

MEMBRANE SEPARATION METHOD AND APPARATUS EQUIPPED WITH PARTICLE FRACTIONATOR

TECHNICAL FIELD

5 [0001] The present invention relates to a method and apparatus for membrane separation to treat raw water for drinking water and various kinds of wastewater such as domestic sewage and industrial wastewater.

BACKGROUND ART

10 [0002] Membrane separation process has been widely used in the field of drinking water and wastewater treatments. For drinking water treatment, coagulants are added to the raw water, and membrane filtration is applied, to remove contaminants and pathogen such as *Cryptosporidium*.

[0003] On the other hand, activated sludge process has been commonly used for wastewater treatment. Wastewater is contacted with activated
15 sludge, and microorganisms in the sludge consume dissolved substances, to purify the wastewater. Activated sludge is separated from treated water by sedimentation or the like after treatment process. Membrane process is applied to an effluent of activated sludge process to remove contaminants and pathogen.

20 [0004] Furthermore, membrane bioreactor (MBR) is widely used in which activated sludge process and membrane separation process are combined. In the MBR system, a stable separation of sludge can be achieved regardless of sludge conditions. And it also has an advantage of reduction of footprint of the reactor.

25 SUMMARY OF THE INVENTION

[0005] It is important for membrane separation process to minimize membrane fouling. It becomes impossible to obtain a sufficient amount of treated water and life time of membrane is reduced by membrane fouling which results in a higher operation cost. Main components of foulants, for
30 example, in MBR system is believed to be colloids and submicron-particles.

Colloid involves metabolic substances released from microorganisms.

[0006] Release of metabolic substances can be suppressed by maintaining conditions of microorganisms well, but it is difficult to keep conditions when feed water quality is rapidly changed.

5 [0007] Colloids and submicron-particles composed of organic and/or inorganic substances can be removed by adding coagulant to MBR system. It results, however, in a higher operation cost.

[0008] US Patent 9,242,882 B2 describes a method to remove colloids and smaller particles from microorganism process by using a gravity separator
10 and describes a possibility of suppression of membrane fouling. This patent, however, does not show data for removal rate of colloids and smaller particles in the membrane separation process by using the gravity separator. It is not clear from this patent whether it is necessary to reduce colloids and/or smaller particles or both of them to suppress membrane fouling.

15 [0009] Furthermore, US Patent 9,242,882 B2 describes a method to extract sludge from a bioprocess and separate larger particles with superior settling characteristics and return them to the bioprocess. It describes that residuals after separating larger particles are rejected or supplied to solid process. In this case, when the amount of extracted sludge is increased, the
20 concentration of microorganisms in bioprocess will be decreased and activity of the process will be reduced. This also results in decrease of production rate of treated water in membrane filtration process. Furthermore, it takes a long period of time to achieve suppression of membrane fouling with this method, because the rate of sludge extraction is limited in order to retain
25 concentration of sludge in a biological treatment process.

[0010] It is therefore an object of the present invention to effectively suppress membrane fouling in a membrane separation process.

[0011] The present invention provides a membrane separation method and a device equipped with a particle fractionator, which selectively removes
30 submicron-particles from water to suppress membrane fouling.

[0012] Analysis of foulants in a membrane separation device was carried out in detail and it was revealed that membrane fouling can be suppressed by removing submicron-particles and retaining larger particles even without removing colloids from water in the membrane separation device.

5 [0013] According to the present invention, there is provided an apparatus for water treatment, including a membrane separator for solids-liquid separation; and a particle fractionator which has at least two exits of a fractionated solid-liquid mixture produced therein, wherein a liquor containing particles of different sizes including submicron particles is fed to
10 the particle fractionator before a membrane separation by the membrane separator, and wherein a first fraction of the fractionated solid-liquid mixture is returned to the membrane separator from one exit of the at least two exits of the particle fractionator, the first fraction being less than the liquor in terms of content or proportion of the submicron particles.

15 [0014] The present invention enables to minimize the amount of reject water with removal of submicron particles from a membrane separation device by returning larger particles and residual water after selectively removing submicron-particles for suppression of membrane fouling. This results in increase of production rate in the membrane separation device.

