

DESCRIPTION

APPARATUS AND METHOD FOR TREATING SILICA-CONTAINING WATER

5

TECHNICAL FIELD

[0001]

The present invention relates to a treatment apparatus and a treatment method for a silica-containing water.

10

BACKGROUND

[0002]

In recent years, the volumes of wastewater discharged from factories and the like are being reduced as much as possible, and methods are being employed in which the wastewater is concentrated using a reverse osmosis membrane or the like, and the permeate is then recovered to reduce the volume of wastewater. There is a growing trend to try and maximize the water recovery rate, and among the various options, methods are being used in which the concentrate from the reverse osmosis membrane is subjected to further treatment with a reverse osmosis membrane, or is further concentrated using a method such as evaporative concentration, and there is a growing number of factories and the like that are now operating under ZLD (Zero Liquid Discharge), in which substantially all of the water is recovered, while impurities are solidified and discarded.

[0003]

When the concentration ratio in a reverse osmosis membrane device or evaporative concentration device is increased in this manner, there is a concomitant increase in the risk of scaling due to hardness components and silica and the like in the wastewater. When scale develops, the reverse osmosis membrane may become blocked, leading to a reduction in the permeate volume, or the heat transfer surface used in the evaporative concentration may become coated with scale, leading to a deterioration in the heat transfer efficiency.

[0004]

Accordingly, it is desirable to reduce the silica in the wastewater as much as possible prior to the reverse osmosis membrane treatment. As disclosed in Patent Document 1, one known example of a method for treating a wastewater containing silica involves adding a magnesium salt under alkaline conditions to remove the silica.

[0005]

In this silica removal method using a magnesium compound such as a magnesium salt, the amount added of the magnesium salt is required to be from several-fold to about 10-fold the silica concentration, and therefore in addition to significant chemical costs, increased sludge generation is a problem. Further, although there are sometimes cases where the water to be treated also contains magnesium from the beginning, in almost all cases, the amount of magnesium contained from the beginning in the water to be treated is insufficient to enable removal of the silica, and therefore a separate magnesium compound must still be added even in these cases, meaning the same problems of chemical costs and increased sludge generation remain.

CITATION LIST

PATENT LITERATURE

[0006]

Patent Document 1: JP H04-367783 A

SUMMARY

TECHNICAL PROBLEM

[0007]

An object of the present invention is to provide a treatment apparatus and a treatment method for a silica-containing water that are capable of reducing the amount of a magnesium compound used in the silica treatment of the silica-containing water.

SOLUTION TO PROBLEM

[0008]

The present invention provides a treatment apparatus for a silica-containing water that includes a reaction tank for insolubilizing silica at a pH of 10 or higher, either by
5 adding a magnesium compound to the silica-containing water to be treated, or by utilizing the magnesium contained in the water to be treated, a solid-liquid separation unit for performing a solid-liquid separation of the obtained insoluble material, and a return unit for adding an acid to at least a portion of the sludge separated by the solid-liquid separation, and returning the resultant material to a stage prior to the solid-liquid separation unit.

10 [0009]

The present invention also provides a treatment apparatus for a silica-containing water that includes a reaction tank for insolubilizing silica at a pH of 10 or higher, either by
adding a magnesium compound to the silica-containing water to be treated, or by utilizing the magnesium contained in the water to be treated, a first solid-liquid separation unit for
15 performing a solid-liquid separation of the obtained insoluble material, an acid addition unit for adding an acid to at least a portion of the sludge separated by the first solid-liquid separation unit, a second solid-liquid separation unit for performing a solid-liquid separation of the sludge containing the added acid, and a return unit for returning at least a portion of the second solid-liquid separation water separated by the second solid-liquid
20 separation unit to a stage prior to the first solid-liquid separation unit.

[0010]

The present invention also provides a treatment apparatus for a silica-containing water that includes an insolubilization unit for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the water to be treated containing organic
25 matter and silica, or by utilizing the magnesium contained in the water to be treated, a membrane filtration unit for performing membrane filtration of the obtained insoluble material, a backwash unit for backwashing the membrane filtration unit, an acid addition unit for adding an acid to at least a portion of the discharged backwash wastewater, and a

backwash wastewater return unit for returning the backwash wastewater containing the added acid to a stage prior to the membrane filtration unit.

[0011]

5 The present invention also provides a treatment apparatus for a silica-containing water that includes an insolubilization unit for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the water to be treated containing organic matter and silica, or by utilizing the magnesium contained in the water to be treated, a membrane filtration unit for performing membrane filtration of the obtained insoluble material, a backwash unit for backwashing the membrane filtration unit, an acid addition
10 unit for adding an acid to at least a portion of the discharged backwash wastewater, a solid-liquid separation unit for performing a solid-liquid separation of the backwash wastewater containing the added acid, and a solid-liquid separation water return unit for returning at least a portion of the solid-liquid separation water separated by the solid-liquid separation unit to a stage prior to the membrane filtration unit.

15 [0012]

In the treatment apparatuses for a silica-containing water described above, the acid is preferably added so as to adjust the pH to a value within a range from 4 to 9.

[0013]

20 The treatment apparatuses for a silica-containing water described above preferably also include, at a latter stage after the solid-liquid separation unit, a reverse osmosis membrane treatment device in which the solid-liquid separation water is supplied to a reverse osmosis membrane to obtain a permeate and a concentrate.

[0014]

25 The treatment apparatuses for a silica-containing water described above preferably also includes, at a latter stage after the membrane filtration unit, a reverse osmosis membrane treatment device in which the membrane filtrate is supplied to a reverse osmosis membrane to obtain a permeate and a concentrate.

[0015]

The present invention also provides a treatment method for a silica-containing water that includes an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water to be treated, or by utilizing the magnesium contained in the water to be treated, a solid-liquid separation step of performing a solid-liquid separation of the obtained insoluble material, and a return step of adding an acid to at least a portion of the sludge separated by the solid-liquid separation, and returning the resultant material to a stage prior to the solid-liquid separation step.

[0016]

The present invention also provides a treatment method for a silica-containing water that includes an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water to be treated, or by utilizing the magnesium contained in the water to be treated, a first solid-liquid separation step of performing a solid-liquid separation of the obtained insoluble material, an acid addition step of adding an acid to at least a portion of the sludge separated in the first solid-liquid separation step, a second solid-liquid separation step of performing a solid-liquid separation of the sludge containing the added acid, and a return step of returning at least a portion of the second solid-liquid separation water separated in the second solid-liquid separation step to a stage prior to the first solid-liquid separation step.

[0017]

The present invention also provides a treatment method for a silica-containing water that includes an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the water to be treated containing organic matter and silica, or by utilizing the magnesium contained in the water to be treated, a membrane filtration step of performing membrane filtration of the obtained insoluble material, a backwashing step of backwashing the membrane used in the membrane filtration step, an acid addition step of adding an acid to at least a portion of the discharged backwash wastewater, and a backwash wastewater return step of returning the backwash wastewater containing the added acid to a stage prior to the membrane filtration step.

[0018]

The present invention also provides a treatment method for a silica-containing water that includes an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the water to be treated containing organic matter and silica, or by utilizing the magnesium contained in the water to be treated, a membrane
5 filtration step of performing membrane filtration of the obtained insoluble material, a backwashing step of backwashing the membrane used in the membrane filtration step, an acid addition step of adding an acid to at least a portion of the discharged backwash wastewater, a solid-liquid separation step of performing a solid-liquid separation of the
10 backwash wastewater containing the added acid, and a solid-liquid separation water return step of returning at least a portion of the solid-liquid separation water separated in the solid-liquid separation step to a stage prior to the membrane filtration step.

[0019]

In the treatment methods for a silica-containing water described above, the acid is
15 preferably added so as to adjust the pH to a value within a range from 4 to 9.

[0020]

The treatment methods for a silica-containing water described above preferably also include, at a latter stage after the solid-liquid separation step, a reverse osmosis membrane treatment step of supplying the solid-liquid separation water to a reverse osmosis
20 membrane to obtain a permeate and a concentrate.

[0021]

The treatment methods for a silica-containing water described above preferably also includes, at a latter stage after the membrane filtration step, a reverse osmosis membrane treatment step of supplying the membrane filtrate to a reverse osmosis membrane to obtain
25 a permeate and a concentrate.

ADVANTAGEOUS EFFECTS OF INVENTION

[0022]

In the present invention, in a silica treatment for a silica-containing water, the amount of magnesium compound used can be reduced.

BRIEF DESCRIPTION OF DRAWINGS

5 [0023]

FIG. 1 is a schematic structural diagram illustrating a first example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

10 FIG. 2 is a schematic structural diagram illustrating a second example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

FIG. 3 is a schematic structural diagram illustrating a third example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

15 FIG. 4 is a schematic structural diagram illustrating a fourth example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

20 FIG. 5 is a schematic structural diagram illustrating a fifth example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

FIG. 6 is a schematic structural diagram illustrating a sixth example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

25 FIG. 7 is a schematic structural diagram illustrating a seventh example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

FIG. 8 is a schematic structural diagram illustrating an eighth example of treatment apparatus for a silica-containing water according to an embodiment of the present invention.

FIG. 9 is a graph illustrating the eluted Mg concentration (mg/L) or SiO₂ concentration (mg/L) relative to the sludge recycling pH in Example 1.

FIG. 10 is a schematic structural diagram illustrating the treatment apparatus used in Example 2.

FIG. 11 is a graph illustrating the SiO₂ concentration (mg/L) relative to the amount added (mg-Mg/L) of magnesium (new material) in Example 2 and Comparative Example 1.

FIG. 12 is a graph illustrating the SiO₂ concentration (mg/L) of the treated water relative to the amount added (mg-Mg/L) of magnesium (new material) in Example 3 and Comparative Example 2.

DESCRIPTION OF EMBODIMENTS

[0024]

Embodiments of the present invention are described below. These embodiments are merely examples of implementing the present invention, and the present invention is in no way limited by these embodiments.

[0025]

A schematic illustration of a first example of the treatment apparatus for a silica-containing water according to an embodiment of the present invention is shown in FIG. 1, and the structure of that apparatus is described below.

[0026]

The silica-containing water treatment apparatus 1 includes a reaction tank 12 for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water to be treated, or by utilizing the magnesium contained in the water to be treated, a settling tank 16 that functions as a solid-liquid separation unit for

performing a solid-liquid separation of the obtained insoluble material, and a sludge recycling tank 18 that functions as a return unit for adding an acid to at least a portion of the sludge separated by the solid-liquid separation, and returning the resultant material to a stage prior to the settling tank 16 that functions as the solid-liquid separation unit. The silica-containing water treatment apparatus 1 may also include a treatment water tank 10 for storing the water to be treated, and a polymer reaction tank 14 for adding a polymer flocculant to the reaction liquid obtained in the reaction tank 12 to conduct a flocculation reaction.

