

DESCRIPTION

TITLE

CONCENTRATION APPARATUS AND CONCENTRATION METHOD

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CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to and the benefit of Japanese Patent Application No. 2021-013736 filed January 29, 2021, the entire contents of which are incorporated herein by reference.

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TECHNICAL FIELD

[0002] The present disclosure relates to a concentration apparatus and a concentration method.

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BACKGROUND

[0003] Microorganisms such as bacteria and viruses are generally negatively charged in neutral to alkaline waters and positively charged in acidic waters. Conventionally, methods of capturing microorganisms from water using this property are known. For example, Non-Patent Literature (NPL) 1 describes a negatively charged membrane method, which uses a negatively charged membrane to capture microorganisms from water.

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CITATION LIST

Non-Patent Literature

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[0004] NPL 1: Katayama et al, "Development of a Virus Concentration Method and Its Application to Detection of Enterovirus and Norwalk Virus from Coastal Seawater", Appl Environ Microbiol, March 2002, Vol. 68, No. 3, p. 1033-1039

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SUMMARY

(Technical Problem)

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[0005] However, detecting viruses in water by applying the negatively charged membrane method is not easy in water treatment infrastructure such as water purification plants, sewage treatment plants, water reclamation facilities or seawater desalination facilities, for example. For example, when trying to implement the negatively charged membrane method at a water

treatment infrastructure site, workers need to assemble onsite the specialized equipment for the processing by the negatively charged membrane method, which requires workers to be arranged, as well as time and effort. Further, when sample water is collected at the water treatment infrastructure site and then processed by the negatively charged membrane method in a laboratory away from the water treatment infrastructure site, additional tools such as containers, and transportation work, are required to properly store and transport the sample water to the laboratory. In this case, the water sampling site and the laboratory where the negatively charged membrane is processed are separated, and therefore changing a policy of use of the negatively charged membrane method according to the sampling conditions of the sample water at the water treatment infrastructure facility may be difficult. Further, the operation of equipment for processing by the negatively charged membrane method has to be done by workers and is therefore a burden on workers.

[0006] It would be helpful to provide a concentration apparatus and a concentration method that improve the convenience of processing by the negatively charged membrane method.

(Solution to Problem)

[0007] A concentration apparatus according to at least one embodiment comprises: a negatively charged membrane that is negatively charged; a sample water supply disposed upstream of the negatively charged membrane and operable to supply sample water; a first solenoid valve disposed on a flow path from the sample water supply to the negatively charged membrane; an acidic solution storage tank disposed upstream of the negatively charged membrane in parallel with the sample water supply and storing an acidic solution; a second solenoid valve disposed on a flow path from the acidic solution storage tank to the negatively charged membrane; an alkaline solution storage tank disposed upstream of the negatively charged membrane in parallel with the sample water supply and the acidic solution storage tank and storing an alkaline solution; a third solenoid valve disposed on a flow path from the alkaline solution storage tank to the negatively charged membrane; an outlet disposed downstream of the negatively charged membrane and operable to discharge fluid externally; a fourth solenoid valve and a first suction pump each disposed on a flow path from the negatively charged membrane to the outlet; a collection container disposed downstream of the negatively charged membrane in parallel with the outlet and in which

fluid is collected; a fifth solenoid valve disposed on a flow path from the negatively charged membrane to the collection container; and a controller that controls opening and closing of the first solenoid valve, the second solenoid valve, the third solenoid valve, the fourth solenoid valve, and the fifth
5 solenoid valve. This automates the processing by the negatively charged membrane method in the concentration apparatus, thereby reducing the labor burden on workers when performing the processing by the negatively charged membrane method. Accordingly, the convenience of processing by the negatively charged membrane method may be improved.

10 **[0008]** According to an embodiment, the concentration apparatus further comprises a mixing solution storage tank disposed upstream of the first solenoid valve in parallel with the sample water supply that stores a mixing solution to be mixed with the sample water. This allows the sample water mixed with the mixing solution to be supplied to the negatively charged
15 membrane.

[0009] According to an embodiment, the concentration apparatus further comprises: a first pump operable to pump the mixing solution downstream; and a second pump operable to pump the sample water downstream, wherein the controller controls the pumping by the first pump and the second pump.
20 This allows the controller to automatically control an amount of the mixing solution mixed with the sample water.

[0010] According to an embodiment, the concentration apparatus further comprises a pressurization tank upstream of the first solenoid valve that stores the sample water supplied from the sample water supply. The sample water
25 may be supplied to the negatively charged membrane at a defined pressure or more.

