore, the efficiency of adsorbing boron (anion) by anion exchangers AER of the downstream EDI apparatus 103 can be enhanced by reducing hydroxide ions in the water to be treated due to the reaction in which hydroxide ions react with hydrogen ions that are adsorbed to cation exchangers CER and are converted into water (H_2O).

[0039]

The water to be treated that flows out of demineralization chamber 23b of EDI apparatus 102 flows into demineralization chamber 23c of EDI apparatus 103 from inlet 23c1.

[0040]

In EDI apparatus 103, the following treatment is assumed to be performed.

When the water to be treated that flows out of demineralization chamber 23b flows into a portion of demineralization chamber 23c that is filled with cation exchangers CER, a treatment is performed that is similar to the treatment of the water to be treated in the portion of demineralization chamber 23b that is filled with cation exchangers CER. Accordingly, the hydroxide ion concentration in the water to be treated that flows out of the portion of demineralization chamber 23c that is filled with cation exchangers CER is lower than the hydroxide ion concentration that would be observed when there were no cation exchangers CER in demineralization chamber 23c.

[0041]

The water to be treated that flows through the portion of demineralization chamber 23c that is filled with cation exchangers CER flows into the portion of demineralization chamber 23c that is filled with anion exchangers AER.

[0042]

When boron in the water to be treated comes into contact with anion exchangers AER that fill the portion of demineralization chamber 23c on the side of outlet 23c2, the boron dissociates in the form of anion and is adsorbed to anion exchangers AER. At this time, since the water to be treated already has passed through cation exchangers CER, the hydroxide ion concentration in the water to be treated is lower than the concentration before the water flows through cation exchangers CER. For this reason, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill the portion of demineralization chamber 23c on the side of outlet 23c2 can be enhanced. Therefore, boron concentration in the treated water that flows out of demineralization chamber 23c can be reduced.

[0043]

Further, boron concentration in the treated water is reduced by using a plurality of EDI apparatuses. Thus, for example, as compared to a configuration where a demineralization chamber of a single EDI apparatus is filled with ion exchangers in the order of "anion exchangers --> cation exchangers --> anion exchangers", the following advantages are provided.

[0044]

(1) A current imbalance in the EDI apparatus can be limited.

For example, when a demineralization chamber of an EDI apparatus is filled with

ion exchangers in the order of "anion exchangers --> cation exchangers --> anion exchangers", a current imbalance occurs depending on the difference of electric resistance between the anion exchangers and the cation exchanger because the electric resistance of the anion exchangers is different from that of the cation exchangers.

5 On the other hand, when a plurality of EDI apparatuses is used, the number of types of ion exchangers that fill a demineralization chamber can be reduced as compared to a configuration having a single EDI apparatus. Accordingly, a current imbalance depending on the difference of electric resistances between ion exchangers can be reduced.

10 [0045]

(2) Since electrode plates can be separately provided, the control of current can be facilitated.

Electrode plates tend to be deteriorated under a high current density. Further, ion exchange membranes and ion exchange resins that constitute an EDI apparatus also
15 tend to deteriorate, such as by electrical burning, when the apparatus operates under a large current and a low ion load. Operation can be more stably performed, for example, by lowering the current in the downstream EDI apparatus having a low ion load.

[0046]

(3) Load in the downstream EDI apparatus can be reduced.

20 Since the downstream EDI apparatus treats treated water that is treated by the upstream EDI apparatus, the downstream EDI apparatus has low treatment load, as compared to a case where the EDI apparatus treats water that have not been treated at all. For this reason, it is expected that the downstream EDI apparatus will deteriorate more slowly than the upstream EDI apparatus and be able to be used for a longer time
25 period. It is expected that the downstream EDI apparatus will be able to be replaced less frequently than the upstream EDI apparatus.

[0047]

<Second embodiment>

Figure 8 is a diagram illustrating water treatment apparatus 202 according to a
30 second embodiment of the present invention.

Water treatment apparatus 202 includes EDI apparatus 101 and EDI apparatus 103. Demineralization chamber 23a of EDI apparatus 101 and demineralization chamber 23c of EDI apparatus 103 communicate in series in this order. Water to be treated flows into demineralization chamber 23a, and the water that flows out of

demineralization chamber 23a flows into demineralization chamber 23c from inlet 23c1. The concentration chambers of EDI apparatus 101 and the concentration chambers of EDI apparatus 103 do not communicate with each other in series, and supply water is supplied separately. Supply water is separately supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 101 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 103.

[0048]

Next, water treatment that is performed in demineralization chambers 23a and 23c of water treatment apparatus 202 will be described.

In EDI apparatuses 101 and 103, water to be treated flows into demineralization chamber 23a of EDI apparatus 101 when supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC voltage is applied between positive electrode 11 and negative electrode 12.

[0049]

In EDI apparatus 101, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23b on the side of inlet 23b1 in the first embodiment. The water to be treated that flows out of demineralization chamber 23a of EDI apparatus 101 flows into demineralization chamber 23c of EDI apparatus 103 from inlet 23c1. In EDI apparatus 103, it is assumed that a treatment will be performed that is similar to the treatment that is performed in EDI apparatus 103 in the first embodiment.

[0050]

Accordingly, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill the portion of demineralization chamber 23 on the side of outlet 23c2 is enhanced in the same manner as in the first embodiment. Thus, the boron concentration in the treated water that flows out of demineralization chamber 23c can be reduced.

[0051]

<Third embodiment>

Figure 9 is a diagram illustrating water treatment apparatus 203 according to a third embodiment of the present invention.

