

WATER TREATMENT METHOD

Field of Invention

[0001]

The present invention relates to a water treatment method for producing feedwater to be supplied to a steam-generating plant such as a boiler. Specifically, the present invention relates to a water treatment method with which an operation with markedly reduced heat and water losses caused due to blowdown compared with an existing method in which softened water is used as feedwater can be realized without using any of a strong alkali, a strong acid, or a large amount of sodium chloride. The present invention relates to a water treatment method with which formation of calcium and magnesium scale on a heating surface and formation of scale caused by iron brought from steam condensation water can be suppressed and thereby the heating surface is maintained clean.

Background of Invention

[0002]

In a steam-generating plant such as a boiler, when the operating pressure is low, generally, city water or the like, such as tap water or groundwater, is treated with a softening device filled with a sodium-cation-exchange resin, and the resulting softened water, in which calcium and magnesium contained in the water have been replaced with

sodium, is used as makeup water. This is in order to prevent hard components such as calcium and magnesium brought into a boiler from forming scale on a heating surface and thereby inhibiting heat transfer, which leads to energy loss and damage to the heating surface due to overheating of the heating surface.

[0003]

In the case where a steam-generating plant is operated using softened water as makeup water, there is a problem in that a large amount of sodium chloride is used for replenishing a cation-exchange resin of a softening device. Since softened water produced with a softening device contains a large amount of dissolved salts, the concentration of the salts in boiler water is increased due to concentration resulting from generation of steam. Thus, carriage of boiler water together with steam, that is, carryover, is likely to occur. Accordingly, there is a need to maintain the concentration rate in a predetermined range by performing blowdown of a relatively large amount of boiler water. Blowdown of boiler water increases the amount of makeup water and the amount of heat dissipated together with blowdown water.

[0004]

The following methods i) to iii) are known methods for reducing the amount of heat dissipated by blowdown, in which

makeup water to be supplied to a low-pressure boiler is treated in order to remove substances dissolved in the makeup water and thereby the amount of blowdown water is reduced. These methods have their own problems as described below.

[0005]

i) A method of removing dissolved ions using a strongly basic anion-exchange resin and a strongly acidic cation-exchange resin (Non Patent Literature 1)

This method requires frequent replenishment of the ion-exchange resin using a strong acid and a strong alkali.

[0006]

ii) A method in which a treatment is performed with a softening device and subsequently salts dissolved in feedwater are removed using a reverse osmosis membrane system (Non Patent Literature 2)

In this method, a large amount of sodium chloride is used for replenishing a cation-exchange resin filled in the softening device as in existing softening methods in which a softening device is used. In addition, a relatively large amount of condensation water is drained through a reverse osmosis membrane treatment. Therefore, the amount of softened water used for the reverse osmosis membrane treatment is further increased, and consequently the amount of sodium chloride used is further increased. As a result,

even considering the reduction in the amount used for blowdown, the amount of water used is increased compared with the case where a treatment is performed using a softening device only.

[0007]

iii) A method in which a treatment is performed with a reverse osmosis membrane system and subsequently a treatment is performed with an electric desalting system using an ion-exchange membrane in combination with a direct-current power supply (Non Patent Literature 3)

Water treated by this method contains very small amount of dissolved substances. However, this method requires a large-scale system, which increases the cost.

[0008]

Collection of water produced by condensation of steam generated from a boiler and reuse of the collected water as feedwater are equivalent to collection of heat and water. In addition, when softened water is used as feedwater, the amount of dissolved substances brought from the feedwater into a boiler is reduced, which leads to further energy conservation due to reduction in the amount of blowdown water. However, iron eluted from a pipe through which the condensation water is collected may be brought into the boiler, and consequently iron oxide scale may adhere to the heating surface of the boiler. This may reduce heat

transfer efficiency and also may cause corrosion trouble at the lower portion of the scale. Therefore, if the iron concentration in the collected condensation water is high, there may be a case where the collected condensation water is drained because it cannot be used as feedwater.

[0009]

A liquid-passing-type electric double-layer capacitor desalting system used in the present invention is employed in production of purified water and the like. A desalting method in which a treatment is performed with a liquid-passing-type electric double-layer capacitor desalting system and an ion-exchange system is also known (Patent Literature 1).