[0027]

In the silica-containing water treatment apparatus 1, the outlet of the treatment water tank 10 and the treatment water inlet of the reaction tank 12 are connected by a line 24 via a pump 20. The outlet of the reaction tank 12 and the inlet of the polymer reaction tank 14 are connected by a line 26. The outlet of the polymer reaction tank 14 and the inlet of the settling tank 16 are connected by a line 28. A treated water line 30 is connected to the solid-liquid separation liquid outlet from the settling tank 16. A sludge outlet at the bottom of the settling tank 16 and the inlet of the sludge recycling tank 18 are connected by a sludge return line 34 via a pump 22. A sludge line 32 is connected partway along the sludge return line 34. The outlet of the sludge recycling tank 18 and a recycled sludge inlet of the reaction tank 12 are connected by a recycled sludge return line 36. A magnesium compound addition line 38 that functions as a magnesium compound addition unit and a pH adjuster addition line 40 that functions as a pH adjuster addition unit are connected to the reaction tank 12, and a stirring device 46 fitted with a stirring blade is provided as a stirring unit. A polymer flocculant addition line 42 that functions as a polymer flocculant addition unit is connected to the polymer reaction tank 14, and a stirring device 48 fitted with a stirring blade is provided as a stirring unit. An acid addition line 44 that functions as an acid addition unit is connected to the sludge recycling tank 18, and a stirring device 50 fitted with a stirring blade is provided as a stirring unit. In the silica-containing water treatment apparatus 1, the sludge recycling tank 18, the acid

addition line 44, the pump 22, the sludge return line 34 and the recycled sludge return line 36 function as a return unit for adding an acid to at least a portion of the sludge separated by the solid-liquid separation, and returning the resultant material to a stage prior to the settling tank 16 that functions as a solid-liquid separation unit.

5 [0028]

The treatment method for a silica-containing water, and the operation of the silica-containing water treatment apparatus 1 according to the present embodiment are described below.

[0029]

10 The silica-containing water that represents the water to be treated is stored in the treatment water tank 10 as required, and is then fed through the line 24 into the reaction tank 12 using the pump 20. The amount of magnesium compound required to be added may vary depending on factors such as the silica concentration of the targeted treated water, and can therefore not be clearly specified, but using the case in which the silica
15 concentration of the treated water is to be reduced to not more than 10 mg/L as an example, the following description applies. For example, in those cases where the water to be treated has a pH of 10 or higher, and either the water to be treated contains no magnesium, or the amount of magnesium in the water to be treated is less than 0.5 mol per 1 mol of the amount of silica, a magnesium compound is added to the silica-containing
20 water in the reaction tank 12 through the magnesium compound addition line 38 to insolubilize the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of less than 10, and either the water to be treated contains no magnesium, or the amount of magnesium in the water to be treated is less than 0.5 mol per 1 mol of the amount of silica, a magnesium compound is added to the silica-containing
25 water in the reaction tank 12 through the magnesium compound addition line 38, and a pH adjuster is added through the pH adjuster addition line 40 to adjust the pH of the water to be treated to a value of 10 or higher, thereby insolubilizing the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of less than 10, and the

amount of magnesium in the water to be treated is at least 0.5 mol per 1 mol of the amount of silica, a pH adjuster is added to the silica-containing water in the reaction tank 12 through the pH adjuster addition line 40 to adjust the pH of the water to be treated to a value of 10 or higher, thereby insolubilizing the silica (insolubilization step). For
5 example, in those cases where the water to be treated has a pH of 10 or higher, and the amount of magnesium in the water to be treated is at least 0.5 mol per 1 mol of the amount of silica, the water to be treated is fed without further modification into the polymer reaction tank 14. In the reaction tank 12, the reaction liquid may be stirred by the stirring device 46.

10 [0030]

The reaction liquid obtained in the insolubilization step is fed from the reaction tank 12 through the line 26 and into the polymer reaction tank 14. In the polymer reaction tank 14, if required, a polymer flocculant may be added to the reaction liquid through the polymer flocculant addition line 42 to perform a polymer flocculation reaction (polymer
15 flocculation step). In the polymer reaction tank 14, the flocculated liquid may be stirred with the stirring device 48.

[0031]

The polymer flocculated liquid obtained in the polymer flocculation step is fed from the polymer reaction tank 14 through the line 28 and into the settling tank 16. In the
20 settling tank 16, a solid-liquid separation is performed by allowing the obtained insoluble material to settle naturally (solid-liquid separation step).

[0032]

The solid-liquid separation liquid obtained in the solid-liquid separation step is passed from the settling tank 16 through the treated water line 30, and is discharged as a
25 treated water.

[0033]

At least a portion of the sludge separated by the solid-liquid separation is fed through the sludge return line 34 and into the sludge recycling tank 18 using the pump 22. In the

sludge recycling tank 18, an acid is added to the sludge through the acid addition line 44 to recycle the sludge. The recycled sludge is fed through the recycled sludge return line 36, and returned to the reaction tank 12 (return step), which represents a stage prior to the settling tank 16 (solid-liquid separation step). The sludge that is not returned and recycled is discharged from the settling tank 16 through the sludge return line 34 and the sludge line 32.

[0034]

In this manner, in the silica-containing water treatment method and treatment apparatus according to the present embodiment, the silica is insolubilized at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water or by utilizing the magnesium contained in the water to be treated, a solid-liquid separation is performed, acid is added to at least a portion of the separated sludge, and the resultant material is returned to a stage prior to the solid-liquid separation step.

[0035]

In this method, by adding an acid to the sludge, the compounds of magnesium and silica contained in the sludge are dissolved, and the magnesium can be eluted in the form of ions. At this time, silica can also be eluted, but because the solubility of silica is typically low, any silica exceeding the degree of solubility tends to gel and precipitate. Typically, this gelling of silica takes a long time (several tens of hours or longer), but in this method, it is thought that because the silica has already been converted once to a solid form, the silica can be satisfactorily gelled even with a reaction time of about 30 minutes.

[0036]

By returning the recycled sludge to a prior stage, the ionized magnesium can be reused as a magnesium compound that functions as a silica removal agent, whereas almost all of the silica gels and precipitates independently, and can therefore be once again separated in the solid-liquid separation step and removed as sludge.

[0037]

Because the magnesium ions that are eluted from the compounds of magnesium and silica contained in the sludge can be reused as a magnesium compound that functions as a silica removal agent, the amount of magnesium compound used can be dramatically reduced compared with the case where the magnesium ions are not reused. As a result, the amount of sludge generated can be reduced. In some cases, the silica can be removed using only the magnesium that already exists in the water to be treated. Furthermore, by reusing the eluted magnesium ions, if an amount of magnesium compound is used that is similar to that used when magnesium ions are not reused, then the amount of silica in the treated water can be further reduced, and the quality of the treated water can be further improved. Accordingly, in those cases where an additional treatment device such as a reverse osmosis membrane treatment device is provided at a latter stage to the solid-liquid separation device, the load on that additional treatment device can be reduced.

[0038]

A schematic illustration of a second example of the treatment apparatus for a silica-containing water according to an embodiment of the present invention is shown in FIG. 2, and the structure of that apparatus is described below.

[0039]

The silica-containing water treatment apparatus 2 includes a reaction tank 12 for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water to be treated, or by utilizing the magnesium contained in the water to be treated, a settling tank 16 that functions as a first solid-liquid separation unit for performing a solid-liquid separation of the obtained insoluble material, a sludge recycling tank 18 and an acid addition line 44 that function as an acid addition unit for adding an acid to at least a portion of the sludge separated by the settling tank 16 that represents the first solid-liquid separation unit, a sludge separation tank 54 that functions as a second solid-liquid separation unit for performing a solid-liquid separation of the sludge containing the added acid, and a solid-liquid separation water return line 66 that functions as a return unit for returning at least a portion of the second solid-liquid separation water

separated by the sludge separation tank 54 that represents the second solid-liquid separation unit to a stage prior to the settling tank 16. The silica-containing water treatment apparatus 2 may also include a treatment water tank 10 for storing the water to be treated, a flocculation tank 52 for adding an inorganic flocculant to the reaction liquid obtained in the reaction tank 12 to conduct a flocculation reaction, and a polymer reaction tank 14 for adding a polymer flocculant to conduct a polymer flocculation reaction.

[0040]

In the silica-containing water treatment apparatus 2, the outlet of the treatment water tank 10 and the treatment water inlet of the reaction tank 12 are connected by a line 24 via a pump 20. The outlet of the reaction tank 12 and the inlet of the flocculation tank 52 are connected by a line 58. The outlet of the flocculation tank 52 and the inlet of the polymer reaction tank 14 are connected by a line 60. The outlet of the polymer reaction tank 14 and the inlet of the settling tank 16 are connected by a line 62. A treated water line 30 is connected to the solid-liquid separation water outlet from the settling tank 16. A sludge outlet at the bottom of the settling tank 16 and the inlet of the sludge recycling tank 18 are connected by a sludge return line 34 via a pump 22. The outlet of the sludge recycling tank 18 and the inlet of the sludge separation tank 54 are connected by a recycled sludge line 64. A solid-liquid separation water outlet from the sludge separation tank 54 and a solid-liquid separation water inlet of the reaction tank 12 are connected by a solid-liquid separation water return line 66. A sludge line 68 is connected to a sludge outlet at the bottom of the sludge separation tank 54 via a pump 56. A magnesium compound addition line 38 that functions as a magnesium compound addition unit and a pH adjuster addition line 40 that functions as a pH adjuster addition unit are connected to the reaction tank 12, and a stirring device 46 fitted with a stirring blade is provided as a stirring unit. An inorganic flocculant addition line 70 that functions as an inorganic flocculant addition unit and a pH adjuster addition line 72 that functions as a pH adjuster addition unit are connected to the flocculation tank 52, and a stirring device 74 fitted with a stirring blade is provided as a stirring unit. A polymer flocculant addition line 42 that functions as a

polymer flocculant addition unit is connected to the polymer reaction tank 14, and a stirring device 48 fitted with a stirring blade is provided as a stirring unit. An acid addition line 44 that functions as an acid addition unit is connected to the sludge recycling tank 18, and a stirring device 50 fitted with a stirring blade is provided as a stirring unit.

5 [0041]

The treatment method for a silica-containing water, and the operation of the silica-containing water treatment apparatus 2 according to the present embodiment are described below.