Water treatment apparatus 203 includes EDI apparatus 102 and EDI apparatus 101. Demineralization chamber 23b of EDI apparatus 102 and demineralization chamber 23a of EDI apparatus 101 communicate in series in this order. Water to be

treated flows into demineralization chamber 23b from inlet 23b1. The water that flows out of demineralization chamber 23b flows into demineralization chamber 23a. The concentration chambers do not communicate in series between EDI apparatus 102 and EDI apparatus 101, and supply water is supplied separately. Supply water is separately
5 supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 102 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 101.

[0052]

Next, water treatment that is performed in demineralization chambers 23b and
10 23a of water treatment apparatus 203 will be described.

In EDI apparatuses 102 and 101, water to be treated flows from inlet 23b1 of demineralization chamber 23b of EDI apparatus 102 when supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC voltage is applied between positive electrode 11 and
15 negative electrode 12.

In EDI apparatus 102, it is assumed that a treatment will be performed that is similar to the treatment that is performed in EDI apparatus 102 described in the first embodiment. The water to be treated that flows out from outlet 23b2 of demineralization chamber 23b of EDI apparatus 102 flows into demineralization
20 chamber 23a of EDI apparatus 101. In EDI apparatus 101, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23c on the side of outlet 23c2 in the first embodiment.

[0053]

Accordingly, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill demineralization chamber 23a is enhanced in the same manner as in the first embodiment. Thus, the boron concentration in the treated water that flows out of demineralization chamber 23a can be reduced.

[0054]

30 <Fourth embodiment>

Figure 10 is a diagram illustrating water treatment apparatus 204 according to a fourth embodiment of the present invention.

Water treatment apparatus 204 includes EDI apparatus 104 and EDI apparatus 101. Demineralization chamber 23d-1 of EDI apparatus 104, demineralization chamber

23d-2 of EDI apparatus 104 and demineralization chamber 23a of EDI apparatus 101 communicate in series in this order. Water to be treated flows through small demineralization chamber 23d-1 first. The concentration chambers do not communicate in series between EDI apparatus 104 and EDI apparatus 101, and supply water is supplied separately. Supply water is separately supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 104 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 101.

[0055]

Next, water treatment that is performed in small demineralization chambers 23d-1, 23d-2 and demineralization chamber 23a of water treatment apparatus 204 will be described.

In EDI apparatuses 104 and 101, water to be treated flows through small demineralization chamber 23d-1 of EDI apparatus 104 when supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC voltage is applied between positive electrode 11 and negative electrode 12.

[0056]

In small demineralization chamber 23d-1 of EDI apparatus 104, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23b on the side of inlet 23b1 in the first embodiment. The water to be treated that flows out of small demineralization chamber 23d-1 flows into small demineralization chamber 23d-2. In small demineralization chamber 23d-2, it is assumed that a treatment will be performed that is similar to the treatment that is performed by cation exchangers CER that fill the portion of demineralization chamber 23b on the side of outlet 23b2 in the first embodiment. The water to be treated that flows out of small demineralization chamber 23d-2 flows into demineralization chamber 23a of EDI apparatus 101. In EDI apparatus 101, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23c on the side of outlet 23c2 in the first embodiment.

[0057]

Accordingly, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill demineralization chamber 23a is enhanced in the same manner as in the first

embodiment. Thus, the boron concentration in the treated water that flows out of demineralization chamber 23a can be reduced.

[0058]

<Fifth embodiment>

5 Figure 11 is a diagram illustrating water treatment apparatus 205 according to a fifth embodiment of the present invention.

Water treatment apparatus 205 includes EDI apparatus 101 and EDI apparatus 105. Demineralization chamber 23a of EDI apparatus 101, small demineralization chamber 23e-2 of EDI apparatus 105 and small demineralization chamber 23e-1 of EDI
10 apparatus 105 communicate in series in this order. Water to be treated flows through demineralization chamber 23a first. The concentration chambers do not communicate in series between EDI apparatus 101 and EDI apparatus 105, and supply water is supplied separately. Supply water is separately supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus
15 101 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 105.

[0059]

Next, water treatment that is performed in demineralization chamber 23a and small demineralization chambers 23e-2 and 23e-1 of water treatment apparatus 205 will
20 be described.

In EDI apparatuses 101 and 105, water to be treated flows through demineralization chamber 23a of EDI apparatus 101 when supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC voltage is applied between positive electrode 11 and
25 negative electrode 12.

[0060]

In demineralization chamber 23a of EDI apparatus 101, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23b on the side of inlet
30 23b1 in the first embodiment. The water to be treated that flows out of demineralization chamber 23a flows into small demineralization chamber 23e-2 of EDI apparatus 105.

[0061]

In small demineralization chamber 23e-2, it is assumed that a treatment will be performed that is similar to the treatment that is performed by cation exchangers CER

that fill the portion of demineralization chamber 23c on the side of inlet 23c1 in the first embodiment. The water to be treated that flows out of small demineralization chamber 23e-2 flows into small demineralization chamber 23e-1. In small demineralization chamber 23e-1, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23c on the side of outlet 23c2 in the first embodiment.

[0062]

Accordingly, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill small demineralization chamber 23e-1 is enhanced in the same manner as in the first embodiment. Thus, the boron concentration in the treated water that flows out of small demineralization chamber 23e-1 can be reduced.

[0063]

<Sixth embodiment>

Figure 12 is a diagram illustrating water treatment apparatus 206 according to a sixth embodiment of the present invention.