Patent Literature

[0010]

Patent Literature 1: Japanese Patent Publication 2002-210468 A

Non Patent Literature

[0011]

Non Patent Literature 1: Boiler Water Control <knowledge and applications> published by Japan Boiler Association, first edition, pp. 146 to 176

Non Patent Literature 2: Boiler Water Control <knowledge and applications> published by Japan Boiler Association, first edition, p. 183

Non Patent Literature 3: Boiler Water Control

<knowledge and applications> published by Japan Boiler Association, first edition, pp. 191 to 193

Object and Summary of Invention

[0012]

The first object of the present invention is to provide a water treatment method with which the operation of a low-pressure boiler with a reduced amount of blowdown is realized by addressing the problems of the related art, that is, need for a large amount of sodium chloride, strong acid, or strong alkali and drainage of a large amount of condensation water during the treatment of feedwater.

The second object of the present invention is to provide a water treatment method with which an energy-saving operation through collection and reuse of heat and water, that is, collection and reuse of steam condensation water as feedwater, which leads to energy and water conservation, and through the resulting reduction in the amount of blowdown is realized without causing energy loss due to the adhesion of scale, corrosion trouble, or the like.

[0013]

In order to address the above-described issues, the inventors of the present invention have conducted extensive studies and, as a result, found that the above-described problems may be addressed by employing a liquid-passing-type

electric double-layer capacitor desalting system and using, as a scale-prevention agent, a water-soluble polymer including a carboxyl group in its molecule.

[0014]

The present invention has been made on the basis of the above-described findings. The summary of the present invention is described below.

[0015]

[1] A water treatment method including passing raw water through a liquid-passing-type electric double-layer capacitor desalting system and a softening device in this order; and supplying the resulting treated water to a steam-generating device.

[0016]

[2] A water treatment method including, in steam-generating equipment in which steam condensation water is collected and reused as feedwater, without using a softening device, passing raw water through a liquid-passing-type electric double-layer capacitor desalting system to produce treated water, supplying a steam-generating device with, as feedwater, the treated water and the collected steam condensation water; and adding a water-soluble polymer including a carboxyl group in its molecule to the feedwater.

[0017]

[3] The water treatment method described in [2],

wherein the amount of the water-soluble polymer including a carboxyl group is, by weight, equal to or 5 times the amount of calcium contained in the feedwater to be supplied to the steam-generating device.

[0018]

[4] The water treatment method described in [2] or [3], wherein the water-soluble polymer including a carboxyl group is a homopolymer of sodium acrylate.

Advantageous Effects of Invention

[0019]

The water treatment method according to the present invention realizes an operation with markedly reduced heat and water losses caused due to blowdown compared with the case where softened water produced by an existing treatment using a softening device only is used as feedwater or compared with the case where the softened water is further treated with a reverse osmosis membrane system without using any of a strong alkali, a strong acid, which are used in the case where a strongly basic anion-exchange resin and a strongly acidic cation-exchange resin are used, and a large amount of sodium chloride, which is used in the case where a treatment is performed using a softening device only. Furthermore, formation of calcium and magnesium scale on a heating surface and formation of scale caused by iron brought from steam condensation water can be suppressed, and

thereby a water treatment capable of maintaining a heating surface clean can be realized.

[0020]

In particular, in the case where steam condensation water is collected and reused, water treated with a liquid-passing-type electric double-layer capacitor desalting system only can be supplied to a steam-generating device by adding a water-soluble polymer including a carboxyl group in its molecule to the treated water. In this case, a softening device becomes unnecessary, which allows equipment to be simplified and eliminates the need for sodium chloride used for replenishing a softening device. In this method, formation of scale caused by iron brought together with steam condensation water can be suppressed by remaining calcium contained in a liquid-passing-type electric double-layer capacitor desalting so as to be present together with the iron and by adding a water-soluble polymer including a carboxyl group in its molecule. Moreover, both the iron and calcium can be drained by blowdown without forming scale.

Brief Description of Drawings

[0021]

Fig. 1 is a schematic diagram illustrating the principle of a softening device in a voltage application (desalting) step.

Fig. 2 is a schematic diagram illustrating the

principle of a softening device in a short-circuiting (draining) step.

Fig. 3 is a system diagram illustrating an example of a water treatment method according to an embodiment of the first aspect of the present invention.

Fig. 4 is a system diagram illustrating an example of a water treatment method according to an embodiment of the second aspect of the present invention.