[0042]

10 The silica-containing water that represents the water to be treated is stored in the treatment water tank 10 as required, and is then fed through the line 24 into the reaction tank 12 using the pump 20. The amount of magnesium compound required to be added may vary depending on factors such as the silica concentration of the targeted treated water, and can therefore not be clearly specified, but using the case in which the silica
15 concentration of the treated water is to be reduced to not more than 10 mg/L as an example, the following description applies. For example, in those cases where the water to be treated has a pH of 10 or higher, and either the water to be treated contains no magnesium, or the amount of magnesium in the water to be treated is less than 0.5 mol per 1 mol of the amount of silica, a magnesium compound is added to the silica-containing
20 water in the reaction tank 12 through the magnesium compound addition line 38 to insolubilize the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of less than 10, and either the water to be treated contains no magnesium, or the amount of magnesium in the water to be treated is less than 0.5 mol per 1 mol of the amount of silica, a magnesium compound is added to the silica-containing
25 water in the reaction tank 12 through the magnesium compound addition line 38, and a pH adjuster is added through the pH adjuster addition line 40 to adjust the pH of the water to be treated to a value of 10 or higher, thereby insolubilizing the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of less than 10, and the

amount of magnesium in the water to be treated is at least 0.5 mol per 1 mol of the amount of silica, a pH adjuster is added to the silica-containing water in the reaction tank 12 through the pH adjuster addition line 40 to adjust the pH of the water to be treated to a value of 10 or higher, thereby insolubilizing the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of 10 or higher, and the amount of magnesium in the water to be treated is at least 0.5 mol per 1 mol of the amount of silica, the water to be treated is fed without further modification into the flocculation tank 52. In the reaction tank 12, the reaction liquid may be stirred by the stirring device 46.

10 [0043]

The reaction liquid obtained in the insolubilization step is fed from the reaction tank 12 through the line 58 and into the flocculation tank 52. In the flocculation tank 52, if required, an inorganic flocculant may be added to the reaction liquid through the inorganic flocculant addition line 70 to perform a flocculation reaction (flocculation step). In the flocculation tank 52, if required, a pH adjuster may be added through the pH adjuster addition line 72. In the flocculation tank 52, the flocculated liquid may be stirred with the stirring device 74.

[0044]

The flocculation reaction liquid obtained in the flocculation step is fed from the flocculation tank 52 through the line 60 and into the polymer reaction tank 14. In the polymer reaction tank 14, if required, a polymer flocculant may be added to the flocculation reaction liquid through the polymer flocculant addition line 42 to perform a polymer flocculation reaction (polymer flocculation step). In the polymer reaction tank 14, the flocculation reaction liquid may be stirred with the stirring device 48.

25 [0045]

The polymer flocculated liquid obtained in the polymer flocculation step is fed from the polymer reaction tank 14 through the line 62 and into the settling tank 16. In the

settling tank 16, a solid-liquid separation is performed by allowing the obtained insoluble material to settle naturally (first solid-liquid separation step).

[0046]

5 The first solid-liquid separation liquid obtained in the first solid-liquid separation step is passed from the settling tank 16 through the treated water line 30, and is discharged as a treated water.

[0047]

10 At least a portion of the sludge separated by the first solid-liquid separation is fed through the sludge return line 34 and into the sludge recycling tank 18 using the pump 22. In the sludge recycling tank 18, an acid is added to the sludge through the acid addition line 44 to recycle the sludge (acid addition step).

[0048]

15 The recycled sludge is fed through the recycled sludge line 64, and supplied to the sludge separation tank 54. In the sludge separation tank 54, a solid-liquid separation is performed by allowing the insoluble material to settle naturally (second solid-liquid separation step).

[0049]

20 The second solid-liquid separation water obtained in the second solid-liquid separation step is returned through the solid-liquid separation water return line 66 to the reaction tank 12 (return step), which represents a stage prior to the settling tank 16 (the first solid-liquid separation step). The sludge separated by the second solid-liquid separation is discharged from the sludge separation tank 54 through the sludge line 68 using the pump 56.

[0050]

25 In this manner, in the silica-containing water treatment method and treatment apparatus according to the present embodiment, the silica is insolubilized at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water or by utilizing the magnesium contained in the water to be treated, a solid-liquid separation is

performed (the first solid-liquid separation step), acid is added to at least a portion of the separated sludge, another solid-liquid separation is performed (the second solid-liquid separation step), and at least a portion of the separated second solid-liquid separation water is returned to a stage prior to the first solid-liquid separation step.

5 [0051]

In this method, by adding an acid to the sludge, the compounds of magnesium and silica contained in the sludge are dissolved, and the magnesium can be eluted in the form of ions. At this time, silica can also be eluted, but because the solubility of silica is typically low (for example, about 120 mg/L at a pH of 4 to 9 and 25°C), any silica
10 exceeding the degree of solubility tends to gel and precipitate. Typically, this gelling of silica takes a long time (several tens of hours or longer), but in this method, it is thought that because the silica has already been converted once to a solid form, the silica can be satisfactorily gelled even with a reaction time of about 30 minutes.

[0052]

15 If the recycled sludge that has been recycled in the acid addition step is returned without further modification to a stage prior to the first solid-liquid separation step, the ionized magnesium can be reused as a magnesium compound that functions as a silica removal agent, whereas almost all of the silica gels and precipitates independently, and can therefore be once again separated in the settling tank 16 and removed as sludge.
20 However, if the silica that has independently gelled is returned to a stage prior to the first solid-liquid separation step, then the silica gradually redissolves. Provided the amount of silica is small, the effect of this redissolution is small, and almost no problems arise provided the silica is rapidly removed from the system as sludge in the settling tank 16, but if a large amount of sludge is recycled and the proportion of independently gelled silica is
25 increased, then the effects become impossible to ignore. Further, if, for example, the treatment apparatus is stopped temporarily and the gelled silica is left to sit inside the system for a long period of time, then redissolution of the silica progresses, and a phenomenon is sometimes observed in which the silica concentration in the treated water

increases significantly. Accordingly, in the treatment method and treatment apparatus according to the present embodiment, by subjecting the recycled sludge that has been recycled in the acid addition step to a solid-liquid separation (the second solid-liquid separation treatment), the eluted magnesium (magnesium ions) can be returned to a stage prior to the first solid-liquid separation step and reused, while limiting the amount of gelled silica returned to the stage prior to the first solid-liquid separation as much as possible, and the amount of magnesium compound used can be reduced. Furthermore, the silica concentration of the treated water can be reduced by using only a small amount of added magnesium compound.

10 [0053]

In this manner, because the magnesium ions that are eluted from the compounds of magnesium and silica contained in the sludge can be reused as a magnesium compound that functions as a silica removal agent, the amount of magnesium compound used can be dramatically reduced compared with the case where the magnesium ions are not reused.

15 As a result, the amount of sludge generated can be reduced. In some cases, the silica can be removed using only the magnesium that already exists in the water to be treated, with this magnesium being used to insolubilize the silica. In those cases where the magnesium concentration is high relative to the silica concentration in the water to be treated, the silica can be removed without adding any additional magnesium compound. Furthermore, by reusing the eluted magnesium ions, if an amount of magnesium compound is used that is similar to that used when magnesium ions are not reused, then the amount of silica in the treated water can be further reduced, and the quality of the treated water can be further improved. Accordingly, in those cases where an additional treatment device such as a reverse osmosis membrane treatment device is provided at a latter stage to the first solid-liquid separation device, the load on that additional treatment device can be reduced.

25 [0054]

In the sludge recycling step in the silica-containing water treatment apparatuses 1 and 2, acid is preferably added to adjust the pH of the separated sludge to a value within a

range from 4 to 9. The amount of magnesium that can be recycled is determined by the amount of acid added to the sludge recycling tank 18, and the larger the amount of acid added, the larger the amount of magnesium that can be recycled. Because the solubility of silica at 25°C within the pH range from 4 to 9 is about 120 mg/L to 150 mg/L, it is thought
5 that any silica exceeding the degree of solubility tends to gel and precipitate.

[0055]

In the sludge recycling step, provided the pH is 9 or lower, magnesium ions are eluted. Magnesium ions are eluted even when the pH is less than 4, but because the dissolved silica is less likely to gel, the pH range is preferably from 4 to 9, and more
10 preferably from 4 to 6.

[0056]

Examples of the acid used in recycling the sludge include hydrochloric acid and sulfuric acid. Of these, in terms of chemical costs and the like, hydrochloric acid is preferable.

15 [0057]

The reaction temperature in the sludge recycling step is not particularly limited, and may, for example, be within a range from 15°C to 30°C. The reaction time in the sludge recycling step is not particularly limited, and may, for example, be within a range from 15 minutes to 120 minutes.

20 [0058]

The amount of recirculated sludge returned to a stage prior to the solid-liquid separation step in the silica-containing water treatment apparatus 1 may be any amount that ensures satisfactory recirculation of the amount of magnesium necessary for recycling, but is preferably within a range from about 2 to 20%, and more preferably within a range from
25 about 5 to 10%, of the flow rate of the water to be treated. If the amount of recirculated sludge is less than 2% of the flow rate of the water to be treated, then the amount of magnesium necessary for recycling may not be able to be supplied satisfactorily, whereas if the amount exceeds 20%, then the flow rate of the water to be treated increases and the

reaction time in each of the reaction tanks shortens, which can sometimes result in a deterioration in the silica processability and a worsening of the flocculation properties.

[0059]

The amount of recirculated second solid-liquid separation water returned to a stage prior to the first solid-liquid separation step in the silica-containing water treatment apparatus 2 may be any amount that ensures satisfactory recirculation of the amount of magnesium necessary for recycling, but is preferably within a range from about 2 to 20%, and more preferably within a range from about 5 to 10%, of the flow rate of the water to be treated. If the amount of recirculated second solid-liquid separation water is less than 2% of the flow rate of the water to be treated, then the amount of magnesium necessary for recycling may not be able to be supplied satisfactorily, whereas if the amount exceeds 20%, then the flow rate of the water to be treated increases and the reaction time in each of the reaction tanks shortens, which can sometimes result in a deterioration in the silica processability and a worsening of the flocculation properties.

[0060]

As the concentration of returned sludge fed into the sludge recycling tank 18 is increased, the concentration in the sludge recycling tank 18 increases, the proportion of gelled silica relative to the amount of eluted magnesium ions increases, and the recycling efficiency improves. The concentration of returned sludge is, for example, within a range from 0.5 to 5.0%, and is preferably within a range from 1.0 to 3.0%.

[0061]

In order to increase the sludge concentration, the aforementioned polymer flocculation step using a polymer flocculant is preferably performed.