20 [0015] Furthermore, the present invention enables to minimize the amount of reject water even if increasing the amount of draw water from membrane separation device to the particle fractionator. Increase in the amount of draw water from the membrane separation device results in increase in removal rate of sub-micron particles. This enables a rapid suppression of
25 membrane fouling.

[0016] Although Examples which will be shown below are examples for MBR system, the present invention can be applied to not only MBR system but also any membrane separation process to treat water containing sub-micron particles, larger particles and foulants such as colloids.

30 **ADVANTAGEOUS EFFECT OF THE INVENTION**

[0017] The present invention enables to minimize the amount of reject water from membrane separation process by returning larger particles and residual water after removing submicron-particles for suppression of membrane fouling. This results in increase of production water by the
5 membrane filtration process and increase of recovery rate.

[0018] Furthermore, the present invention enables to minimize the amount of reject water even if increasing the amount of feed from membrane separation process to the particle fractionator with a high rate of draw water to the membrane system. This enables a rapid removal of sub-micron
10 particles from membrane separation process and a rapid achievement of suppression of membrane fouling.

BRIEF DESCRIPTION OF THE DRAWING

[0019]

- Fig. 1 is a schematic diagram for Example 1;
- 15 Fig. 2 is a schematic diagram for Example 2;
- Fig. 3 is a schematic diagram for Example 3;
- Fig. 4 is a schematic diagram for Comparative Example;
- Fig. 5 is a graph showing a variation in TMP in the membrane filtration process in Example 1;
- 20 Fig. 6 is a graph showing a variation in TMP in the membrane filtration process in Comparative Example;
- Fig. 7 is a graph showing measurement results of particle size distribution for inlet, underflow outlet and upper flow outlet of the particle fractionator in Example 1; and
- 25 Fig. 8 is a graph showing a variation in colloidal TOC (total organic carbon) before and after starting the particle fractionator in Example 1.

DETAILED DESCRIPTION

[0020] Detail of the present invention will be described with explanation of Examples below.

30 [0021] Figure 1 shows a flow diagram of membrane separation process

equipped with a particle fractionator which selectively removes submicron-particles in water according to Example 1. The membrane separation device includes the reaction tank 2, membrane tank 3 and recirculation tank 6.

5 [0022] Influent 1 is supplied to a reaction tank 2, and then goes to a membrane tank 3. In the reaction tank 2, a biological process using activated sludge was used for Example 1. Treatment process for the reactor 2 can be selected from biological process with activated sludge, coagulation process, oxidation process such as ozonation, combination of these processes,
10 or any other process required for pretreatment before membrane separation process.

[0023] Production water 5 can be obtained as a permeate from a membrane module 4 in the membrane tank 3. Production water 5 is applied to post treatment and is supplied as drinking water for water treatment system.
15 Production water 5 is applied to post treatment, if necessary, and reused as reclaimed water or discharged as treated water in treatment system for domestic sewage and industrial wastewater.

[0024] UF membrane with a nominal pore size of 0.04 μm was used as membrane module 4 in the membrane tank 3. MF membrane, UF
20 membrane, NF membrane or a combination of these membranes can be used as membrane module 4. Both types of submerged-type and pressurized-type can be used as membrane module 4. When pressurized-type is used, a combined system of modules is used instead of membrane tank 3.

25 [0025] Unfiltered water in membrane tank 3 is supplied to the return tank 6, and draw water 8 from the recirculation tank 6 is fed to a particle fractionator 9 by using a pump 7 in the return tank 6. Draw water 8 can be directly taken from the membrane tank 3 without using the recirculation tank 6. Draw water 8 can be also taken from the reaction tank 2 when a

recirculation flow line is applied between the reaction tank 2 and the membrane tank 3.

[0026] Sub-micron particles in draw water 8 are fractionated into first fraction 10. Residual particles after fractionating sub-micron particle are
5 contained in second fraction 11. The second fraction 11 contains larger particles. It is not necessary to fractionate sub-micron particles completely into the first fraction 10, and the second fraction 11 can contain both larger particles and sub-micron particles. The first fraction 10 is rejected from the membrane filtration system. The second fraction 11 is return to the
10 reaction tank 2.

[0027] The concentration of sub-micron particles in the membrane separation device can be reduced by removing sub-micron particles in the first fraction 10. Consequently, larger particles can be retained in the membrane separation device.