Description of Embodiments

[0022]

Embodiments of the present invention are described below in detail.

[0023]

A water treatment method according to a first aspect of the present invention includes passing raw water through a liquid-passing-type electric double-layer capacitor desalting system and a softening device in this order and then supplying the resulting treated water to a steam-generating device.

According to the first aspect, raw water is treated with a liquid-passing-type electric double-layer capacitor desalting system to remove cations such as sodium ions, calcium ions, and magnesium ions and anions such as chloride ions, sulphate ions, and phosphate ions contained in the raw water and, as a result, the amount of ions in the raw water

can be markedly reduced. Therefore, the ion load of the following softening device can be reduced, and consequently the amount of sodium chloride used for replenishment of the softening device can be markedly reduced. According to the first aspect, the concentration of salts brought into boiler water can be markedly reduced and consequently an increase in electric conductivity due to the dissolved salts can also be markedly reduced, which markedly reduces the amount of blowdown water. According to the first aspect, a strong alkali and a strong acid, which are necessary in the case where an ion-exchange resin is used, are also unnecessary. The softening device causes calcium ions, magnesium ions, and the like to be replaced with sodium ions using a cation-exchange resin. A dense aqueous sodium chloride solution is used for replenishing a cation-exchange resin.

[0024]

A water treatment method according to a second aspect of the present invention, in steam-generating equipment in which steam condensation water is collected and reused as feedwater, without using a softening device, passing raw water through a liquid-passing-type electric double-layer capacitor desalting system to produce treated water, supplying a steam-generating device with, as feedwater, the treated water and the collected steam condensation water, and adding a water-soluble polymer including a carboxyl

group in its molecule to the feedwater.

According to the second aspect, a softening device is unnecessary, which eliminates the need for sodium chloride used for replenishing the softening device. According to the second aspect, the concentration of salts brought into a boiler is markedly reduced compared with the case where raw water is treated using a softening device only, which reduces the amount of blowdown. According to the second aspect, since the amounts of heat and water drained and the amounts of water treatment chemical components are reduced and consequently the amount of feedwater is reduced, the amount of water treatment chemicals to be added is also reduced.

According to the second aspect, calcium contained in water treated with a liquid-passing-type electric double-layer capacitor desalting system and a water-soluble polymer including a carboxyl group in its molecule, which is added to feedwater, suppress formation of scale caused by iron brought together with steam condensation water and cause the iron to be drained into the blowdown water. Thus, it is preferable that calcium be present in the feedwater. Therefore, the water treated with a liquid-passing-type electric double-layer capacitor desalting system is used as feedwater without being treated with a softening device.

[0025]

The liquid-passing-type electric double-layer capacitor desalting system includes two conductive layers having a large specific surface area, a liquid passage interposed between the conductive layers, and collecting electrodes disposed on the outer surface of the respective conductive layers. Application of a voltage to the collecting electrodes causes the ions contained in raw water to be electrically adsorbed onto the conductive layers. Thus, treated water having a reduced concentration of dissolved salts can be produced. For example, active carbon may be suitably used as the conductive material having a large specific surface area.

[0026]

In the liquid-passing-type electric double-layer capacitor desalting system, ionic substances contained in an influent are removed through the following steps. The mechanism will be described with reference to Figs. 1 and 2 taking, as an example, the case where the ionic substance contained in the influent is sodium chloride and the conductive material having a large specific surface area is active carbon.

[0027]

As shown in Fig. 1, in a voltage application step, sodium ions contained in the influent are electrically adsorbed onto an active-carbon layer 2 that is in contact

with a cathode-side collecting electrode 1, and chloride ions are electrically adsorbed onto an active-carbon layer 4 that is in contact with an anode-side collecting electrode 3. Thus, treated water drained through an outlet has a markedly reduced concentration of sodium chloride. After a long period of several hours of passing water, the adsorption of the ions onto the active-carbon layers 2 and 4 becomes nearly saturated, which increases the concentration of sodium chloride contained in the treated water drained through the outlet. Thus, if the anode-side and cathode-side are short-circuited or exchanged with each other prior to adsorption saturation, the sodium ions and the chloride ions adsorbed on the active-carbon layers 2 and 4, respectively, are desorbed and an effluent containing sodium chloride at a concentration far higher than the concentration of sodium chloride contained in the influent is drained through the outlet as shown in Fig. 2. The sodium chloride adsorbed on the active-carbon layers 2 and 4 can be drained using a small amount of water flow by reducing the flow rate at this time.