Water treatment apparatus 206 includes EDI apparatus 106 and EDI apparatus 101. Small demineralization chamber 23f-1 of EDI apparatus 106, small demineralization chamber 23f-2 of EDI apparatus 106 and demineralization chamber 23a of EDI apparatus 101 communicate in series in this order. Water to be treated flows through small demineralization chamber 23f-1 first. The concentration chambers do not communicate in series between EDI apparatus 106 and EDI apparatus 101, and supply water is supplied separately. Supply water is separately supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 106 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 101.

[0064]

Next, water treatment that is performed in small demineralization chambers 23f-1, 23f-2 and demineralization chamber 23a of water treatment apparatus 206 will be described.

In EDI apparatuses 106 and 101, water to be treated flows through small demineralization chamber 23f-1 of EDI apparatus 106 when supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC voltage is applied between positive electrode 11 and negative electrode 12.

[0065]

In small demineralization chamber 23f-1 of EDI apparatus 106, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23b on the side of inlet 23b1 in the first embodiment. The water to be treated that flows out of small demineralization chamber 23f-1 flows into small demineralization chamber 23f-2 from the side of inlet 23f-21 (the portion that is filled with cation exchangers CER) of small demineralization chamber 23f-2. In the portion that is filled with cation exchangers CER on the side of inlet 23f-21 of small demineralization chamber 23f-2, it is assumed that a treatment will be performed that is similar to the treatment that is performed by cation exchangers CER that fill the portion of demineralization chamber 23b on the side of outlet 23b2 in the first embodiment. The water to be treated that flows through the portion that is filled with cation exchangers CER of small demineralization chamber 23f-2 flows through the portion that is filled with anion exchangers AER of small demineralization chamber 23f-2. In the portion that is filled with anion exchangers AER of small demineralization chamber 23f-2, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23c on the side of outlet 23c2 in the first embodiment.

[0066]

The water to be treated that flows through the portion that is filled with anion exchangers AER of small demineralization chamber 23f-2 flows through demineralization chamber 23a of EDI apparatus 101. In demineralization chamber 23a, it is assumed that a treatment will be performed that is similar to the treatment that is performed by anion exchangers AER that fill the portion of demineralization chamber 23c on the side of outlet 23c2 in the first embodiment.

[0067]

Accordingly, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill demineralization chamber 23a is enhanced in the same manner as in the first embodiment. Thus, the boron concentration in the treated water that flows out of demineralization chamber 23a can be reduced.

[0068]

<Seventh embodiment>

Figure 13 is a diagram illustrating water treatment apparatus 207 according to a

seventh embodiment of the present invention.

Water treatment apparatus 207 includes two EDI apparatuses 106. Hereinafter, EDI apparatus 106 through which water to be treated flows first is referred to as "first stage EDI apparatus 106-1", and EDI apparatus 106 through which water to be treated
5 flows last is referred to as "final stage EDI apparatus 106-2".

[0069]

Small demineralization chamber 23f-1 of first stage EDI apparatus 106-1, small demineralization chamber 23f-2 of first stage EDI apparatus 106-1, small demineralization chamber 23f-1 of final stage EDI apparatus 106-2 and small
10 demineralization chamber 23f-2 of final stage EDI apparatus 106-2 communicate in series in this order. Water to be treated first flows through small demineralization chamber 23f-1 of first stage EDI apparatus 106-1. The concentration chambers do not communicate in series between first stage EDI apparatus 106-1 and final stage EDI apparatus 106-2, and supply water is supplied separately. Supply water is separately
15 supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of first stage EDI apparatus 106-1 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of final stage EDI apparatus 106-2.

[0070]

20 Next, water treatment that is performed in each demineralization chamber of water treatment apparatus 207 will be described.

In first stage EDI apparatus 106-1 and final stage EDI apparatus 106-2, water to be treated flows through small demineralization chamber 23f-1 of first stage EDI apparatus 106-1 when supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC
25 voltage is applied between positive electrode 11 and negative electrode 12.

[0071]

In first stage EDI apparatus 106-1, it is assumed that a treatment will be performed that is similar to the treatment that is performed by EDI apparatus 106 of the sixth embodiment (see Figure 12). The water to be treated that flows out of first stage
30 EDI apparatus 106-1 flows through small demineralization chamber 23f-1 of final stage EDI apparatus 106-2. In final stage EDI apparatus 106-2, it is assumed that a treatment will be performed on the water to be treated that flows out of first stage EDI apparatus 106-1, the treatment being similar to the treatment that is performed by EDI

apparatus 106 of the sixth embodiment (see Figure 12).

[0072]

Accordingly, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill the portion of small demineralization chamber 23f-2 of final stage EDI apparatus 106-2 on the side of outlet 23f-22 is enhanced. Thus, the boron concentration in the treated water that flows out of small demineralization chamber 23f-2 of final stage EDI apparatus 106-2 can be reduced.

[0073]

<Eighth embodiment>

Figure 14 is a diagram illustrating water treatment apparatus 208 according to an eighth embodiment of the present invention.

Water treatment apparatus 208 includes EDI apparatus 106 and EDI apparatus 105. Small demineralization chamber 23f-1 of EDI apparatus 106, small demineralization chamber 23f-2 of EDI apparatus 106, small demineralization chamber 23e-2 of EDI apparatus 105 and small demineralization chamber 23e-1 of EDI apparatus 105 communicate in series in this order. Water to be treated flows through small demineralization chamber 23f-1 first. The concentration chambers do not communicate in series between EDI apparatus 106 and EDI apparatus 105, and supply water is supplied separately. Supply water is separately supplied to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 106 and to the electrode chambers (the negative electrode chamber and the positive electrode chamber) of EDI apparatus 105.

[0074]

Next, water treatment that is performed in each demineralization chamber of water treatment apparatus 208 will be described.