[0062]

In order to increase the sludge concentration, or in order to improve the solid-liquid separability of the recycled sludge, at least one of the aforementioned flocculation step using an inorganic flocculant and the aforementioned polymer flocculation step using a polymer flocculant is preferably performed. In the silica-containing water treatment

apparatus 1, the flocculation step using an inorganic flocculant may be performed at a stage prior to the polymer flocculation step. In the silica-containing water treatment apparatus 2, the flocculation step using an inorganic flocculant may be omitted.

[0063]

5 In the silica-containing water treatment apparatus 1, there are no particular limitations on the return destination for the recycled sludge by the return unit, provided the destination is a stage prior to the settling tank 16 (the solid-liquid separation step). For example, the recycled sludge may be returned to at least one of the treatment water tank 10, the reaction tank 12, the polymer reaction tank 14, and the lines 24, 26 and 28, but
10 returning the recycled sludge to the reaction tank 12 enables the magnesium ion concentration in the reaction tank 12 to be increased and the coprecipitation reaction of magnesium and silica to be accelerated, and is therefore particularly desirable.

[0064]

In the silica-containing water treatment apparatus 2, there are no particular
15 limitations on the return destination for the second solid-liquid separation water by the return unit, provided the destination is a stage prior to the settling tank 16 (the first solid-liquid separation step). For example, that may be returned to at least one of the treatment water tank 10, the reaction tank 12, the flocculation tank 52, the polymer reaction tank 14, and the lines 24, 58, 60 and 62, but returning to the reaction tank 12 enables the
20 magnesium ion concentration in the reaction tank 12 to be increased and the coprecipitation reaction of magnesium and silica to be accelerated, and is therefore particularly desirable.

[0065]

In the silica-containing water treatment apparatuses 1 and 2, the silica-containing
25 water that represents the treatment target may be, for example, groundwater, water used for industry, or factory wastewater or the like. The amount of silica in the silica-containing water is, for example, from 10 to 400 mg/L. In those cases where the silica-containing water contains a hardness component, the amount of calcium hardness component in the

silica-containing water is, for example, from 50 to 5,000 mg-CaCO₃/L, and the amount of magnesium hardness component is, for example, from 10 to 1,000 mg-CaCO₃/L.

[0066]

Examples of the magnesium compound used in the insolubilization step include
5 inorganic salts of magnesium such as magnesium hydroxide (Mg(OH)₂), magnesium
chloride (MgCl₂) and magnesium oxide (MgO). Among these, in terms of chemical costs
and the like, magnesium hydroxide is preferable. In those cases where a compound such
as magnesium hydroxide or magnesium oxide that is only sparingly soluble in water or the
like is used as the magnesium compound, a separate dissolution tank may be provided to
10 dissolve the magnesium compound in water or the like prior to addition to the reaction tank
12 or the sludge recycling tank 18, and in order to achieve better dissolution of the
magnesium compound, the magnesium compound is preferably added to the sludge
recycling tank 18.

[0067]

15 The amount added of the magnesium compound in the insolubilization step is
preferably within a range from 0.5 mol to 5.0 mol, and more preferably within a range
from 1.0 mol to 2.5 mol, per 1 mol of the amount of the silica in the silica-containing water
that represents the water to be treated. If the amount added of the magnesium compound
in the insolubilization step is less than 0.5 mol per 1 mol of silica in the water to be treated,
20 then the insolubilization reaction may sometimes not proceed satisfactorily, whereas
addition of an amount exceeding 5.0 mol may sometimes be disadvantageous in terms of
chemical costs and the like.

[0068]

In those cases where a pH adjustment is performed in the insolubilization step, the
25 pH inside the reaction tank 12 is preferably adjusted to a pH of 10 or higher, more
preferably adjusted to a pH within a range from 10 to 12, and even more preferably
adjusted to a pH within a range from 10 to 11. If the pH in the reaction tank 12 is less
than 10, then the magnesium insolubilization may be unsatisfactory and the silica

removability may deteriorate, whereas if the pH exceeds 12, the solubility of silica increases, and the silica removability may sometimes deteriorate.

[0069]

Examples of pH adjusters that can be used for the pH adjustment include acids such
5 as hydrochloric acid and sulfuric acid, or alkaline agents such as sodium hydroxide.

[0070]

In those cases where the silica-containing water contains a hardness component, at least one of an alkaline agent and a carbonate compound may be added to insolubilize the hardness component, either in the reaction tank 12, or in a separate reaction tank (second
10 reaction tank) provided prior to or after the reaction tank 12, with the insoluble material then removed in the above solid-liquid separation step. The hardness component may also be removed at a stage prior to the reaction tank 12 using an ion exchange resin or the like.

[0071]

Examples of alkaline agents that may be used for the insolubilization of the hardness
15 component include calcium hydroxide ($\text{Ca}(\text{OH})_2$), sodium hydroxide (NaOH) and potassium hydroxide (KOH). Among these, in terms of chemical costs and the like, calcium hydroxide and sodium hydroxide are preferable. Examples of carbonate compounds that may be used for the insolubilization of the hardness component include sodium carbonate (Na_2CO_3), sodium bicarbonate (NaHCO_3) and carbon dioxide gas.
20 Among these, in terms of chemical costs and the like, sodium carbonate is preferable.

[0072]

The amount added of the alkaline agent and the carbonate compound in the insolubilization step is preferably within a range from 1.0 mol to 1.2 mol, and more preferably within a range from 1.0 mol to 1.1 mol, per 1 mol of the amount of the hardness
25 component in the water to be treated. If the amount added of the alkaline agent and the carbonate compound in the insolubilization step is less than 1.0 mol per 1 mol of the hardness component in the water to be treated, then the insolubilization reaction may

sometimes not proceed satisfactorily, whereas addition of an excess amount may sometimes be disadvantageous in terms of chemical costs and the like.

[0073]

The reaction temperature during the insolubilization step is not particularly limited,
5 and is, for example, typically within a range from 15°C to 30°C.

[0074]

Examples of inorganic flocculants that may be used in the flocculation step include iron-based inorganic flocculants such as ferric chloride and polyferric sulfate, and aluminum-based inorganic flocculants such as aluminum sulfate and polyaluminum
10 chloride (PAC).

[0075]

The amount added of the inorganic flocculant in the flocculation step is preferably within a range from 30 to 300 mg/L, and is more preferably within a range from 50 to 100 mg/L. If the amount added of the inorganic flocculant in the flocculation step is less than
15 30 mg/L, then the flocculation reaction may sometimes not proceed satisfactorily, whereas addition of an excess amount may sometimes be disadvantageous in terms of chemical costs and the like.

[0076]

The reaction temperature during the flocculation step is not particularly limited, and
20 is, for example, typically within a range from 15°C to 30°C.

[0077]

Examples of polymer flocculants that may be used in the polymer flocculation step include acrylamide-based and acrylate ester-based polymer flocculants. Among these, in terms of chemical costs and the like, an acrylamide-based polymer flocculant is preferable.

25 [0078]

The amount added of the polymer flocculant in the polymer flocculation step is preferably within a range from 0.5 to 5.0 mg/L, and is more preferably within a range from 1 to 2 mg/L. If the amount added of the polymer flocculant in the polymer flocculation

step is less than 0.5 mg/L, then the flocculation reaction may sometimes not proceed satisfactorily, whereas addition of an excess amount may sometimes be disadvantageous in terms of chemical costs and the like.

[0079]

5 The reaction temperature during the polymer flocculation step is not particularly limited, and is, for example, typically within a range from 15°C to 30°C.

[0080]

 There are no particular limitations on the solid-liquid separation method used in the solid-liquid separation step performed in the silica-containing water treatment apparatus 1,
10 or the first solid-liquid separation step and the second solid-liquid separation step performed in the silica-containing water treatment apparatus 2, and in addition to a settling tank that utilizes natural settling, other methods include sand filtration, membrane filtration and cyclone methods. Among these, in terms of equipment costs and the like, a settling tank that utilizes natural settling is preferable.

15 [0081]

 By using the silica-containing water treatment methods and treatment apparatuses 1 and 2 according to embodiments of the present invention, the amount of magnesium compound used can be reduced to a value within a range from 1/2 to about zero compared with the case where the recycled sludge or the second solid-liquid separation water is not
20 returned. Further, the silica content of the treated water can be reduced to about 10 mg/L or less.

[0082]

 A third example of the treatment apparatus for a silica-containing water according to an embodiment of the present invention is shown in FIG. 3.

25 [0083]

 The silica-containing water treatment apparatus 3 of FIG. 3 includes a reaction tank 12 that functions as an insolubilization unit for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the water to be treated containing organic

matter and silica, or by utilizing the magnesium contained in the water to be treated, a membrane filtration device 76 for performing membrane filtration of the obtained insoluble material, a pump 80 and a backwash water line 92 that function as a backwash unit for backwashing the membrane used in the membrane filtration device 76, a sludge recycling tank 18 and an acid addition line 44 that function as an acid addition unit for adding an acid to at least a portion of the discharged backwash wastewater, and a recycled sludge return line 90 that functions as a backwash wastewater return unit for returning the backwash wastewater containing the added acid to a stage prior to the membrane filtration device 76. The silica-containing water treatment apparatus 3 may also contain a treatment water tank 10 for storing the water to be treated, and a treated water tank 78 for storing the treated water.

[0084]

In the silica-containing water treatment apparatus 3 of FIG. 3, the outlet of the treatment water tank 10 and the treatment water inlet of the reaction tank 12 are connected by a line 24 via a pump 20. The outlet of the reaction tank 12 and the inlet of the membrane filtration device 76 are connected by a line 82. The membrane filtrate outlet of the membrane filtration device 76 and the inlet of the treated water tank 78 are connected by a treated water line 84. A treated water line 86 is connected to the treated water outlet of the treated water tank 78. A backwash water outlet from the treated water tank 78 and a location partway along the treated water line 84 are connected by a backwash water line 92 via a pump 80. A backwash wastewater outlet from the membrane filtration device 76 and the inlet of the sludge recycling tank 18 are connected by a backwash wastewater line 88. The outlet of the sludge recycling tank 18 and a recycled sludge inlet of the reaction tank 12 are connected by a recycled sludge return line 90. A magnesium compound addition line 38 that functions as a magnesium compound addition unit and a pH adjuster addition line 40 that functions as a pH adjuster addition unit are connected to the reaction tank 12, and a stirring device 46 fitted with a stirring blade is provided as a stirring unit. An acid addition line 44 that functions as an acid addition unit is connected to the sludge

recycling tank 18, and a stirring device 50 fitted with a stirring blade is provided as a stirring unit.