[0028]

In the present invention, the above-described liquid-passing-type electric double-layer capacitor desalting system is used for producing boiler feedwater.

[0029]

In the liquid-passing-type electric double-layer capacitor desalting system, since a desalting step and a draining step are alternately repeated in its electrode section as described above, it is impossible to produce desalted water during the draining step. If there is a need to continuously produce treated water, a plurality of liquid-passing-type electric double-layer capacitors may be installed and the operation timing may be controlled so as to maintain a necessary amount of treated water.

[0030]

Examples of raw water that is treated in the present invention include any water such as well water, tap water, river water, industrial water, recycled wastewater, and sewage.

[0031]

The first aspect of the present invention is specifically described below with reference to Fig. 3.

[0032]

Fig. 3 is a system diagram illustrating an embodiment of the first aspect of the present invention. Raw water is firstly introduced into a liquid-passing-type electric double-layer capacitor desalting system 11 and treated to remove cations such as sodium ions, calcium ions, and magnesium ions and anions such as chloride ions, sulphate ions, and phosphate ions. The liquid-passing-type electric

double-layer capacitor desalting system 11 is capable of removing at least several tens of percent of the amount of ions contained in the raw water, which reduces the ion load of the following softening device 12 to be an ion load in the range of one tenth thereof to one hundredth thereof. Consequently, the amount of sodium chloride used for replenishing the softening device 12 is also reduced to be an amount of sodium chloride in the range of one tenth thereof to one hundredth thereof. In addition, the concentration of salts brought into the boiler water as a result of water treated with the softening device 12 being supplied to a boiler 14 through a feedwater tank 13 can be markedly reduced. Furthermore, an increase in electric conductivity due to the dissolved salts can also be markedly suppressed. This allows the amount of blowdown water to be markedly reduced, which reduces the amounts of water and heat drained due to blowdown and the amount of water supplied to a boiler which is used for generating a predetermined amount of steam. As a result, the amount of water to be treated with the liquid-passing-type electric double-layer capacitor desalting system 11 and the softening device 12 can be advantageously reduced, which further reduces the amount of sodium chloride used for replenishing the softening device. Moreover, the amount of water to be supplied to the boiler 14 is reduced, which also reduces the

amount of water treatment chemicals to be added to feedwater at a predetermined concentration. In addition, since the concentration of the boiler water is increased due to the reduction in blowdown, the concentration of the water treatment chemicals, which are to be added to the boiler water at a predetermined concentration in order to suppress corrosion and formation of scale in the boiler, can be reduced compared with the ordinary concentration. Addition of the water-soluble polymer including a carboxyl group in its molecule to the feedwater suppresses formation of scale in the boiler caused by a trace amount of hard component contained in the feedwater, which realizes a water treatment in which heat-transfer loss, occurrence of corrosion at the lower portion of the scale, and the like are suppressed.

[0033]

In the first aspect, the water collection rate of the liquid-passing-type electric double-layer capacitor desalting system is preferably about 80% to 95%, and the dissolved salt removal rate thereof is preferably about 70% to 90%. An excessively low water collection rate of the liquid-passing-type electric double-layer capacitor desalting system results in an increase in the amount of raw water used. If the water collection rate is excessively high, the dissolved salts cannot be removed by a sufficient degree. An excessively low dissolved salt removal rate of

the liquid-passing-type electric double-layer capacitor desalting system increases the ion load of the following softening device, which increases the frequency of replenishment of the softening device. An excessively high dissolved salt removal rate of the liquid-passing-type electric double-layer capacitor desalting system results in an increase in the amount of electric power used, which reduces cost-effectiveness.