15 [0028] Hydrocyclone was used as the particle fractionator in validation test for Example 1. As the hydrocyclone of the present invention, a known one such as described in US Pat. No. 9,242,882 B2 or a modified one thereof can be used. Herein, the particle fractionator is a device for conducting particle fractionation by wet classification. Its method is classified into
20 gravitational classification using the sedimentation speed difference of particles, centrifugal classification using the sedimentation speed difference in centrifugal field, and similar classifications. As the particle fractionator, it is possible to cite a hydrocyclone or centrifugal classifier using centrifugal classification, a hydroseparator or decanter using gravitational classification,
25 etc. These can be used singly or in combination as the particle fractionator.

[0029] Suppression of membrane fouling can be achieved effectively by retaining larger particles with the particles fractionator. When concentration of sub-micron particles in the membrane tank is reduced, membrane fouling can be suppressed by avoiding sub-micron particles to
30 enter membrane pores. Furthermore, when larger particles become

predominant in the membrane tank, a cake layer is formed predominantly with these larger particles on the surface of membrane and this cake layer prevents colloids and smaller particles from entering into membrane pores. Thus, membrane fouling can be suppressed effectively even when colloids
5 remain in the membrane tank. Example 2 is a membrane separation device equipped with a particle fractionator in which particles are fractionated into three fractions instead of two fractions as is for Example 1. Figure 2 shows a flow diagram for Example 2. The flow diagram for Example 2 is as same as that for Example 1 except draw water is fractionated into three fractions
10 by the fractionator.

[0030] Draw water 8 from recirculation tank 6 is fractionated into first fraction 10, second fraction 11 and third fraction 12 in the fractionator 9. Sub-micron particles are predominately in the third fraction 12. Larger particles are contained in the second fraction 11. The first fraction 10 is
15 residual of the second and third fractions and it contains much less particles. The third fraction 12, in which sub-micron particles are contained, is rejected from the membrane separation device. The second fraction 11 and first fractions 10 are returned to the reaction tank 2, thus larger particles are retained in the membrane separation device.

20 [0031] Three-phase hydrocyclone can be used as the particle fractionator which can divide particles into three fractions. In a two-phase hydrocyclone, up flow is formed in the center and down flow is generated around the inner wall. Larger particles are fractionated into the down flow and come out from the bottom of the hydrocyclone, and residual particles are contained in
25 the up flow and come out as over flow from the top.

[0032] In three-phase hydrocyclone, which is utilized in Example 2, piping is installed in the up flow of the hydrocyclone. Particles in middle range with size are fractionated into this piping and can be taken as the third fraction. Sub-micron particles can be fractionated into the middle flow of
30 the three-phase hydrocyclone and rejected from the device.

[0033] By returning the second fraction containing larger particles and the first fraction as residual of the second fraction containing sub-micron particles to the membrane separation device, it is possible to make the ratio of the amount of return water to the draw water larger than that for

5 Example 1. This results in reduction of the amount of reject and increase in the amount of product water from the membrane separation device.

[0034] Furthermore, Example 2 enables to minimize the amount of reject water even if increasing the amount of draw water from the membrane separation device to the particle fractionator. Increase in the amount of
10 draw water from the membrane separation device results in increase in removal rate of sub-micron particles from the membrane separation device. This enables achievement of suppression of membrane fouling in a short period.

[0035] Figure 3 shows a flow diagram for Example 3 in which the
15 membrane separation device is equipped with two particle fractionators.

[0036] The flow diagram for Example 3 is as same as that for Example 1 except draw water is fractionated by using two particle fractionators.

[0037] Draw water 8 from recirculation tank 6 is fractionated into first fraction 10 and second fraction 11 by using the particle fractionator 9.
20 Sub-micron particles are predominantly contained in the first fraction 10 and larger particles are contained in the second fraction 11. The second fraction 11 is returned to the reaction tank 2. The first fraction 10 is further fractionated into the third fraction 15 and the fourth fraction 16. Sub-micron particles in the first fraction 10 are predominantly fractionated into the third
25 fraction 15 by using the particle fractionator 14.