In EDI apparatuses 106 and 105, water to be treated flows through small demineralization chamber 23f-1 of EDI apparatus 106 when supply water flows through positive electrode chamber 21, concentration chambers 22, 24 and negative electrode chamber 25 and when a DC voltage is applied between positive electrode 11 and negative electrode 12.

[0075]

In EDI apparatus 106, it is assumed that a treatment will be performed that is similar to the treatment that is performed by EDI apparatus 106 of the sixth embodiment (see Figure 12). The water to be treated that flows out of EDI apparatus 106 flows

through small demineralization chamber 23e-2 of EDI apparatus 105. In EDI apparatus 105, it is assumed that a treatment will be performed that is similar to the treatment that is performed by EDI apparatus 105 of the fifth embodiment (see Figure 11).

[0076]

5 Accordingly, the efficiency of adsorbing boron (anion) by anion exchangers AER that fill small demineralization chamber 23e-1 of EDI apparatus 105 is enhanced. Thus, the boron concentration in the treated water that flows out of demineralization chamber 23e-1 can be reduced.

[0077]

10 The configurations that are illustrated in the embodiments described above are merely examples, and the present invention is not limited to these configurations.

For example, a water treatment apparatus using two EDI apparatuses is utilized in each embodiment described above. However, the number of EDI apparatuses is not limited to two, but may be three or more, as long as, out of a plurality of demineralization
15 chambers, the farthest upstream part of the first stage demineralization chamber into which water to be treated flows first and the farthest downstream part of the final stage demineralization chamber that outputs treated water are only filled with anion exchangers, and a portion which is a part of the plurality of demineralization chambers that communicate in series and which is located between the farthest upstream part of
20 the first stage demineralization chamber and the farthest downstream part of the final stage demineralization chamber is filled with at least cation exchangers.

[0078]

Further, in each embodiment, a basic configuration (a cell set) that is formed of
[concentration chamber (C) | anion exchange membrane (AEM) | demineralization
25 chamber (D) | cation exchange membrane (CEM) | concentration chamber (C)] is disposed between the positive electrode and the negative electrode. However, in order to increase the capacity of treatment, it is also possible to arrange a plurality of such cell sets side by side between the electrodes and to electrically connect the plurality of cell sets to each other in series such that one end of the cell sets is the positive electrode
30 and the other end is the negative electrode.

[0079]

In this case, concentration chambers that are adjacent to each other in adjacent cell sets can be shared. Accordingly, as a configuration of an EDI apparatus, a configuration of [positive electrode chamber | C | AEM | D | CEM | C | AEM | D | CEM | C |

AEM | D | CEM [...] C | negative electrode chamber] may also be used. The number of demineralization chambers in an EDI apparatus of such a serial arrangement is also referred to as "a cell pair number of demineralization chambers".

[0080]

5 Moreover, in such a serial arrangement, for the demineralization chamber that is closest to the positive electrode, the positive electrode chamber itself may function as a concentration chamber without interposing any independent concentration chamber that is adjacent to the positive electrode chamber, and for the demineralization chamber that is closest to the negative electrode, the negative electrode chamber itself may function
10 as a concentration chamber without interposing any independent concentration chamber that is adjacent to the negative electrode chamber. In order to limit electric power that is consumed by the application of a DC voltage, at least any one of the chambers selected from the concentration chambers, the positive electrode chamber and the negative electrode chamber may be filled with ion exchangers in order to reduce the electric
15 resistance of the EDI apparatus.

[0081]

 In each embodiment, pure water is used as the supply water that flows through the negative electrode chamber and the positive electrode chamber. However, the supply water that is supplied to the negative electrode chamber and the positive
20 electrode chamber does not need to be pure water, and may be water to be treated, for example. In addition, the negative electrode chamber and the positive electrode chamber of the same EDI apparatus does not need to be connected with each other, but may be connected in parallel.

[0082]

25 In each embodiment, pure water is supplied to each concentration chamber. However, instead of pure water, treated water that is outputted from the second stage EDI apparatus may be supplied. Alternatively, treated water that is outputted from the second stage EDI apparatus may be supplied to each concentration chamber of the second stage EDI apparatus, and the water that is discharged from the concentration
30 chambers of the second stage EDI apparatus may be supplied to the concentration chambers of the first stage EDI apparatus. Water to be treated may also be supplied to the concentration chambers of the first stage EDI apparatus.

Examples

[0083]

Next, examples according to the present invention and comparative examples will be described.

5 In the examples and the comparative examples, a water treatment apparatus having two EDI apparatuses whose demineralization chambers communicate in series was used. Hereinafter, out of the two EDI apparatuses, the EDI apparatus through which water to be treated flows first is referred to as "a first stage EDI apparatus", and the EDI apparatus (the final stage EDI apparatus) through which the water to be treated that flows out of the first stage EDI apparatus flows is referred to as "a second stage EDI
10 apparatus".

[0084]

<Examples 1 to 8>

As water treatment apparatuses of the examples 1 to 8, water treatment apparatuses 201 to 208 (see Figure 20) according to the first to eighth embodiments
15 illustrated in Figures 7 to 14 were used.

Next, EDI apparatus 301 used in the comparative examples will be described.

Figure 15 is a diagram illustrating EDI apparatus 301. As EDI apparatus 301, an EDI apparatus in which demineralization chamber 23g is filled with anion exchangers A and cation exchangers K in a mixed bed form was used.

20 [0085]

Next, water treatment apparatuses of the comparative examples 1 to 4 will be described.

Figures 16 to 19 are diagrams illustrating the water treatment apparatuses of the comparative examples 1 to 4, respectively.