[0034]

Fig. 4 is a system diagram illustrating an embodiment of the second aspect of the present invention. Raw water is passed through a liquid-passing-type electric double-layer capacitor desalting system 21. The resulting treated water, in which the amount of dissolved ions has been reduced to an amount of dissolved ions in the range of one tenth thereof to one hundredth thereof, is directly supplied to a feedwater tank 22 without being passed through a softening device. The feedwater tank 22 is also supplied with collected steam condensation water (drain). A certain amount of a water-soluble polymer including a carboxyl group in its molecule, which is proportional to the amount of water treated with the liquid-passing-type electric double-layer capacitor desalting system 21, is added to water contained in the feedwater tank 22. Then, the resulting water is supplied to a boiler. In this embodiment, a

softening device is not used, which allows the equipment to be simple and eliminates the need for sodium chloride used for replenishing the softening device. Moreover, the concentration of salts brought into a boiler is markedly reduced compared with the case where raw water is treated with a softening device only, and therefore the amount of blowdown can be reduced. As a result, the amounts of heat and water drained and the content of water treatment chemicals are reduced. In addition, since the amount of feedwater is reduced, the amount of water treatment chemicals to be added is also reduced. Iron that is eluted from a heat exchanger or a pipe and contained in steam condensation water, which is collected as feedwater, can be drained effectively by blowdown due to the effects of hard components contained in water treated with the liquid-passing-type electric double-layer capacitor desalting system 21 and the water-soluble polymer including a carboxyl group in its molecule, which is added therein. Thus, adhesion of scale onto a heating surface caused by iron being brought into the boiler can be effectively suppressed. [0035]

In the second aspect, the liquid-passing-type electric double-layer capacitor desalting system preferably has a water collection rate of about 80% to 95% and a dissolved salt removal rate of about 70% to 90%. An excessively low

water collection rate of the liquid-passing-type electric double-layer capacitor desalting system increases the amount of raw water used. An excessively high water collection rate results in an insufficient removal of the dissolved salts. An excessively low dissolved salt removal rate of the liquid-passing-type electric double-layer capacitor desalting system results in the need for increasing the amount of blowdown water. An excessively high dissolved salt removal rate of the liquid-passing-type electric double-layer capacitor desalting system results in an insufficient effect of suppressing the formation of iron scale, which is produced by calcium contained in water treated with the liquid-passing-type electric double-layer capacitor desalting system.

Thus, it is preferable to leave a certain amount of calcium so that the concentration of calcium in the boiler feedwater is about 0.1 to 10 mg-CaCO₃/L by appropriately controlling the dissolved salt removal rate of the liquid-passing-type electric double-layer capacitor desalting system.

[0036]

Examples of the water-soluble polymer including a carboxyl group in its molecule used in the present invention include a homopolymer, a copolymer, or a terpolymer of carboxylic acids and/or salts thereof such as acrylic acid

and/or a salt thereof, maleic acid and/or a salt thereof, itaconic acid and/or a salt thereof, and methacrylic acid and/or a salt thereof; a copolymer of 2-hydroxy-3-allyloxypropanesulfonic acid and/or a salt thereof and the above-described carboxylic acid and/or a salt thereof; a copolymer of 2-acrylamido-2-methylpropanesulfonic acid and/or a salt thereof and the above-described carboxylic acid and/or a salt thereof; bis(poly-2-carboxyethyl)phosphinic acid and/or a salt thereof; and carboxymethylcellulose. Examples of the salts of the above-described carboxylic acids, sulfonic acids, and phosphinic acids include alkali metal salts such as a sodium salt and a potassium salt.

In particular, a homopolymer of sodium acrylate is preferably used as the water-soluble polymer including a carboxyl group in its molecule.

[0037]

The weight-average molecular weight of the water-soluble polymer including a carboxyl group in its molecule is preferably 1000 to 100000 and is more preferably 1500 to 50000. If the molecular weight is excessively large, a gelled product may be formed due to bonding between the water-soluble polymer and calcium, which poses a risk of clogging in a strainer or the like. The water-soluble polymer having an excessively small molecular weight may not

be able to exert its full effect.

[0038]

The amount of the water-soluble polymer including a carboxyl group in its molecule to be added is preferably controlled so as to be 0.5 to 10 times and more desirably equal to or more and 5 times or less the concentration of calcium contained in the boiler feedwater. When the concentration of the water-soluble polymer is less than the above lower limit, the effect of dispersing iron brought from the steam condensation water-collection line is reduced, which results in an increase in the amount of adhered scale. When the concentration of the water-soluble polymer is more than the above upper limit, the effect of preventing the hard component contained in water treated with the liquid-passing-type electric double-layer capacitor desalting system from adhering to the inside of a boiler as scale may fail to be exerted at full.