[0038] The residual becomes the fourth fraction 16, and the fourth fraction 16 contains almost no particles. The third fraction 15 containing sub-micron particles is rejected from the membrane separation device, and the fourth fraction 16 is returned to the reaction tank 2.

30 [0039] Furthermore, chemicals such as coagulant can be added to the first

fraction 10 before feeding to the particle fractionator 14 as shown in the flow diagram for Example 3 in Fig. 3. Particles in the first fraction 10 can be easily fractionated by fractionator 14 by adding coagulant to the first fraction 10. Coagulant, flocculent and other chemicals can be used for this purpose.

[0040] By returning the second fraction 11 containing larger particles and the fourth fraction 16 as residual of the second fraction 11 containing sub-micron particles to the membrane separation device, it is possible to make the ratio of the amount of return water to the draw water larger than that for Example 1. This results in reduction of the amount of reject and increase in the amount of product water from the membrane separation device.

[0041] Furthermore, as same as Example 2, Example 3 enables to minimize the amount of reject water even if increasing the amount of draw water from the membrane separation device to the particle fractionator. Increase in the amount of draw water from the membrane separation device results in increase in removal rate of sub-micron particles from the membrane separation device. This enables achievement of suppression of membrane fouling in a short period. Figure 4 shows a flow diagram for Comparative Example.

[0042] The flow diagram for Comparative Example is as same as that for Example 1 except that draw water 8 is divided into return water 16 and reject 17 without using a particle fractionator. Particles in the draw water 8 are divided according to the ratio of the return water 16 to reject 17. Therefore, the ratio of sub-micron particles to larger particles is same in the return water 16 and reject 17. Thus, particle distribution in the membrane separation device does not change even by separating draw water 8 into return water 16 and reject 17.

[0043] Test data will be shown below to verify the effectiveness of the method by Example 1 as compared with data by Comparative Example.

[0044] Biological process with activated sludge was used for the process in the reaction tank 2, and membrane separation process with UF membrane was utilized in the membrane tank 3 for Example 1. A submerged-type UF membrane with nominal pore size of 0.04 μm was used for the testing.

5 Hydrocyclone was used as a particles fractionator 9. The volumes of the reaction tank 2 and the membrane tank 3 were 400 m^3 and 50 m^3 , respectively. Draw water 8 was taken from the membrane tank 3 at the average rate of 36 m^3/day to keep the concentration of the activated sludge in the reaction tank at 2,000 mg/L . When the rate of the draw water is larger
10 than this value, the sludge concentration will decrease which results in reduction of rate of the biological process.

[0045] Draw water 8 was supplied to the hydrocyclone, and up flow was taken from the top of the hydrocyclone and rejected as the first fraction 10. The residual was taken from the down flow of the hydrocyclone and returned
15 to the reaction tank 2 as the second fraction 11. It was required to make the ratio of the amount of the first fraction 10 to the second fraction 11 to be 1:4 to maintain the sludge concentration in the reaction tank 2 at a proper value. Thus, 20 % of the draw water 8 was discarded from the membrane separation device, and the rate of the reject was 36 m^3/day in average. The
20 reject was fed to the sludge digestion process.

[0046] Figure 5 shows changes in TMP (Trans Membrane Pressure) during verification testing for Example 1. Hydrocyclone was used as a particle fractionator and was started on the 14th day. TMP was increased from beginning to 49th days, then was kept almost constant after 49th days.
25 Thus, TMP became constant after about 35 days from starting of the hydrocyclone which indicates membrane fouling was suppressed during this period. Operating condition was not changed except starting the hydrocyclone during the test period. From these results, it was verified that membrane fouling is suppressed by using hydrocyclone.

[0047] Figure 6 shows changes in TMP in the case of Comparative Example in which particle fractionator was not used as shown in Fig. 4. It was noticed that TMP was gradually increased from beginning to 50 days. And TMP increased rapidly after 50 days, which indicates that membrane fouling proceeded rapidly. It was shown that TMP increased and membrane fouling proceeded during the test period in Comparative Example. It is concluded from these results that membrane fouling can be suppressed by using hydrocyclone with the membrane separation device.