25 In the comparative example 1, EDI apparatuses 301 were used as the first and second stage EDI apparatuses, as illustrated in Figure 16. In the comparative example 2, EDI apparatus 301 was used as the first stage EDI apparatus, and EDI apparatus 103 was used as the second stage EDI apparatus, as illustrated in Figure 17. In the comparative example 3, EDI apparatus 301 was used as the first stage EDI apparatus, and EDI apparatus 102 was used as the second stage EDI apparatus, as illustrated in
30 Figure 18. In the comparative example 4, EDI apparatus 101 was used as the first stage EDI apparatus, and EDI apparatus 301 was used as the second stage EDI apparatus, as illustrated in Figure 19.

[0086]

Specification of the EDI apparatuses and operation condition, such as water flow rate, applied current and water quality of water to be treated in the examples 1 to 8 and the comparative examples 1 to 4 are as follows.

- As anion exchangers, anion exchange resins [product name: AMBERJET (registered trademark) 4002 (strongly basic anion exchange resin 4002), manufactured by the Dow Chemical Company] were used, and as cation exchangers, cation exchange resins [product name: AMBERJET (registered trademark) 1020 (the strongly acidic positive ion exchange resin 1020), manufactured by the Dow Chemical Company] were used.
- In demineralization chambers 23b, 23c, small demineralization chamber 23f-2 and demineralization chamber 23g, each of which is filled with both the anion exchange resins and the cation exchange resins, the volume ratio of the anion exchange resins and the cation exchange resins was set to 1:1.
- The volume of the cells (the demineralization chambers, the concentration chambers, the positive electrode chambers and the negative electrode chambers) were set to 100 mm × 100 mm × 10 mm.
- The cell pair number of the demineralization chambers was set to one.
- As water to be treated to flow through the first stage EDI apparatus, water (electric conductivity: 3 to 4 $\mu\text{S}/\text{cm}$, boron concentration: 90 to 100 $\mu\text{g B/L}$) treated by a dual-stage RO (reverse osmosis membrane) was used.
- The flow rate of the water to be treated was set to 20 L/h.
- The electric current that flows between the positive electrode and the negative electrode was set to 0.4A.
- As the supply water that is supplied to the concentration chambers, pure water provided by a different system was used.
- The flow rate of the supply water supplied to the concentration chambers was set to 5 L/h.
- As the supply water that is supplied to the positive electrode chambers and the supply water that is supplied to the negative electrode chambers, pure water provided by a different system was used.
- The flow rate of the supply water that is supplied to each positive electrode chamber and the flow rate of the supply water that is supplied to each negative electrode chamber were set to 5 L/h.

[0087]

Figure 20 shows the measurement of boron concentration in the treated water (unit: ng B/L) in the examples 1 to 8 and the comparative examples 1 to 4. In Figure 20, the state of the demineralization chamber of each EDI apparatus (the form in which the chamber is filled with anion exchange resins and cation exchange resins) is schematically illustrated. In Figure 20, the anion exchange resin layer is denoted by "A", the cation exchange resin layer is denoted by "K", and the mixed layer of the anion exchange resins and the cation exchange resins is denoted by "MB".

[0088]

As will be understood from the boron concentration in the treated water in the examples 1 to 8 and in the comparative examples 1 to 4, it was impossible to reduce the boron concentration to 50 ng B/L or less merely by making the demineralization chambers of the two EDI apparatuses communicate in series. It is considered to be desirable, for example, for pure water that is used in semiconductor processes to reduce the boron concentration to 50 ng B/L or less.

[0089]

On the other hand, it was possible to reduce the boron concentration to 50 ng B/L or less by filling the farthest upstream part of the demineralization chamber of the first stage EDI apparatus only with anion exchange resins, filling the farthest downstream part of the demineralization chamber of the second stage (the final stage) EDI apparatus only with anion exchange resins, and by filling an area between the farthest upstream part and the farthest downstream part with cation exchange resins, as shown in the examples 1 to 8.

[0090]

As will be understood from the comparison between the example 1 and the examples 2, 3 and between the comparative examples 1 to 3 and the comparative example 4, it was possible to further reduce the boron concentration in the treated water by filling the demineralization chamber of the first stage EDI apparatus with anion exchange resins in a single bed form or by filling the demineralization chamber of the second stage EDI apparatus with anion exchange resins in a single bed form.

[0091]

As will be understood from the comparison between the examples 2, 3 and the examples 4, 5, it was possible to further reduce the boron concentration in the treated water when at least one of the demineralization chambers that communicate in series is a demineralization chamber that includes an intermediate ion exchange membrane, a

first small demineralization chamber and a second small demineralization chamber (hereinafter, referred to as "a D2 demineralization chamber"). However, when D2 demineralization chambers are connected in series, the pressure difference may be increased. For this reason, if the boron concentration in the treated water can be reduced to or below the target value (for example, 50 ng B/L) without unnecessarily increasing the number of D2 demineralization chambers, as shown in the examples 4 to 6, then merit is provided in terms of the pressure difference.

[0092]

As will be understood from the comparison between the example 7 and the example 8, it was possible to further reduce the boron concentration in the treated water by filling the farthest downstream demineralization chamber of the final stage (the second stage) EDI apparatus with anion exchange resins in a single bed form.

[0093]

<Examples 9 and 10>

Next, water treatment apparatuses of the examples 9 and 10 will be described with reference to Figure 21.