[0039]

In the present invention, the above-described water-soluble polymer may be used in combination with an alkali chemical commonly used as a water treatment chemical (e.g., NaOH, KOH, K_2CO_3 , and Na_2CO_3), a deoxidizer (e.g., hydrazine, tannine, tannic acid and/or a salt thereof, erythorbic acid and/or a salt thereof, ascorbic acid and/or a salt thereof, and glucose), a corrosion inhibitor (e.g., gluconic acid

and/or a salt thereof, glucoheptonic acid and/or a salt thereof, succinic acid and/or a salt thereof, citric acid and/or a salt thereof, and tartaric acid and/or a salt thereof), phosphoric acid and/or a salt thereof, polyphosphoric acid and/or a salt thereof, or phosphonic acid and/or a salt thereof.

EXAMPLES

[0040]

The present invention is described more specifically with reference to the following Examples and Comparative Examples.

[0041]

The raw water treated in the following Examples and Comparative Examples was tap water of Nogi-machi, Tochigi prefecture, Japan, which had the following water quality.

<Raw Water Quality>

Electric conductivity: 25 mS/m

M alkalinity: 23 mg-CaCO₃/L

Silica: 18 mg/L

Ca hardness: 30 mg-CaCO₃/L

Mg hardness: 15 mg-CaCO₃/L

[0042]

[Comparative Example 1]

Nogi-machi water was passed through a softening device including 18 L of a cation-exchange resin, and the resulting

treated water was charged to a feedwater tank. While a water treatment chemical, that is, 30 mg/L of sodium erythorbate serving as a deoxidizer, and 27 mg/L of NaOH serving as an alkali chemical, such that the P alkalinity of the boiler water became 1.7 times the silica concentration in the boiler water, were added to the treated water, the treated water was supplied to an experimental boiler at 0.450 m³/h. The boiler was operated for 10 days at a pressure of 0.7 MPa while blowdown was performed so that the electric conductivity of the boiler water became 300 mS/m.

The blowdown frequency rate was 13.5% on average and the amount of evaporation was 0.39 ton/h. Replenishment of the softening device was performed 6 times during the examination, and the amount of sodium chloride used for the replenishment was 13.8 kg.

[0043]

[Comparative Example 2]

Nogi-machi tap water was treated with a softening device as in Comparative Example 1. Subsequently, the resulting treated water was passed through a reverse osmosis membrane system that was operated at a water collection rate of 80% (at that time, the dissolved salt removal rate was 98% on average). The water treated with the reverse osmosis membrane system was charged to a feedwater tank. While a water treatment chemical, that is, 30 mg/L of sodium

erythorbate serving as a deoxidizer, and 19 mg/L of NaOH serving as an alkali chemical, which was determined so that the boiler water had a pH of 11.5 and an electric conductivity of 300 mS/m at a blowdown frequency rate of 3.0%, were added to the treated water, the treated water was supplied to an experimental boiler. The boiler was operated for 10 days at a pressure of 0.7 MPa.

The amount of evaporation was 0.39 t/h. The amount of water supplied to the boiler was 0.401 m³/h and the flow rate of raw water was 0.501 m³/h on average. Replenishment of the softening device was performed 7 times during the examination, and the amount of sodium chloride used for the replenishment was 16.1 kg.

[0044]

[Example 1]

Nogi-machi tap water was passed through a liquid-passing-type electric double-layer capacitor desalting system that was operated at a water collection rate of 90% (at that time, the dissolved salt removal rate was 80% on average). The water treated with the liquid-passing-type electric double-layer capacitor desalting system was then passed through a softening device as in Comparative Example 1, and the resulting treated water was charged to a feedwater tank. While a water treatment chemical, that is, 30 mg/L of sodium erythorbate serving as a deoxidizer, and

17 mg/L of NaOH serving as an alkali chemical, such that the P alkalinity of the boiler water became 1.7 times the silica concentration in the boiler water, were added to the treated water, the treated water was supplied to an experimental boiler. The boiler was operated for 10 days at a pressure of 0.7 MPa while blowdown was performed so that the electric conductivity of the boiler water became 300 mS/m.

The blowdown frequency rate was 3.0% on average and the amount of evaporation was 0.39 t/h. The amount of water supplied to the boiler was 0.401 m³/h and the flow rate of raw water was 0.446 m³/h on average. Replenishment of the softening device was performed once during the examination, and the amount of sodium chloride used for the replenishment was 2.3 kg.

[0045]

The results of Comparative Examples 1 and 2 and Example 1 above show the following.