[0048] Particle size distribution of particles in fractions of the hydrocyclone was measured during the verification testing in Example 1 to examine mechanism of suppression of membrane fouling by hydrocyclone. The particle size distribution measurement was conducted by using a particle size analyzer (trade name: Zetasizer Nano ZS 3600 made by Malvern Co.) through dynamic light scattering. Besides, the concentration variation of colloids in the membrane tank during the testing was examined. The concentration of colloids was determined by the colloidal total organic carbon (TOC), which is the TOC difference between the filtrate TOC of 1.5 μm filter paper and the permeate TOC of 0.04 μm membrane.

[0049] Figure 7 shows the result of measurement for the particle size distribution. There were two large peaks for the draw water from the recirculation tank. One is ranged from 0.03 to 0.2 μm with a peak of 0.1 μm . The other is ranged from 0.3 to 2 μm with a peak of 0.9 μm . Similar peaks were observed for the second fraction 11, down flow of the hydrocyclone. The peak for the larger particles was higher than that for the draw water, which indicates that concentration of the larger particles increased in the second fraction 11 which was returned to the reaction tank.

[0050] Furthermore, the large peak was scarcely observed for the second fraction 11, upper flow of the hydrocyclone, and sub-micron particles ranged

from 0.03 to 0.4 μm with a peak of 0.1 μm was dominant. It is concluded from these results that sub-micron particles were predominantly fractionated into the first fraction 10 by the hydrocyclone and those particles were selectively removed from the membrane separation device with
5 rejecting the first fraction 10 out of the membrane separation device.
[0051] Particle size of the rejected particles by using the hydrocyclone was ranged from 0.03 to 0.4 μm , and this size is slightly smaller or larger than that of the membrane pore which was used in the membrane separation device. It should be noted that the particle size by the laser-scattering
10 meter is approximation value as a sphere particle and the measurement value becomes larger when biding compounds exists on the surface of the particle. For these reasons, particles can be penetrated into the membrane pores even if the measured size of the particle is equal or slightly larger than that of the membrane pores. It is concluded that membrane fouling was
15 suppressed by fractionating sub-micron particles with the hydrocyclone and rejecting those particles from the membrane separation device.
[0052] Figure 8 shows changes in the concentration of colloid in the membrane tank during the same period as the measurement of TMP in Example 1 which was shown in Fig. 5. It is revealed from Fig. 8 that the
20 concentration of colloids varied in a certain range and decrease in the concentration was not observed even after starting operation of the hydrocyclone. Colloids are expected to be one of major foulants in the membrane separation process and it was expected that membrane fouling is suppressed by removing colloids with a hydrocyclone as is described in US
25 Patent 9,242,882 B2. It was revealed, however, that the concentration of colloids in the membrane tank was not changed even after operating the hydrocyclone, and it was verified by the present invention that membrane fouling can be suppressed without reducing colloids in the membrane tank.
[0053] Mechanism for the suppression of fouling even without reduction of

colloids is explained as follows.

[0054] Larger particles become predominant after removing sub-micron particles from the membrane separation device by using hydrocyclone.

When larger particles become predominant in the membrane tank, a cake
5 layer is formed predominantly with these larger particles on the surface of membrane, and this cake layer prevents colloids and smaller particles from entering into membrane pores. Thus, membrane fouling can be suppressed effectively even when colloids remain in the membrane tank.

[0055] Suppression of membrane fouling was achieved only after 35 days
10 from the starting operation of the hydrocyclone as shown in Fig. 5. This time delay is attributed to that the rate of draw water from the membrane tank was limited and it took a long time to remove sub-micron particles from the membrane tank.

[0056] The total volume of the reaction tank and the membrane tank was
15 450 m³, and the rate of the reject from the hydrocyclone was 36 m³/day, as described above. Expected time for removal of the sub-micron particles was 38 days, which was calculated by dividing the total volume by the rate of the reject, and then multiply by three (so-called 3 HRT, hydraulic retention time). The suppression of the fouling was achieved after 35 days from operation of
20 the hydrocyclone, and this duration almost corresponded with the expected value.