[0085]

In the silica-containing water treatment apparatus 3 of FIG. 3, the silica-containing water containing organic matter and silica, which represents the water to be treated, is stored in the treatment water tank 10 as required, and is then fed through the line 24 into the reaction tank 12 using the pump 20. The amount of magnesium compound required to be added may vary depending on factors such as the silica concentration of the targeted treated water, and can therefore not be clearly specified, but using the case in which the silica concentration of the treated water is to be reduced to not more than 10 mg/L as an example, the following description applies. For example, in those cases where the water to be treated has a pH of 10 or higher, and either the water to be treated contains no magnesium, or the amount of magnesium in the water to be treated is less than 0.5 mol per 1 mol of the amount of silica, a magnesium compound is added to the silica-containing water in the reaction tank 12 through the magnesium compound addition line 38 to insolubilize the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of less than 10, and either the water to be treated contains no magnesium, or the amount of magnesium in the water to be treated is less than 0.5 mol per 1 mol of the amount of silica, a magnesium compound is added to the silica-containing water in the reaction tank 12 through the magnesium compound addition line 38, and a pH adjuster is added through the pH adjuster addition line 40 to adjust the pH of the water to be treated to a value of 10 or higher, thereby insolubilizing the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of less than 10, and the amount of magnesium in the water to be treated is at least 0.5 mol per 1 mol of the amount of silica, a pH adjuster is added to the silica-containing water in the reaction tank 12 through the pH adjuster addition line 40 to adjust the pH of the water to be treated to a value of 10 or higher, thereby insolubilizing the silica (insolubilization step). For example, in those cases where the water to be treated has a pH of 10 or higher, and the

amount of magnesium in the water to be treated is at least 0.5 mol per 1 mol of the amount of silica, the water to be treated is fed without further modification into the membrane filtration device 76. In the reaction tank 12, the reaction liquid may be stirred by the stirring device 46.

5 [0086]

Addition of the magnesium compound to the water to be treated may be performed by providing the reaction tank 12 as illustrated in FIG. 3, or may be performed without providing the reaction tank 12, by line injection using an inline mixer or the like provided in the line connecting the treatment water tank 10 and the membrane filtration device 76.

10 [0087]

In those cases where a pH adjustment is performed, the pH adjustment may be performed in the reaction tank 12 as illustrated in FIG. 3, or a separate pH adjustment tank may be provided at a stage prior to or after the reaction tank 12, and pH adjustment then performed in this pH adjustment tank. In other words, the magnesium compound may be added to the water to be treated that has already undergone pH adjustment, or the water to be treated containing the added magnesium compound may be subjected to pH adjustment.

[0088]

By stirring the water to be treated containing the added magnesium compound under alkaline conditions of pH 10 or higher, preferably for a reaction time of 1 to 15 minutes, for example for about 10 minutes, a magnesium floc is formed. The magnesium floc contains magnesium silicate produced by the reaction of silica and magnesium, and also incorporates at least a portion of the organic matter contained in the water to be treated. In those cases where a membrane is used to remove the insolubilized silica, settling such as flocculation settling need not be performed, and therefore the reaction time is shortened and the floc may be small.

[0089]

Next, the reaction liquid obtained in the insolubilization step is fed from the reaction tank 12 through the line 82 and into the membrane filtration device 76. In the membrane

filtration device 76, the insoluble material obtained in the insolubilization step is subjected to membrane filtration (membrane filtration step). The membrane filtrate obtained in the membrane filtration step is fed from the membrane filtration device 76 through the treated water line 84, and may be stored, if required, in the treated water tank 78. At least a
5 portion of the membrane filtrate may be discharged as treated water through the treated water line 86.

[0090]

After performing the membrane filtration treatment in the membrane filtration device 76 for a prescribed time (for example, about once in 30 minutes to 1 hour), at least a
10 portion of the membrane filtrate is fed from the secondary side of the membrane filtration device 76 through the backwash water line 92 and the treated water line 84 using the pump 80, and backwashing of the membrane used in the membrane filtration step is performed (backwashing step). The backwash wastewater is discharged from the primary side of the membrane filtration device 76 through the backwash wastewater line 88, and is fed into the
15 sludge recycling tank 18.

[0091]

In the sludge recycling tank 18, an acid is added to the backwash wastewater containing the sludge through the acid addition line 44 to recycle the sludge (acid addition step). The backwash wastewater containing the recycled sludge to which the acid has
20 been added passes through the recycled sludge return line 90 and is returned to the reaction tank 12 which represents a stage prior to the membrane filtration device 76 (membrane filtration step).

[0092]

In this manner, in the silica-containing water treatment method and the treatment
25 apparatus 3 according to the present embodiment, the silica is insolubilized at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water or by utilizing the magnesium contained in the water to be treated, a membrane filtration treatment is performed (membrane filtration step), acid is added to at least a portion of the

backwash wastewater discharged during backwashing of the membrane used in the membrane filtration step (acid addition step), and the resultant material is returned to a stage prior to the membrane filtration step (backwash wastewater return step). By subjecting the magnesium floc obtained in the insolubilization step to a membrane
5 filtration treatment, the silica contained in the water to be treated can be removed.

Further, by incorporating the organic matter that tends to block the membrane within the magnesium floc, blockages of the filtration membrane can be alleviated. By using this method, during silica treatment of a silica-containing water containing organic matter and silica, the silica can be removed by a stable operation. By adding a magnesium compound
10 to the silica-containing water, two effects can be achieved, namely the silica can be removed, and any increase in the filtration resistance in the membrane filtration device 76 can be suppressed, contributing to stable operation of the membrane.

[0093]

Further, in this method, by adding an acid to the sludge, the compounds of
15 magnesium and silica contained in the sludge are dissolved, and the magnesium can be eluted in the form of ions. At this time, silica is also eluted, but because the solubility of silica is typically low, any silica exceeding the degree of solubility tends to gel and precipitate. Typically, this gelling of silica takes a long time (several tens of hours or longer), but in this method, it is thought that because the silica has already been converted
20 once to a solid form, the silica can be satisfactorily gelled even with a reaction time of about 30 minutes.

[0094]

By returning the recycled sludge to a stage prior to the membrane filtration device 76 (membrane filtration step), the ionized magnesium can be reused as a magnesium
25 compound that functions as a silica removal agent, whereas almost all of the silica gels and precipitates independently, and can therefore be once again separated in the membrane filtration step.

[0095]

Because the magnesium ions that are eluted from the compounds of magnesium and silica contained in the sludge can be reused as a magnesium compound that functions as a silica removal agent, the amount of magnesium compound used can be dramatically reduced compared with the case where the magnesium ions are not reused. As a result, the amount of sludge generated can be reduced. In some cases, the silica can be removed using only the magnesium that already exists in the water to be treated. Furthermore, by reusing the eluted magnesium ions, if an amount of magnesium compound is used that is similar to that used when magnesium ions are not reused, then the amount of silica in the treated water can be further reduced, and the quality of the treated water can be further improved. Accordingly, in those cases where an additional treatment device such as a reverse osmosis membrane treatment device is provided at a latter stage to the membrane filtration device, the load on that additional treatment device can be reduced.

[0096]

A fourth example of the treatment apparatus for a silica-containing water according to an embodiment of the present invention is shown in FIG. 4.

[0097]

The silica-containing water treatment apparatus 4 of FIG. 4 includes a reaction tank 12 that functions as an insolubilization unit for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to the water to be treated containing organic matter and silica, or by utilizing the magnesium contained in the water to be treated, a membrane filtration device 76 for performing membrane filtration of the obtained insoluble material, a pump 80 and a backwash water line 92 that function as a backwash unit for backwashing the membrane used in the membrane filtration device 76, a sludge recycling tank 18 and an acid addition line 44 that function as an acid addition unit for adding an acid to at least a portion of the discharged backwash wastewater, a sludge separation tank 54 that functions as a solid-liquid separation unit for performing a solid-liquid separation of the backwash wastewater containing the added acid, and a solid-liquid separation water return line 96 that functions as a solid-liquid separation return unit for

returning at least a portion of the solid-liquid separation water separated by the sludge separation tank 54 that functions as a solid-liquid separation unit to a stage prior to the membrane filtration device 76. The silica-containing water treatment apparatus 4 may also contain a treatment water tank 10 for storing the water to be treated, and a treated water tank 78 for storing the treated water.

[0098]

In the silica-containing water treatment apparatus 4 of FIG. 4, the outlet of the treatment water tank 10 and the treatment water inlet of the reaction tank 12 are connected by a line 24 via a pump 20. The outlet of the reaction tank 12 and the inlet of the membrane filtration device 76 are connected by a line 82. The membrane filtrate outlet of the membrane filtration device 76 and the inlet of the treated water tank 78 are connected by a treated water line 84. A treated water line 86 is connected to the treated water outlet of the treated water tank 78. A backwash water outlet from the treated water tank 78 and a location partway along the treated water line 84 are connected by a backwash water line 92 via a pump 80. A backwash wastewater outlet from the membrane filtration device 76 and the inlet of the sludge recycling tank 18 are connected by a backwash wastewater line 88. The outlet of the sludge recycling tank 18 and the inlet of the sludge separation tank 54 are connected by a line 94. A solid-liquid separation water outlet of the sludge separation tank 54 and a solid-liquid separation water inlet of the reaction tank 12 are connected by a solid-liquid separation water return line 96. A sludge line 68 is connected to a sludge outlet at the bottom of the sludge separation tank 54 via a pump 56. A magnesium compound addition line 38 that functions as a magnesium compound addition unit and a pH adjuster addition line 40 that functions as a pH adjuster addition unit are connected to the reaction tank 12, and a stirring device 46 fitted with a stirring blade is provided as a stirring unit. An acid addition line 44 that functions as an acid addition unit is connected to the sludge recycling tank 18, and a stirring device 50 fitted with a stirring blade is provided as a stirring unit.

[0099]

In the silica-containing water treatment apparatus 4 of FIG. 4, the silica-containing water containing organic matter and silica, which represents the water to be treated, is stored in the treatment water tank 10 as required, and is then fed through the line 24 into the reaction tank 12 using the pump 20. An insolubilization step is conducted in the reaction tank 12 in the same manner as that described for the silica-containing water treatment apparatus 3 of FIG. 3.

[0100]

Next, the reaction liquid obtained in the insolubilization step is fed from the reaction tank 12 through the line 82 and into the membrane filtration device 76. In the membrane filtration device 76, the obtained insoluble material is subjected to membrane filtration (membrane filtration step). The membrane filtrate obtained in the membrane filtration step is fed from the membrane filtration device 76 through the treated water line 84, and may be stored, if required, in the treated water tank 78. At least a portion of the membrane filtrate may be discharged as treated water through the treated water line 86.