In Example 1, in which a treatment was performed using a liquid-passing-type electric double-layer capacitor desalting system and a softening device, the amount of water used was reduced by about 1 m³, the amount of sodium chloride used was reduced by 11.5 (= 13.8 - 2.3) kg, and the amount of fuel, that is, A-heavy oil, was reduced by 2.5% compared with Comparative Example 1 in which a treatment was performed using a softening device only. Furthermore, in

Example 1, the amount of water used was reduced by 132 (= $(0.501 - 0.446) \times 24 \times 10$) m³ and the amount of sodium chloride used was reduced by 13.8 (= 16.1 - 2.3) kg compared with Comparative Example 2 in which a treatment was performed using a softening device and a reverse osmosis membrane system, and the amount of fuel used was substantially equal to that of Comparative Example 2.

[0046]

[Examples 2 to 7]

Nogi-machi tap water was passed through a liquid-passing-type electric double-layer capacitor desalting system that was operated at a water collection rate of 90% (at that time, the dissolved salt removal rate was 80% on average). The water treated with the liquid-passing-type electric double-layer capacitor desalting system was then passed through a softening device to replace Ca ions and Mg ions contained in the treated water with Na ions, and the resulting treated water was charged to a feedwater tank having a volume of 10 L. Water simulating the steam condensation water collected in the feedwater tank, which was prepared by adding ferric chloride to purified water heated to 90°C at an iron concentration of 2 mg/L under the assumption that elution of iron occurred during the collection line, was supplied to the feedwater tank at 4 L/h. While a water treatment chemical, that is, 10 mg/L of

succinic acid serving as a corrosion inhibitor, the water-soluble polymer shown in Table 1 at the concentration shown in Table 1, and 13 mg/L of NaOH serving as an alkali chemical, such that the P alkalinity of the boiler water became 1.7 times the silica concentration in the boiler water, were added to water supplied from the feedwater tank, the treated water was supplied to a stainless test boiler having a volume of 5 L. The boiler was operated at a pressure of 0.7 MPa, an evaporation rate of 8 L/h, and a blowdown frequency rate of 5%.

After being continuously operated for one week, the boiler was stopped and heating tubes (composed of stainless steel, surface area: $200\text{ cm}^2 \times 3\text{ tubes}$) were removed from the boiler. Adhesion of a large amount of reddish brown scale was observed. The scale was scratched off, and the amount of scale adhered was measured. Table 1 shows the results.

[0047]

[Examples 8 to 19]

The boiler was operated under the same condition as in Example 2, except that the softening device used in Example 2 was removed and the water-soluble polymer shown in Table 1 was added as a water-soluble polymer at the concentration shown in Table 1. After the boiler was continuously operated for one week, the amount of adhesion to the heating tube was measured as in Example 2. Table 1 shows the

results.

[0048]

In Examples 1 to 17, the calcium concentration in water treated with the liquid-passing-type electric double-layer capacitor desalting system was 6 mg-CaCO₃/L. In Examples 2 to 7, in which the water treated with the liquid-passing-type electric double-layer capacitor desalting system was further treated with a softening device and used as boiler feedwater together with the above-described water simulating collected condensation water, the calcium concentration in the boiler feedwater was less than 0.1 mg-CaCO₃/L. In Examples 8 to 19, in which the water treated with the liquid-passing-type electric double-layer capacitor desalting system was used as boiler feedwater together with the above-described water simulating collected condensation water without being treated with a softening device, the calcium concentration in the boiler feedwater was 3 mg-CaCO₃/L.

Table 1 shows the ratio of the added polymer concentration to the calcium concentration in the boiler feedwater in Examples 2 to 19.

[0049]

[Table 1]

	Use of softening device	Water-soluble polymer		Ratio of water-soluble polymer concentration to calcium concentration in boiler feedwater	Amount adhered to heating tube (mg/200cm ²)
		Type	Additive concentration in boiler feedwater (mg/L)		
Example 2	Yes	A	3	1	262
Example 3	Yes	A	6	2	229
Example 4	Yes	A	15	5	231
Example 5	Yes	A	30	10	255
Example 6	Yes	B	6	2	248
Example 7	Yes	C	6	2	211
Example 8	No	A	1.5	0.5	103
Example 9	No	A	3	1	18
Example 10	No	A	6	2	<10
Example 11	No	A	15	5	<10
Example 12	No	A	22.5	7.5	65
Example 13	No	A	30	10	121
Example 14	No	B	6	2	<10
Example 15	No	C	6	2	10
Example 16	No	D	6	2	15
Example 17	No	E	6	2	28
Example 18	No	F	6	2	12
Example 19	No	G	6	2	31

[0050]

[Table 2]

Table 2 shows the water-soluble polymers A to G shown in Table 1.