[0057] Example 2 and Example 3 were invented to shorten the time lag for suppression of membrane fouling in Example 1. In Example 2, for example,
by returning the second fraction containing larger particles and the first
25 fraction as residual of the second fraction containing sub-micron particles to the membrane separation device, the ratio of the amount of return water to the draw water becomes larger than that of Example 1. This results in reduction of the amount of reject and increase in the amount of product water from the membrane separation device. Furthermore, Example 2
30 enables to minimize the amount of reject water, even if increasing the

amount of draw water from membrane separation device to the particle fractionator. Increase in the amount of draw water from the membrane separation device results in increase in removal rate of sub-micron particles from the membrane separation device. This enables achievement of

5 suppression of membrane fouling in a short period of time.

CLAIMS

1. An apparatus for water treatment, comprising:
 - a membrane separator for solids-liquid separation; and
 - 5 a particle fractionator which has at least two exits of a fractionated solid-liquid mixture produced therein,
 - wherein a liquor containing particles of different sizes including submicron particles is fed to the particle fractionator before a membrane separation by the membrane separator, and
 - 10 wherein a first fraction of the fractionated solid-liquid mixture is returned to the membrane separator from one exit of the at least two exits of the particle fractionator, the first fraction being less than the liquor in terms of content of the submicron particles.
- 15 2. An apparatus for water treatment, comprising:
 - a membrane separator for solids-liquid separation;
 - a first particle fractionator which has at least two exits of a first fractionated solid-liquid mixture produced therein; and
 - a second particle fractionator which has at least two exits of a second
 - 20 fractionated solid-liquid mixture produced therein,
 - wherein a liquor containing particles of different sizes including submicron particles is fed to the first particle fractionator before a membrane separation by the membrane separator,
 - wherein a first fraction of the first fractionated solid-liquid mixture
 - 25 from the first particle fractionator is returned to the membrane separator from one exit of the at least two exits of the first particle fractionator, the first fraction of the first fractionated solid-liquid mixture being less than the liquor in terms of content of the submicron particles,
 - wherein a second fraction of the first fractionated solid-liquid
 - 30 mixture from another exit of the at least two exits of the first particle

fractionator is fed to the second particle fractionator, and

wherein a first fraction of the second fractionated solid-liquid mixture from one exit of the at least two exits of the second particle fractionator is returned to the membrane separator, the first fraction of the
5 second fractionated solid-liquid mixture being less than the second fraction of the first fractionated solid-liquid mixture in terms of content of the submicron particles.

3. An apparatus for water treatment, comprising:
10 a membrane separator for solids-liquid separation;
a reactor for pretreatment before a membrane separation by the membrane separator; and
a particle fractionator which has at least two exits of a fractionated solid-liquid mixture,
15 wherein a liquor containing particles of different sizes including submicron particles is fed to the particle fractionator before the membrane separation, and
wherein a first fraction of the fractionated solid-liquid mixture is returned to the membrane separator or the reactor for pretreatment from
20 one exit of the at least two exits of the particle fractionator, the first fraction being less than the liquor in terms of content of the submicron particles.
4. An apparatus for water treatment, comprising:
a membrane separator for solids-liquid separation;
25 a reactor for pretreatment before a membrane separation by the membrane separator;
a first particle fractionator which has at least two exits of a first fractionated solid-liquid mixture produced therein; and
a second particle fractionator which has at least two exits of a second
30 fractionated solid-liquid mixture produced therein,

wherein a liquor containing particles of different sizes including submicron particles is fed to the first particle fractionator before the membrane separation by the membrane separator,

wherein a first fraction of the first fractionated solid-liquid mixture
5 from the first particle fractionator is returned to the membrane separator or the reactor for pretreatment from one exit of the at least two exits of the first particle fractionator, the first fraction of the first fractionated solid-liquid mixture being less than the liquor in terms of content of the submicron particles,

10 wherein a second fraction of the first fractionated solid-liquid mixture from another exit of the at least two exits of the first particle fractionator is fed to the second particle fractionator, and

wherein a first fraction of the second fractionated solid-liquid mixture from one exit of the at least two exits of the second particle
15 fractionator is returned to the membrane separator or the reactor for pretreatment, the first fraction of the second fractionated solid-liquid mixture being less than the second fraction of the first fractionated solid-liquid mixture in terms of content of the submicron particles.

20 5. The apparatus of any one of claims 1-4, wherein the particle fractionator comprises at least one hydrocyclone.