[0101]

After performing the membrane filtration treatment in the membrane filtration device 76 for a prescribed time (for example, about once in 30 minutes to 1 hour), at least a portion of the membrane filtrate is fed from the secondary side of the membrane filtration device 76 through the backwash water line 92 and the treated water line 84 using the pump 80, and backwashing of the membrane used in the membrane filtration step is performed (backwashing step). The backwash wastewater is discharged from the primary side of the membrane filtration device 76 through the backwash wastewater line 88, and is fed into the sludge recycling tank 18.

[0102]

In the sludge recycling tank 18, an acid is added to the backwash wastewater containing the sludge through the acid addition line 44 to recycle the sludge (acid addition step). The backwash wastewater containing the recycled sludge to which the acid has been added passes through the line 94 and is fed into the sludge separation tank 54. In the

sludge separation tank 54, a solid-liquid separation is performed by allowing the obtained insoluble material to settle naturally (solid-liquid separation step).

[0103]

The solid-liquid separation water obtained in the solid-liquid separation step is passed through the solid-liquid separation water return line 96 and is returned to the reaction tank 12 (membrane filtration step) which represents a stage prior to the membrane filtration device 76 (solid-liquid separation water return step). The sludge separated by the solid-liquid separation is discharged from the sludge separation tank 54 through the sludge line 68 using the pump 56.

[0104]

In this manner, in the silica-containing water treatment method and treatment apparatus 4 according to the present embodiment, the silica is insolubilized at a pH of 10 or higher, either by adding a magnesium compound to the silica-containing water or by utilizing the magnesium contained in the water to be treated, a membrane filtration treatment is performed (membrane filtration step), acid is added to at least a portion of the backwash wastewater discharged during backwashing of the membrane used in the membrane filtration step (acid addition step), a solid-liquid separation is performed (solid-liquid separation step), and at least a portion of the separated solid-liquid separation water is returned to a stage prior to the membrane filtration step (solid-liquid separation water return step).

[0105]

In this method, by adding an acid to the sludge, the compounds of magnesium and silica contained in the sludge are dissolved, and the magnesium can be eluted in the form of ions. At this time, silica is also eluted, but because the solubility of silica is typically low (for example, about 120 mg/L at a pH of 4 to 9 and 25°C), any silica exceeding the degree of solubility tends to gel and precipitate. Typically, this gelling of silica takes a long time (several tens of hours or longer), but in this method, it is thought that because the

silica has already been converted once to a solid form, the silica can be satisfactorily gelled even with a reaction time of about 30 minutes.

[0106]

If the recycled sludge that has been recycled in the acid addition step is returned
5 without further modification to a stage prior to the membrane filtration step, the ionized
magnesium can be reused as a magnesium compound that functions as a silica removal
agent, whereas almost all of the silica gels and precipitates independently, and can
therefore be once again separated by the membrane filtration device 76. However, if the
silica that has independently gelled is returned to a stage prior to the membrane filtration
10 step, then the silica gradually redissolves. Provided the amount of silica is small, the
effect of this redissolution is small, and almost no problems arise provided membrane
filtration is performed by the membrane filtration device 76, but if a large amount of
sludge is recycled and the proportion of independently gelled silica is increased, then the
effects become impossible to ignore. Further, if, for example, the treatment apparatus is
15 stopped temporarily and the gelled silica is left to sit inside the system for a long period of
time, then redissolution of the silica progresses, and a phenomenon is sometimes observed
in which the silica concentration in the treated water increases significantly. Accordingly,
in the treatment method and treatment apparatus 4 according to the present embodiment,
by subjecting the recycled sludge that has been recycled in the acid addition step to a solid-
20 liquid separation (solid-liquid separation treatment), the eluted magnesium (magnesium
ions) can be returned to a stage prior to the membrane filtration step and reused, while
limiting the amount of gelled silica returned to the stage prior to the membrane filtration
step as much as possible, and the amount of magnesium compound used can be reduced.
Furthermore, the silica concentration of the treated water can be reduced by using only a
25 small amount of added magnesium compound.

[0107]

In this manner, because the magnesium ions that are eluted from the compounds of
magnesium and silica contained in the sludge can be reused as a magnesium compound

that functions as a silica removal agent, the amount of magnesium compound used can be dramatically reduced compared with the case where the magnesium ions are not reused.

As a result, the amount of sludge generated can be reduced. In some cases, the silica can

be removed using only the magnesium that already exists in the water to be treated, with

5 this magnesium being used to insolubilize the silica. In those cases where the magnesium

concentration is high relative to the silica concentration in the water to be treated, the silica

can be removed without adding any additional magnesium compound. Furthermore, by

reusing the eluted magnesium ions, if an amount of magnesium compound is used that is

similar to that used when magnesium ions are not reused, then the amount of silica in the

10 treated water can be further reduced, and the quality of the treated water can be further

improved. Accordingly, in those cases where an additional treatment device such as a

reverse osmosis membrane treatment device is provided at a latter stage to the membrane

filtration device 76, the load on that additional treatment device can be reduced.

[0108]

15 In the acid addition step in the silica-containing water treatment apparatuses 3 and 4,

acid is preferably added to adjust the pH of the backwash wastewater to a value within a

range from 4 to 9. The amount of magnesium that can be recycled is determined by the

amount of acid added to the sludge recycling tank 18, and the larger the amount of acid

added, the larger the amount of magnesium that can be recycled. Because the solubility of

20 silica at 25°C within the pH range from 4 to 9 is about 120 mg/L to 150 mg/L, it is thought

that any silica exceeding the degree of solubility tends to gel and precipitate.

[0109]

In the acid addition step, provided the pH is 9 or lower, magnesium ions are eluted.

Magnesium ions are eluted even when the pH is less than 4, but because the dissolved

25 silica is less likely to gel, the pH range is preferably from 4 to 9, and more preferably from

4 to 6.

[0110]

Examples of the acid used in recycling the sludge include hydrochloric acid and sulfuric acid. Of these, in terms of chemical costs and the like, hydrochloric acid is preferable.

[0111]

5 The reaction temperature in the acid addition step is not particularly limited, and may, for example, be within a range from 15°C to 30°C. The reaction time in the acid addition step is not particularly limited, and may, for example, be within a range from 15 minutes to 120 minutes.

[0112]

10 The amount of recirculated backwash wastewater returned to a stage prior to the membrane filtration step in the silica-containing water treatment apparatus 3 may be any amount that ensures satisfactory recirculation of the amount of magnesium necessary for recycling, but is preferably within a range from about 2 to 20%, and more preferably within a range from about 5 to 10%, of the flow rate of the water to be treated. If the
15 amount of recirculated backwash wastewater is less than 2% of the flow rate of the water to be treated, then the amount of magnesium necessary for recycling may not be able to be supplied satisfactorily, whereas if the amount exceeds 20%, then the flow rate of the water to be treated increases and the reaction time in each of the reaction tanks shortens, which can sometimes result in a deterioration in the silica processability and a worsening of the
20 flocculation properties.

[0113]

 The amount of recirculated solid-liquid separation water returned to a stage prior to the membrane filtration step in the silica-containing water treatment apparatus 4 may be any amount that ensures satisfactory recirculation of the amount of magnesium necessary
25 for recycling, but is preferably within a range from about 2 to 20%, and more preferably within a range from about 5 to 10%, of the flow rate of the water to be treated. If the amount of recirculated solid-liquid separation water is less than 2% of the flow rate of the water to be treated, then the amount of magnesium necessary for recycling may not be able

to be supplied satisfactorily, whereas if the amount exceeds 20%, then the flow rate of the water to be treated increases and the reaction time in each of the reaction tanks shortens, which can sometimes result in a deterioration in the silica processability and a worsening of the flocculation properties.

5 [0114]

As the concentration of sludge in the backwash wastewater fed into the sludge recycling tank 18 is increased, the concentration in the sludge recycling tank 18 increases, the proportion of gelled silica relative to the amount of eluted magnesium ions increases, and the recycling efficiency improves. The concentration of returned sludge in the backwash wastewater is, for example, within a range from 0.5 to 5.0%, and is preferably within a range from 1.0 to 3.0%.

[0115]

In the silica-containing water treatment apparatus 3, there are no particular limitations on the return destination for the recycled sludge by the backwash wastewater return unit, provided the destination is a stage prior to the membrane filtration device 76 (the membrane filtration step). For example, the recycled sludge may be returned to at least one of the treatment water tank 10, the reaction tank 12, the lines 24 and 82, and the flocculation tank and polymer reaction tank when included, but returning the recycled sludge to the reaction tank 12 enables the magnesium ion concentration in the reaction tank 12 to be increased and the coprecipitation reaction of magnesium and silica to be accelerated, and is therefore particularly desirable.

[0116]

In the silica-containing water treatment apparatus 4, there are no particular limitations on the return destination for the solid-liquid separation water by the solid-liquid separation water return unit, provided the destination is a stage prior to the membrane filtration device 76 (the membrane filtration step). For example, that may be returned to at least one of the treatment water tank 10, the reaction tank 12, lines 24 and 82, and the flocculation tank and polymer reaction tank when included, but returning to the reaction

tank 12 enables the magnesium ion concentration in the reaction tank 12 to be increased and the coprecipitation reaction of magnesium and silica to be accelerated, and is therefore particularly desirable.

[0117]

5 By using the silica-containing water treatment method and treatment apparatuses 3 and 4 according to embodiments of the present invention, the amount of magnesium compound used can be reduced to a value within a range from 1/2 to about zero compared with the case where the recycled sludge or the solid-liquid separation water is not returned to a stage prior to the membrane filtration step.

10 [0118]

By using the silica-containing water treatment method and treatment apparatuses 3 and 4 according to embodiments of the present invention, the silica content of the treated water can be reduced to about 10 mg/L or less, and the organic matter content of the treated water can be reduced to about 1 mg/L or less.

15 [0119]

In the silica-containing water treatment apparatuses 3 and 4, the silica-containing water that represents the treatment target may be, for example, groundwater, water used for industry, or factory wastewater or the like. The amount of silica in the silica-containing water is, for example, from 10 to 400 mg/L. The amount of organic matter in the silica-
20 containing water is, for example, from 1 to 10 mg/L. In those cases where the silica-containing water contains a hardness component, the amount of calcium hardness component in the silica-containing water is, for example, from 50 to 5,000 mg-CaCO₃/L, and the amount of magnesium hardness component is, for example, from 10 to 1,000 mg-CaCO₃/L.