Type	Compound name	Molecular weight
A	Sodium polyacrylate	4000
B	Sodium polyacrylate	50000
C	Sodium polymaleate	10000
D	Polyacrylic acid-sodium 2-hydroxy-3-allyloxypropanesulfonate (AA-HAPS)	2800
E	Polyacrylic acid-sodium 2-acrylamido-2-methylpropanesulfonate (AA-AMPS)	10000
F	Sodium polybis(poly-2-carboxylethyl)phosphinate	1500
G	Carboxymethylcellulose	25000

[0051]

The results of Examples 2 to 19 shown in Table 1 show that, in the case where steam condensation water is collected and reused, it is possible to continuously, stably operate a boiler while scale defects are suppressed by adding a certain a specific amount of a water-soluble polymer including a carboxyl group in its molecule, without using a softening device but using only a liquid-passing-type electric double-layer capacitor desalting system.

[0052]

The present invention is described in detail with reference to the specific aspects thereof. It will be apparent to those skilled in the art that various modifications can be made without departing from the spirit and scope of the present invention.

This application is based on Japanese Patent Application 2011-201947, filed on September 15, 2011, which is hereby incorporated by reference herein in its entirety.

CLAIMS

1 A water treatment method for producing feedwater to be supplied to a steam-generating device, the method comprising the steps of:

passing raw water through a liquid-passing-type electric double-layer capacitor desalting system to produce treated water without using a softening device;

mixing the treated water and steam condensation water to produce feedwater; and

adding a water-soluble polymer including a carboxyl group in its molecule to the feedwater.

2 The water treatment method according to Claim 1, wherein the amount of the water-soluble polymer including a carboxyl group is, by weight, equal to or more and 5 times or less the amount of calcium contained in the feedwater to be supplied to the steam-generating device.

3 The water treatment method according to Claim 1 or 2, wherein the water-soluble polymer including a carboxyl group is at least one compound selected from the group consisting of a homopolymer, a copolymer, and a terpolymer of carboxylic acid and/or a salt thereof, such as acrylic acid and/or a salt thereof, maleic acid and/or a salt thereof,

itaconic acid and/or a salt thereof, or methacrylic acid and/or a salt thereof; a copolymer of 2-hydroxy-3-allyloxypropanesulfonic acid and/or a salt thereof and the carboxylic acid and/or a salt thereof; a copolymer of 2-acrylamido-2-methylpropanesulfonic acid and/or a salt thereof and the carboxylic acid and/or a salt thereof; bis(poly-2-carboxyethyl)phosphinic acid and/or a salt thereof; and carboxymethylcellulose.

4 The water treatment method according to Claim 1 or 2, wherein the water-soluble polymer including a carboxyl group is a homopolymer of sodium acrylate.

5 The water treatment method according to Claim 1 or 2, wherein the water-soluble polymer including a carboxyl group is polyacrylic acid-sodium 2-hydroxy-3-allyloxypropanesulfonate, polyacrylic acid-sodium 2-acrylamido-2-methylpropanesulfonate, sodium polybis(poly-2-carboxylethyl)phosphinate, or carboxymethylcellulose.

6 The water treatment method according to Claim 1 or 2, wherein the raw water is well water, tap water, or river water.

7 The water treatment method according to Claim 1 or 2, wherein a dissolved salt removal rate of the liquid-passing-type electric double-layer capacitor desalting system is 70% to 90%.

8 A water treatment method for producing feedwater to be supplied to a steam-generating device, the method comprising the steps of:

passing raw water through a liquid-passing-type electric double-layer capacitor desalting system; and

passing water treated with the desalting system through a softening device.

9 The water treatment method according to Claim 8, wherein the raw water is well water, tap water, or river water.

10 The water treatment method according to Claim 8 or 9, wherein a dissolved salt removal rate of the liquid-passing-type electric double-layer capacitor desalting system is 70% to 90%.