6. The apparatus of claim 3 or 4, wherein the reactor for pretreatment before the membrane separation includes a biological process.

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7. The apparatus of any one of claims 3-5, wherein the reactor for pretreatment before the membrane separation includes a physical-chemical process like coagulation.

30 8. A method for water treatment, comprising the steps of:

a membrane separation step for solid-liquid separation using a membrane separator; and

a fractionation step using a particle fractionator which has at least two exits of a fractionated solid-liquid mixture produced therein,

5 wherein a liquor containing particles of different sizes including submicron particles is fed to the fractionation step before the membrane separation step by a membrane in the membrane separator, and

wherein a first fraction of the fractionated solid-liquid mixture is returned to the membrane separator, the first fraction being less than the
10 liquor in terms of content of the submicron particles.

9. A method for water treatment, comprising the steps of:

a membrane separation step for solids-liquid separation using a membrane separator;

15 a first fractionation step using a first particle fractionator, the first particle fractionator having at least two exits of a first fractionated solid-liquid mixture produced therein; and

a second fractionation step using a second particle fractionator, the second particle fractionator having at least two exits of a second fractionated
20 solid-liquid mixture produced therein,

wherein a liquor containing particles of different sizes including submicron particles is fed to the first fraction step before the membrane separation step,

wherein a first fraction of the first fractionated solid-liquid mixture
25 from the first particle fractionator is returned to the membrane separation step from one exit of the at least two exits of the first particle fractionator, the first fraction of the first fractionated solid-liquid mixture being less than the liquor in terms of content of the submicron particles,

wherein a second fraction of the first fractionated solid-liquid
30 mixture from another exits of the at least two exits of the first particle

fractionator is fed to the second particle fractionator, and

wherein a first fraction of the second fractionated solid-liquid mixture from one exit of the at least two exits of the second particle fractionator is returned to the membrane step, the first fraction of the second
5 fractionated solid-liquid mixture being less than the second fraction of the first fractionated solid-liquid mixture in terms of content of the submicron particles.

10. A method for water treatment, comprising the steps of:
10 a membrane separation step for solids-liquid separation using a membrane separator;
a pretreatment step before the membrane separation step; and
a fractionation step using a particle fractionator which has at least two exits of a fractionated solid-liquid mixture produced therein,
15 wherein a liquor containing particles of different sizes including submicron particles is fed to the fractionation step before the membrane separation step, and
wherein a first fraction of the fractionated solid-liquid mixture from one exit of the at least two the exits of the particle fractionator in the fraction
20 step is returned to the membrane separation step or the pretreatment step, the first fraction being less than the liquor in terms of content of the submicron particles.

11. A method for water treatment, comprising the steps of:
25 a membrane separation step for solids-liquid separation,
a pretreatment step before the membrane separation step, and
a first fractionation step using a first particle fractionator, the first particle fractionator having at least two exits of a first fractionated solid-liquid mixture produced therein, and
30 a second fractionation step using a second particle fractionator, the

second particle fractionator having at least two exits of a second fractionated solid-liquid mixture produced therein,

wherein a liquor containing particles of different sizes including submicron particles is fed to the first particle fractionator before the
5 membrane separation step,

wherein a first fraction of the first fractionated solid-liquid mixture from the first particle fractionator is returned to the membrane separation step or pretreatment step from one exit of the at least two exits of the first particle fractionator, the first fraction being less than the liquor in terms of
10 content of the submicron particles,

wherein a second fraction of the first fractionated solid-liquid mixture from another exit of the at least two exits of the first particle fractionator is fed to the second particle fractionator, and

wherein a first fraction of the second fractionated solid-liquid
15 mixture from one exit of the at least two exits of the second particle fractionator is returned to the membrane separation step or the pretreatment step, the first fraction of the second fractionated solid-liquid mixture being less than the second fraction of the first fractionated solid-liquid mixture in terms of content of the submicron particles.

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12. The method of claim 10 or 11, wherein the pretreatment step before the membrane separation step includes a biological process.

25 13. The method of any one of claims 10 or 11, wherein the pretreatment step before the membrane separation step includes a physical-chemical process like coagulation.

14. The method of any one of claims 8-13, wherein the particle
30 fractionator comprises at least one hydrocyclone.