25 [0120]

The filtration membrane used in the membrane filtration step is, for example, at least one of a microfiltration membrane (MF membrane) and an ultrafiltration membrane (UF membrane). The pore size of a microfiltration membrane is at least 0.1 μm but not more

than 10 μm , whereas the nominal pore size of an ultrafiltration membrane is at least 0.01 μm but less than 0.1 μm . The filtration membrane may be an inorganic membrane such as a ceramic membrane, or an organic membrane such as PVDF (polyvinylidene fluoride), PES (polyethersulfone), PS (polysulfone) or PTFE (polytetrafluoroethylene). Further, the
5 filtration membrane may be an external pressure-type or internal pressure-type membrane.
[0121]

The reaction liquid obtained in the insolubilization step may, before the membrane filtration step, be subjected to a flocculation reaction, for example by adding an inorganic flocculant as required to the reaction liquid in the flocculation tank (flocculation step). In
10 the flocculation tank, a pH adjuster may be added if required. In the flocculation tank, the flocculated liquid may be stirred with a stirring device.
[0122]

The flocculation reaction liquid obtained in the flocculation step may be further subjected to a polymer flocculation reaction, for example by adding a polymer flocculant
15 as required to the flocculation reaction liquid in the polymer reaction tank (polymer flocculation step). In the polymer reaction tank, the flocculation reaction liquid may be stirred with a stirring device.
[0123]

The polymer flocculated liquid obtained in the polymer flocculation step is fed to the
20 membrane filtration device 76, and the obtained insoluble material is subjected to membrane filtration in the membrane filtration device 76 (membrane filtration step).
[0124]

In the treatment methods and the treatment apparatuses 1 and 2 according to embodiments of the present invention, as illustrated in FIGS. 5 and 6 respectively, it is
25 preferable that a reverse osmosis membrane treatment device 100 in which the solid-liquid separation treatment water or the first solid-liquid separation treatment water (the treated water) is passed through a reverse osmosis membrane to obtain a permeate and a concentrate is also provided at a latter stage to the settling tank 16 (the solid-liquid

separation step or the first solid-liquid separation step) to perform a reverse osmosis membrane treatment.

[0125]

In the silica-containing water treatment apparatus 5 of FIG. 5, the solid-liquid separation treatment water (the treated water) obtained in the settling tank 16 (solid-liquid separation step), is passed through a reverse osmosis membrane in the reverse osmosis membrane treatment device 100 to obtain a permeate and a concentrate (reverse osmosis membrane treatment step). The permeate is discharged through a permeate line 102, and the concentrate is discharged through a concentrate line 104. Because the silica content of the solid-liquid separation treatment water (the treated water) has been reduced, scaling and the like due to silica in the reverse osmosis membrane treatment device can be suppressed, and blockages of the reverse osmosis membrane can also be suppressed.

[0126]

In the silica-containing water treatment apparatus 6 of FIG. 6, the first solid-liquid separation treatment water (the treated water) obtained in the settling tank 16 (first solid-liquid separation step), is passed through a reverse osmosis membrane in the reverse osmosis membrane treatment device 100 to obtain a permeate and a concentrate (reverse osmosis membrane treatment step). The permeate is discharged through the permeate line 102, and the concentrate is discharged through the concentrate line 104. Because the silica content of the first solid-liquid separation treatment water (the treated water) has been reduced, scaling and the like due to silica in the reverse osmosis membrane treatment device can be suppressed, and blockages of the reverse osmosis membrane can also be suppressed.

[0127]

In the treatment methods and the treatment apparatuses 3 and 4 according to embodiments of the present invention, as illustrated in FIGS. 7 and 8 respectively, it is preferable that a reverse osmosis membrane treatment device 100 in which the membrane filtered liquid (the treated water) is passed through a reverse osmosis membrane to obtain a

permeate and a concentrate is also provided at a latter stage to the membrane filtration device 76 (the membrane filtration step) to perform a reverse osmosis membrane treatment.

[0128]

5 In the silica-containing water treatment apparatuses 7 and 8 of FIG. 7 and 8, the membrane filtered liquid (the treated water) obtained in the membrane filtration device 76 (membrane filtration step) is passed through the treated water line 84, and after storage in the treated water tank 78 as required, is fed through the treated water line 86 and into the reverse osmosis membrane treatment device 100. In the reverse osmosis membrane
10 treatment device 100, the treated water is passed through a reverse osmosis membrane to obtain a permeate and a concentrate (reverse osmosis membrane treatment step). The permeate is discharged through the permeate line 102, and the concentrate is discharged through the concentrate line 104. Because the silica content of the membrane filtered liquid (the treated water) has been reduced, the risk of silica scale occurring on the
15 concentrate side of the reverse osmosis membrane can be reduced, even if the water recovery rate for the reverse osmosis membrane treatment device 100 is increased.

[0129]

 In those cases where the water to be treated contains a hardness component such as calcium, by adding a pH adjuster between the membrane filtration device 76 and the
20 reverse osmosis membrane treatment device 100 to reduce the pH to a value of 4 to 7 and reduce the Langelier index to a value less than 0, the risk of scale caused by calcium carbonate or the like can be reduced.

[0130]

 The permeate from the reverse osmosis membrane treatment device 100 may be
25 reused as makeup water for a cooling tower, or as water for production or the like.

EXAMPLES

[0131]

The present invention is described below in further detail using a series of examples and comparative examples, but the present invention is in no way limited by the following examples.

[0132]

5 <Example 1>

Jar tests were used to confirm the effects of the pH of the sludge recycling.

[0133]

(Water to be Treated)

Water to be treated: RO concentrate from pure water production line (contains silica)

10 $\text{SiO}_2 = 95.7 \text{ mg/L}$

[0134]

(Sludge Production Method)

An aqueous solution of magnesium chloride (MgCl_2) was added in an amount of 200 mg-Mg/L as a magnesium compound to 50 mL of the water to be treated. Sodium
15 hydroxide (NaOH) was added as a pH adjuster to adjust the pH to 11.0, and a reaction was conducted for 30 minutes. Next, 2 mg/L of ORFLOCK M-4216 (manufactured by Organo Corporation) was added as a polymer flocculant. After standing and settling, the supernatant liquid was discarded to concentrate the sludge to 4.4 L. The amounts of Mg and SiO_2 in the supernatant liquid were measured. A portion of the concentrated sludge
20 was dewatered by centrifugal separation, hydrochloric acid (HCl) was then added to dissolve the residue, and the amounts of Mg and SiO_2 in the sludge were measured. The results are shown in Table 1.

[0135]

The amount of Mg in the water and the sludge was measured using an ion
25 chromatography apparatus (761 Compact, manufactured by Metrohm AG). The amount of SiO_2 in the water and the sludge was measured by molybdenum blue absorbance spectrometry in accordance with JIS K 0101, using an absorptiometer (U-2900 manufactured by Hitachi, Ltd.).

[0136]

[Table 1]

Table 1. Sludge Properties

Raw water SiO ₂ [mg/L]	95.7
Supernatant Mg [mg/L]	4.19
Supernatant SiO ₂ [mg/L]	3.73
Sludge Mg [mg/L]	2200
Sludge SiO ₂ [mg/L]	1100

5 [0137]

(Sludge Recycling Test)

Hydrochloric acid (HCl) was added as an acid to 100 mL samples of the concentrated sludge to achieve the various pH levels (pH 3 to 10) shown in Table 2, and each mixture was reacted for 30 minutes. Following filtering through a filter paper (5C), the amounts of Mg and SiO₂ in the filtrate were measured. A sample prepared by dewatering the sludge by suction filtration and then performing drying at 105°C for 2 hours was once again added to 100 mL of pure water, hydrochloric acid (HCl) was added to dissolve the sludge, and the amounts of Mg and SiO₂ in the sludge were measured. The results are shown in Table 2 and FIG. 9. FIG. 9 is a graph illustrating the eluted Mg concentration (mg/L) or SiO₂ concentration (mg/L) relative to the sludge recycling pH.

[0138]

[Table 2]

Table 2. Sludge Recycling Test Results

Recycling pH [-]	3	4	5	6	7	8	9	10
Eluted Mg [mg/L]	2200	2100	1900	1500	1300	1000	600	90
Eluted SiO ₂ [mg/L]	540	300	280	190	180	150	7.4	0.62
Sludge Mg [mg/L]	0	100	310	700	890	1190	1600	2100
Sludge SiO ₂ [mg/L]	550	740	670	570	480	370	290	44

20 [0139]

As the pH during sludge recycling is lowered, Mg ions are increasingly eluted. These Mg ions can be used as a SiO₂ removal agent. On the other hand, SiO₂ is also eluted, but in the pH range from 4 to 9, the amount of elution is small, and is close to the degree of solubility. The portion of SiO₂ that exceeds this degree of solubility and is
5 detected is thought to represent the portion for which gelling has not occurred due to insufficient reaction time (pH 3). At pH 9, almost no SiO₂ elution occurs.

[0140]

<Example 2, Comparative Example 1>

(Continuous Water Flow Test)

10 For confirmation purposes, a water flow test was performed using the flow test equipment illustrated in FIG. 10. In Comparative Example 1, sludge recirculation was performed, but acid (hydrochloric acid) was not added to the sludge recycling tank.

[0141]

(Water to be Treated)

15 Water to be treated: RO concentrate from pure water production line (contains silica)
SiO₂ = 95.7 mg/L

[0142]

The water to be treated was supplied to the reaction tank at a rate of 10 L/h. Sodium hydroxide (NaOH) was added to the reaction tank as a pH adjuster to adjust the pH
20 to a value from 10.8 to 11.0, and magnesium chloride (MgCl₂) was added as a magnesium compound in an amount of 12.5 to 200 mg-Mg/L. In the polymer reaction tank, 2 mg/L of ORFLOCK M-4216 (manufactured by Organo Corporation) was added as a polymer flocculant. Using a settling tank as a solid-liquid separation device, a solid-liquid separation was performed. Following settling, the sludge was returned to the sludge
25 recycling tank at a rate of 10% (about 1 L/h) of the flow rate of the water to be treated, and in the sludge recycling tank, hydrochloric acid (HCl) was added as an acid to adjust the pH to either 7 or 9. Following recycling, the recycled sludge was returned to the reaction tank. After 8 hours had elapsed from the commencement of water flow, the SiO₂

concentration of the treated water was measured. The results are shown in FIG. 11. FIG. 11 is a graph illustrating the SiO₂ concentration (mg/L) relative to the amount added (mg-Mg/L) of magnesium (new material) in Example 2 and Comparative Example 1.

[0143]

5 In Example 2, by performing recycling of the sludge, the SiO₂ concentration of the treated water was able to be reduced even when the amount added of the magnesium compound (magnesium chloride) was small. The lower the recycling pH, the greater that effect became. In Comparative Example 1, because sludge recycling was not performed, the amount of added magnesium compound (magnesium chloride) increased.