The example 9 is an example in which, in the example 1, the volume ratio of the anion exchange resins and the cation exchange resins in the demineralization chamber of the first stage EDI apparatus is changed (the volume ratio of the anion exchange resins is changed in the range of 5 to 100%) while the volume ratio of the cation exchange resins and the anion exchange resins in the demineralization chamber of the second stage EDI apparatus of the example 1 is constant (cation exchange resins : anion exchange resins = 9:1).

[0094]

The example 10 is an example in which, in the example 1, the volume ratio of the anion exchange resins and the cation exchange resins in the demineralization chamber of the second stage EDI apparatus is changed (the volume ratio of the anion exchange resins is changed in the range of 5 to 100%) while the volume ratio of the cation exchange resins and the anion exchange resins in the demineralization chamber of the first stage EDI apparatus of the example 1 is constant (anion exchange resins : cation exchange resins = 1:9).

[0095]

Figure 21 shows the measurement of boron concentration in the treated water in the examples 9 and 10. It should be noted that, in Figure 21, the state of the

demineralization chamber of each EDI apparatus (the form in which the chamber is filled with anion exchange resins and the cation exchange resins) is schematically illustrated, wherein the anion exchange resin layer is denoted by "A" or "AER", and the cation exchange resin layer is denoted by "K".

5 [0096]

10 In Figure 21, regarding the measurement of the example 9, the degree of reduction of boron concentration in the treated water when the ratio of anion exchange resins is increased is plotted as an elimination rate, wherein the boron concentration in the treated water was defined as "1" when the ratio of anion exchange resins in the first stage EDI apparatus is 5%. On the other hand, regarding the measurement of the example 10, the degree of reduction of the boron concentration in the treated water when the ratio of anion exchange resins is increased is plotted as an elimination rate, wherein the boron concentration in the treated water was defined as "1" when the ratio of anion exchange resins in the second stage EDI apparatus is 5%. In the examples 9 and 10, the water supplying test was conducted under the same condition of supply water load as in the examples 1 to 8 and the comparative examples 1 to 4 (for example, as the water to be treated, water that flows through a dual-RO was used, and the boron concentration in the water to be treated that is supplied to the demineralization chamber of the first stage EDI apparatus was set to 90 to 100 $\mu\text{g B/L}$).

20 [0097]

The examples 9 and 10 show that the boron concentration in the treated water is reduced as the ratio of anion exchange resins is increased. The comparison of the ratio of anion exchange resins between 5% and 10% shows that the degree of reduction in the boron concentration in the treated water is significantly higher for the ratio of 10% than the degree for the ratio less than 10%. This means that the degree of reduction in the boron concentration in the treated water is significantly large when the ratio of the volume of anion exchangers that fill the farthest upstream part of the first stage demineralization chamber alone to the volume of the first stage demineralization chamber is 10% or larger, as well as when the ratio of the volume of anion exchangers that fill the farthest downstream part of the final stage demineralization chamber alone to the volume of the final stage demineralization chamber is 10 % or larger.

30 [0098]

In addition, as compared to the case where the ratio of anion exchange resins is equal to or larger than 10% and less than 50%, the effect of reducing the boron

concentration in the treated water was confirmed to be large when the ratio of anion exchange resins was 50% or larger. This means that the degree of reduction in the boron concentration in the treated water was further significantly large when the ratio of the volume of anion exchangers that fill the farthest upstream part of the first stage demineralization chamber alone to the volume of the first stage demineralization chamber was 50% or larger, as well as when the ratio of the volume of the anion exchangers that fill the farthest downstream part of the final stage demineralization chamber alone to the volume of the final stage demineralization chamber was 50% or larger,.

[0099]

<Examples 11 to 13>

Next, water treatment apparatuses of the examples 11 to 13 will be described with reference to Figure 22.

The example 11 is an example in which, in the example 1, carbonic acid concentration (mg CO₂/L) in the water to be treated that flows into the demineralization chamber of the first stage EDI apparatus was changed while the silica concentration and boron concentration were constant around 100 micrograms per liter (silica: 98 µg SiO₂/L, boron: 97 µg B/L).

[0100]

The example 12 is an example in which, in the example 1, silica concentration (µg SiO₂/L) in the water to be treated that flows into the demineralization chamber of the first stage EDI apparatus was changed while boron concentration and carbonic acid concentration were constant (boron: 97 µg B/L, carbonic acid: 5 mg CO₂/L).

[0101]

The example 13 is an example in which, in the example 1, boron concentration (µg B/L) in the water to be treated that flows into the demineralization chamber of the first stage EDI apparatus was changed while silica concentration and carbonic acid concentration were constant (silica: 98 µg SiO₂/L, carbonic acid: 5 mg CO₂/L).

[0102]

Figure 22 shows the measurement of the boron concentration in the treated water in the examples 11 to 13. In Figure 22, the anion exchange resins are denoted by "A" and the cation exchange resins are denoted by "K".

[0103]

From the examples 11 to 13, it is confirmed that the boron concentration in the

treated water can be 50 ng B/L or less when the carbonic acid concentration is 5 mg CO₂/L or less, the silica concentration is 100 µg SiO₂/L or less and the boron concentration is 100 µg B/L or less in the water to be treated that flows into the demineralization chamber of the first stage EDI apparatus.

5 [0104]

In addition, in the example 13, a test was conducted in which the boron concentration in the water to be treated that flows into the demineralization chamber of the first stage EDI apparatus was approximately 200 (198) µg B/L and a current of 0.8A was applied between the positive electrode and the negative electrode. It was impossible to reduce the boron concentration in the treated water to 50 ng B/L or less in the test. Therefore, it was confirmed that the boron concentration in the treated water was not reduced to 50 ng B/L or less by merely increasing the current.