10 [0144]

<Example 3, Comparative Example 2>

(Continuous Water Flow Test)

For confirmation purposes, a water flow test was performed using the flow test equipment illustrated in FIG. 2. In Comparative Example 2, sludge recirculation was performed, but acid (hydrochloric acid) was not added to the sludge recycling tank, and the

15 [0145]

(Water to be Treated)

Water to be treated: RO concentrate from pure water production line (contains silica)

20 SiO₂ = 100 mg/L

[0146]

The water to be treated was supplied to the reaction tank (17 L) at a rate of 100 L/h. Sodium hydroxide (NaOH) was added to the reaction tank as a pH adjuster to adjust the pH to a value from 10.8 to 11.0, and magnesium chloride (MgCl₂) was added as a magnesium compound in an amount of 50 mg-Mg/L. In the flocculation tank (17 L), 100 mg/L of a 35 wt% aqueous solution of iron (III) chloride (FeCl₃) was added as an inorganic flocculant, and sodium hydroxide was added as a pH adjuster to adjust the pH to a value from 10.8 to 11.0. In the polymer reaction tank (17 L), 2 mg/L of ORFLOCK OA-3H

(manufactured by Organo Corporation) was added as a polymer flocculant. Using a settling tank as the first solid-liquid separation device, a solid-liquid separation was performed. Following settling, the sludge was returned to the sludge recycling tank (5 L) at a rate of 10 vol% (about 10 L/h) of the flow rate of the water to be treated, and in the sludge recycling tank, hydrochloric acid (HCl) was added as an acid to adjust the pH to 5. Following recycling, the recycled sludge was subjected to a solid-liquid separation in the sludge separation tank, and the supernatant liquid (the second solid-liquid separation water) was returned to the reaction tank. After 24 hours had elapsed from the commencement of water flow, the SiO₂ concentration of the treated water was measured.

The results are shown in FIG. 12. FIG. 12 is a graph illustrating the SiO₂ concentration (mg/L) relative to the amount added (mg-Mg/L) of magnesium (new material) in Example 3 and Comparative Example 2.

[0147]

Further, for Example 3 and Comparative Example 2, the SiO₂ concentration of the treated water after 24 hours, and the SiO₂ concentration of the treated water after the test apparatus was stopped for 2 hours and then restarted are shown in Table 3.

[0148]

[Table 3]

	Comparative Example 2	Example 3
Treated water SiO ₂ after 24 hours [mg/L]	8	8
Treated water SiO ₂ after stopping apparatus for 2 hours and then restarting [mg/L]	150	8

[0149]

As illustrated in FIG. 12, in Example 3, by performing sludge recycling with an acid, conducting a second solid-liquid separation treatment, and then returning at least a portion of the second solid-liquid separation water to stage prior to the first solid-liquid separation, the SiO₂ concentration of the treated water was able to be reduced even though the amount added of the magnesium compound (magnesium chloride) was less than that used in

Comparative Example 2. In Comparative Example 2, because sludge recycling was not performed, the amount of added magnesium compound (magnesium chloride) increased.

[0150]

As shown in Table 3, in Example 3, even when the treatment apparatus was stopped temporarily, the silica concentration of the treated water was substantially unchanged. In Comparative Example 2, when the treatment apparatus was stopped temporarily, the silica concentration of the treated water increased dramatically.

[0151]

In this manner, by using the apparatuses and methods from the examples, the amount of magnesium compound used in performing silica treatment of a silica-containing water can be reduced.

REFERENCE SIGNS LIST

[0152]

- 1, 2, 3, 4, 5, 6, 7, 8: Silica-containing water treatment apparatus
- 10: Treatment water tank
- 12: Reaction tank
- 14: Polymer reaction tank
- 16: Settling tank
- 18: Sludge recycling tank
- 20, 22, 56, 80: Pump
- 24, 26, 28, 58, 60, 62, 82, 90: Line
- 30, 84, 86: Treated water line
- 32, 68: Sludge line
- 34: Sludge return line
- 36, 90: Recycled sludge return line
- 38: Magnesium compound addition line
- 40, 72: pH adjuster addition line

- 42: Polymer flocculant addition line
- 44: Acid addition line
- 46, 48, 50, 74: Stirring device
- 52: Flocculation tank
- 5 54: Sludge separation tank
- 64: Recycled sludge line
- 66, 96: Solid-liquid separation water return line
- 70: Inorganic flocculant addition line
- 76: Membrane filtration device
- 10 78: Treated water tank
- 88: Backwash wastewater line
- 92: Backwash water line
- 100: Reverse osmosis membrane treatment device
- 102: Permeate line
- 15 104: Concentrate line

CLAIMS

1. A treatment apparatus for a silica-containing water comprising:
 - a reaction tank for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a silica-containing water to be treated, or by utilizing magnesium contained in the water to be treated,
 - a solid-liquid separation unit for performing a solid-liquid separation of an obtained insoluble material, and
 - a return unit for adding an acid to at least a portion of a sludge separated by the solid-liquid separation to adjust the pH of the separated sludge to a value within a range from 4 to 6, and returning a resultant material to a stage prior to the solid-liquid separation unit.
2. A treatment apparatus for a silica-containing water comprising:
 - a reaction tank for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a silica-containing water to be treated, or by utilizing magnesium contained in the water to be treated,
 - a first solid-liquid separation unit for performing a solid-liquid separation of an obtained insoluble material,
 - an acid addition unit for adding an acid to at least a portion of a sludge separated by the first solid-liquid separation unit to adjust the pH of the separated sludge to a value within a range from 4 to 6,
 - a second solid-liquid separation unit for performing a solid-liquid separation of the sludge containing the added acid, and

a return unit for returning at least a portion of a second solid-liquid separation water separated by the second solid-liquid separation unit to a stage prior to the first solid-liquid separation unit.

3. A treatment apparatus for a silica-containing water comprising:

an insolubilization unit for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a water to be treated containing organic matter and silica, or by utilizing magnesium contained in the water to be treated,

a membrane filtration unit for performing membrane filtration of an obtained insoluble material,

a backwash unit for backwashing the membrane filtration unit,

an acid addition unit for adding an acid to at least a portion of a discharged backwash wastewater to adjust the pH of the backwash wastewater to a value within a range from 4 to 6, and

a backwash wastewater return unit for returning the backwash wastewater containing the added acid to a stage prior to the membrane filtration unit.

4. A treatment apparatus for a silica-containing water comprising:

an insolubilization unit for insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a water to be treated containing organic matter and silica, or by utilizing magnesium contained in the water to be treated,

a membrane filtration unit for performing membrane filtration of an obtained insoluble material,

a backwash unit for backwashing the membrane filtration unit,

an acid addition unit for adding an acid to at least a portion of a discharged backwash wastewater to adjust the pH of the backwash wastewater to a value within a range from 4 to 6,

a solid-liquid separation unit for performing a solid-liquid separation of the backwash wastewater containing the added acid, and

a solid-liquid separation water return unit for returning at least a portion of a solid-liquid separation water separated by the solid-liquid separation unit to a stage prior to the membrane filtration unit.

5. The treatment apparatus for a silica-containing water as claimed in any one of Claims 1 to 4, wherein

the amount of returning is within a range from 2 to 20% of the flow rate of the water to be treated.

6. The treatment apparatus for a silica-containing water as claimed in Claim 1 or 2, further comprising, at a latter stage after the solid-liquid separation unit, a reverse osmosis membrane treatment device in which a solid-liquid separation water is supplied to a reverse osmosis membrane to obtain a permeate and a concentrate.

7. The treatment apparatus for a silica-containing water as claimed in Claim 3 or 4, further comprising, at a latter stage after the membrane filtration unit, a reverse osmosis membrane treatment device in which a membrane filtrate is supplied to a reverse osmosis membrane to obtain a permeate and a concentrate.

8. A treatment method for a silica-containing water comprising:

- an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a silica-containing water to be treated, or by utilizing magnesium contained in the water to be treated,
- a solid-liquid separation step of performing a solid-liquid separation of an obtained insoluble material, and
- a return step of adding an acid to at least a portion of a sludge separated by the solid-liquid separation to adjust the pH of the separated sludge to a value within a range from 4 to 6, and returning a resultant material to a stage prior to the solid-liquid separation step.

9. A treatment method for a silica-containing water comprising:

- an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a silica-containing water to be treated, or by utilizing magnesium contained in the water to be treated,
- a first solid-liquid separation step of performing a solid-liquid separation of an obtained insoluble material,
- an acid addition step of adding an acid to at least a portion of a sludge separated in the first solid-liquid separation step to adjust the pH of the separated sludge to a value within a range from 4 to 6,
- a second solid-liquid separation step of performing a solid-liquid separation of the sludge containing the added acid, and
- a return step of returning at least a portion of a second solid-liquid separation water separated in the second solid-liquid separation step to a stage prior to the first solid-liquid separation step.

10. A treatment method for a silica-containing water comprising:
- an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a water to be treated containing organic matter and silica, or by utilizing magnesium contained in the water to be treated,
 - a membrane filtration step of performing membrane filtration of an obtained insoluble material,
 - a backwashing step of backwashing a membrane used in the membrane filtration step,
 - an acid addition step of adding an acid to at least a portion of a discharged backwash wastewater to adjust the pH of the backwash wastewater to a value within a range from 4 to 6, and
 - a backwash wastewater return step of returning the backwash wastewater containing the added acid to a stage prior to the membrane filtration step.
11. A treatment method for a silica-containing water comprising:
- an insolubilization step of insolubilizing silica at a pH of 10 or higher, either by adding a magnesium compound to a water to be treated containing organic matter and silica, or by utilizing magnesium contained in the water to be treated,
 - a membrane filtration step of performing membrane filtration of an obtained insoluble material,
 - a backwashing step of backwashing a membrane used in the membrane filtration step,
 - an acid addition step of adding an acid to at least a portion of a discharged backwash wastewater to adjust the pH of the backwash wastewater to a value within a range from 4 to 6,
 - a solid-liquid separation step of performing a solid-liquid separation of the backwash wastewater containing the added acid, and

a solid-liquid separation water return step of returning at least a portion of a solid-liquid separation water separated in the solid-liquid separation step to a stage prior to the membrane filtration step.

12. The treatment method for a silica-containing water as claimed in any one of Claims 8 to 11, wherein

the amount of returning is within a range from 2 to 20% of the flow rate of the water to be treated.

13. The treatment method for a silica-containing water as claimed in Claim 8 or 9, further comprising, at a latter stage after the solid-liquid separation step, a reverse osmosis membrane treatment step of supplying a solid-liquid separation water to a reverse osmosis membrane to obtain a permeate and a concentrate.

14. The treatment method for a silica-containing water as claimed in Claim 10 or 11, further comprising, at a latter stage after the membrane filtration step, a reverse osmosis membrane treatment step of supplying a membrane filtrate to a reverse osmosis membrane to obtain a permeate and a concentrate.