[0105]

<Example 14>

15 Next, water treatment apparatus of the example 14 will be described with reference to Figure 23.

The example 14 is an example in which, in the example 8, boron concentration (µg B/L) in the water to be treated that flows into small demineralization chamber 23f-1 of the first stage EDI apparatus was changed while silica concentration and carbonic acid concentration were constant (silica: 101 µg SiO₂/L, carbonic acid: 5 mg CO₂/L).

20 [0106]

Figure 23 shows the measurement of boron concentration in the treated water in example 14. In Figure 23, the anion exchange resins are denoted by "A", and the cation exchange resins are denoted by "K".

25 [0107]

The examples 11 to 13 show that, in order to reduce the boron concentration in the treated water to 50 ng B/L or less when demineralization chambers that are not separated by intermediate ion exchange membranes (hereinafter referred to as "D1 demineralization chambers") communicate in series, the boron concentration in water to be treated that flows into the first stage EDI apparatus needs to be set to approximately 100 µg B/L or less.

[0108]

However, as shown in the examples 4 to 8, the boron concentration in the treated water can be reduced by increasing the number of EDI apparatuses having D2

demineralization chambers in a water treatment apparatus. Regarding this point, it was confirmed that the boron concentration in the treated water could be 50 ng B/L or less in the example 14 even when the boron concentration in the water to be treated that flows into the first stage EDI apparatus was approximately to 300 (298) $\mu\text{g B/L}$, which was higher than the boron concentration in the water to be treated in the example 13.

[0109]

Here, the reason why the farthest upstream part of the demineralization chambers that communicate in series is only filled with anion exchange resins is as follows. When boron in water to be treated comes into contact with anion exchange resins, which is a solid base, dissociation of boron in the form of anion is facilitated. As a result, the adsorbing and removing efficiency by the anion exchange resins can be enhanced.

[0110]

Next, the reason why the farthest downstream part of the demineralization chambers that communicate in series is only filled with anion exchange resins and why an area between the farthest upstream part and the farthest downstream part is filled with at least cation exchange resins is as follows. When water to be treated flows into the anion exchange resins in the farthest downstream part after cation components in the water to be treated are eliminated by using cation exchange resins, the concentration of hydrogen ions that exist in the water to be treated that flows into the anion exchange resins in the farthest downstream part can be reduced, and the efficiency of eliminating boron by the anion exchange resins can be enhanced, as compared to a case where the water to be treated flows into the anion exchange resins in the farthest downstream part without eliminating the cation components by means of cation exchange resins.

[0111]

It should be noted that, in example 7, a current imbalance occurs in the electric current that flows through the final stage second small demineralization chamber because the chamber is filled with ion exchange resins in a mixed bed form (the anion exchange resins and the cation exchange resins are separately charged). This current imbalance is caused by a difference in electric resistance between the anion exchange resins and the cation exchange resins, and is a phenomenon in which larger electric current flows through exchange resins having a lower electric resistance out of anion exchange resins and cation exchange resins. On the other hand, in the example 8, since the final stage second small demineralization chamber is only filled with anion

exchange resins in a single bed form, a current imbalance was less likely to occur and the efficiency of eliminating boron is improved, as compared to the example 7.

[0112]

Next, advantages of using a D2 demineralization chamber are as follows. As
5 described above, a current imbalance occurs in a double bed demineralization chamber. For this reason, it is possible to allow electric current to flow through anion exchange resins more efficiently and thereby to enhance the demineralizing efficiency, by filling two small demineralization chambers of the D2 demineralization chamber with anion
10 exchange resins and cation exchange resins separately in a single bed form, than by filling a single demineralization chamber with anion exchange resins and cation exchange resins in a double bed form. However, since a D2 demineralization chamber has a passage about twice as long as that of a D1 demineralization chamber, a high pressure difference may occur. Accordingly, an increase in pressure difference can be reduced by limiting the number of EDI apparatuses that use D2 demineralization
15 chambers as long as the target boron concentration in the treated water can be achieved.

[0113]

Here, "the farthest upstream part of the demineralization chamber" refers to a (certain) part through which the water to be treated passes first when the water to be
20 treated flows into the demineralization chamber, and the "farthest downstream part of the demineralization chamber" refers to a (certain) part through which the water to be treated passes last when the water to be treated flows out of the demineralization chamber. The terms "the farthest upstream part of the demineralization chamber" and "the farthest downstream part of the demineralization chamber" do not necessarily mean a physically
25 vertical relationship. For example, water to be treated may flow into the upper side surface of a demineralization chamber and may flow out of the lower side surface of the demineralization chamber.

Claims

[Claim 1]

A water treatment apparatus including a plurality of electric deionized water
5 production apparatuses, wherein

each electric deionized water production apparatus has a demineralization
chamber between a positive electrode and a negative electrode, wherein the
demineralization chamber is defined by an anion exchange membrane that is positioned
on a side of the positive electrode and a cation exchange membrane that is positioned
10 on a side of the negative electrode and that is filled with ion exchangers,

the demineralization chambers of the plurality of electric deionized water
production apparatuses communicate in series,

the plurality of demineralization chambers which communicate in series allows
water to be treated to flow therethrough and allows treated water to flow out therefrom,

15 a farthest upstream part of a first stage demineralization chamber into which the
water to be treated flows first and a farthest downstream part of a final stage
demineralization chamber from which the treated water flows out are only filled with
anion exchangers, and

a portion which is a part of the plurality of demineralization chambers and which
20 is located between the farthest upstream part of the first stage demineralization chamber
and the farthest downstream part of the final stage demineralization chamber is filled
with at least cation exchangers.

[Claim 2]

25 The water treatment apparatus according to claim 1, wherein

a ratio of a volume of anion exchangers that fill the farthest upstream part of the
first stage demineralization chamber alone to a volume of the first stage demineralization
chamber, and a ratio of a volume of anion exchangers that fill the farthest downstream
part of the final stage demineralization chamber alone to a volume of the final stage
30 demineralization chamber are 10% or larger.

[Claim 3]

The water treatment apparatus according to claim 1 or 2, wherein

the first stage demineralization chamber or the final stage demineralization

chamber is filled with anion exchangers in a single bed form.

[Claim 4]

The water treatment apparatus according to any one of claims 1 to 3, wherein

at least one of the plurality of demineralization chambers has

an intermediate ion exchange membrane that is positioned between the anion exchange membrane and the cation exchange membrane,

a first small demineralization chamber that is defined by the anion exchange membrane and the intermediate ion exchange membrane,

a second small demineralization chamber that is defined by the cation exchange membrane and the intermediate ion exchange membrane, and

the first small demineralization chamber and the second small demineralization chamber communicate in series.

[Claim 5]

The water treatment apparatus according to claim 4, wherein

the first stage demineralization chamber has the intermediate ion exchange membrane, the first small demineralization chamber and the second small demineralization chamber, and

in the first stage demineralization chamber, the first small demineralization chamber is positioned upstream of the second small demineralization chamber, and the first small demineralization chamber is filled with anion exchangers in a single bed form.

[Claim 6]

The water treatment apparatus according to claim 4 or 5, wherein

the final stage demineralization chamber has the intermediate ion exchange membrane, the first small demineralization chamber and the second small demineralization chamber,

in the final stage demineralization chamber, the first small demineralization chamber is positioned downstream of the second small demineralization chamber, and the first small demineralization chamber is filled with anion exchangers in a single bed form.

[Claim 7]

The water treatment apparatus according to claim 4 or 5, wherein
two or more of the electric deionized water production apparatuses are provided,
each of the first stage demineralization chamber and the final stage
demineralization chamber has the intermediate ion exchange membrane, the first small
5 demineralization chamber and the second small demineralization chamber, and

in the first stage demineralization chamber and the final stage demineralization
chamber, the first small demineralization chambers are positioned upstream of the
second small demineralization chambers, the first small demineralization chambers are
filled with anion exchangers in a single bed form, the farthest upstream parts of the
10 second small demineralization chambers are only filled with cation exchangers, and
areas of the second small demineralization chambers other than the farthest upstream
parts are filled with anion exchangers.

[Claim 8]

15 The water treatment apparatus according to any one of claims 4 to 6, wherein
two or more of the electric deionized water production apparatuses are provided,
each of the first stage demineralization chamber and the final stage
demineralization chamber has the intermediate ion exchange membrane, the first small
demineralization chamber and the second small demineralization chamber,

20 in the first stage demineralization chamber, the first small demineralization
chamber is positioned upstream of the second small demineralization chamber, the first
small demineralization chamber is filled with anion exchangers in a single bed form, the
farthest upstream part of the second small demineralization chamber is only filled with
cation exchangers, and an area of the second small demineralization chamber other
25 than the farthest upstream part is only filled with anion exchangers, and

in the final stage demineralization chamber, the first small demineralization
chamber is positioned downstream of the second small demineralization chamber, the
first small demineralization chamber is filled with anion exchangers in a single bed form,
and the second small demineralization chamber is filled with cation exchangers in a
30 single bed form.

[Claim 9]

The water treatment apparatus according to any one of claims 1 to 8, wherein
a reverse osmosis membrane device is provided upstream of the first stage

demineralization chamber .

[Claim 10]

The water treatment apparatus according to any one of claims 1 to 9, wherein
5 a decarboxylation membrane device is provided upstream of the first stage demineralization chamber .

[Claim 11]

A water treatment method using a water treatment apparatus including a plurality
10 of electric deionized water production apparatuses each having a demineralization chamber between a positive electrode and a negative electrode, wherein the demineralization chamber is defined by an anion exchange membrane that is positioned on a side of the positive electrode and a cation exchange membrane that is positioned on a side of the negative electrode and that is filled with ion exchangers, wherein the
15 demineralization chambers of the plurality of electric deionized water production apparatuses communicate in series, the plurality of demineralization chambers which communicate in series allows water to be treated to flow therethrough and allows treated water to flow out therefrom, a farthest upstream part of a first stage demineralization chamber into which the water to be treated flows first and a farthest downstream part of a
20 final stage demineralization chamber from which the treated water flows out are only filled with anion exchangers, and a portion which is a part of the plurality of demineralization chambers and which is located between the farthest upstream part of the first stage demineralization chamber and the farthest downstream part of the final stage demineralization chamber is filled with at least cation exchangers,
25 wherein the water to be treated flows through the plurality of demineralization chambers which communicate in series when a DC voltage is applied between the positive electrode and the negative electrode, whereby the water to be treated is treated and flows out.

30 [Claim 12]

The water treatment method according to claim 11, wherein
a silica concentration in water to be treated that flows into the first stage electric deionized water production apparatus is 100 $\mu\text{g SiO}_2/\text{L}$ or less.

[Claim 13]

The water treatment method according to claim 11 or 12, wherein
a boron concentration in water to be treated that flows into the first stage electric
deionized water production apparatus is 100 $\mu\text{g B/L}$ or less.

5

[Claim 14]

The water treatment method according to any one of claims 11 to 13, wherein
a carbonic acid concentration in water to be treated that flows into the first stage
electric deionized water production apparatus is 5 $\text{mg CO}_2/\text{L}$ or less.