[0011] According to an embodiment, the controller is operable to execute a sequence of: a first step of opening the first solenoid valve and the fourth solenoid valve, closing the second solenoid valve, the third solenoid valve,
30 and the fifth solenoid valve, and causing the first suction pump to be driven; a second step of opening the second solenoid valve and the fourth solenoid valve, closing the first solenoid valve, the third solenoid valve, and the fifth solenoid valve, and causing the first suction pump to be driven; and a third step of opening the third solenoid valve and closing the first solenoid valve,
35 the second solenoid valve, the fourth solenoid valve and the fifth solenoid valve. This performs the processing by the negatively charged membrane

method and purifies a microbial concentrate.

[0012] According to an embodiment, the concentration apparatus further comprises a second suction pump operable to create negative pressure inside the collection container. This allows negative pressure inside the collection
5 container to draw a concentration into the collection container.

[0013] According to an embodiment, the controller is operable to execute a sequence of: a fourth step of closing the fifth solenoid valve and causing the second suction pump to be driven to create negative pressure inside the collection container; and a fifth step of closing the first solenoid valve, the
10 second solenoid valve, the third solenoid valve, and the fourth solenoid valve and opening the fifth solenoid valve. This properly collects the microbial concentrate in the collection container in the processing by the negatively charged membrane method.

[0014] According to an embodiment, the concentration apparatus is
15 configured as one integrated device. This allows the concentration apparatus to be transported to a location where processing by the negatively charged membrane method is required. This increases the convenience of processing by the negatively charged membrane method.

[0015] According to an embodiment, the concentration apparatus is
20 configured as an integrated device by being entirely housed inside an enclosure. This facilitates transportation of the concentration apparatus and protects each mechanism inside the concentration apparatus.

[0016] According to an embodiment, the enclosure is provided with a handle that is graspable by a user. This allows a user to grasp the handle and carry the
25 concentration apparatus.

[0017] According to an embodiment, the concentration apparatus further comprises wheels. This allows the concentration apparatus to be transported by traveling on wheels on the ground.

[0018] A concentration method according to at least one embodiment is
30 executed by a a concentration apparatus comprising: a negatively charged membrane that is negatively charged; a sample water supply disposed upstream of the negatively charged membrane and operable to supply sample water; a first solenoid valve disposed on a flow path from the sample water supply to the negatively charged membrane; an acidic solution storage tank
35 disposed upstream of the negatively charged membrane in parallel with the sample water supply and storing an acidic solution; a second solenoid valve

disposed on a flow path from the acidic solution storage tank to the negatively charged membrane; an alkaline solution storage tank disposed upstream of the negatively charged membrane in parallel with the sample water supply and the acidic solution storage tank and storing an alkaline solution; a third solenoid valve disposed on a flow path from the alkaline solution storage tank to the negatively charged membrane; an outlet disposed downstream of the negatively charged membrane and operable to discharge fluid externally; a fourth solenoid valve and a first suction pump each disposed on a flow path from the negatively charged membrane to the outlet; a collection container disposed downstream of the negatively charged membrane in parallel with the outlet and in which fluid is collected; and a fifth solenoid valve disposed on a flow path from the negatively charged membrane to the collection container, the concentration method comprising: a first step of opening the first solenoid valve and the fourth solenoid valve, closing the second solenoid valve, the third solenoid valve, and the fifth solenoid valve, and causing the first suction pump to be driven; a second step of opening the second solenoid valve and the fourth solenoid valve, closing the first solenoid valve, the third solenoid valve, and the fifth solenoid valve, and causing the first suction pump to be driven; and a third step of opening the third solenoid valve and closing the first solenoid valve, the second solenoid valve, the fourth solenoid valve and the fifth solenoid valve. This automates the processing by the negatively charged membrane method in the concentration apparatus, thereby reducing the labor burden on workers when performing the processing by the negatively charged membrane method. Accordingly, the convenience of processing by the negatively charged membrane method may be improved.

(Advantageous Effect)

[0019] According to the present disclosure, a concentration apparatus and a concentration method that improve the convenience of processing by the negatively charged membrane method are provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] In the accompanying drawings:

FIG. 1 is a schematic diagram for explanation of a Comparative Example of equipment capable of performing processing by a negatively charged membrane method;

FIG. 2 is a schematic diagram for explanation of a processing step of

the negatively charged membrane method executed via the equipment illustrated in FIG. 1;

FIG. 3 is a schematic diagram for explanation of a processing step of the negatively charged membrane method executed via the equipment
5 illustrated in FIG. 1;

FIG. 4 is a schematic diagram for explanation of a processing step of the negatively charged membrane method executed via the equipment illustrated in FIG. 1;

FIG. 5 is a schematic diagram of a concentration apparatus according
10 to an embodiment of the present disclosure;

FIG. 6 is a schematic diagram for explanation of a first step of processing of a negatively charged membrane method executed by the concentration apparatus illustrated in FIG. 5;

FIG. 7 is a schematic diagram for explanation of a second step of
15 processing of the negatively charged membrane method executed by the concentration apparatus illustrated in FIG. 5;

FIG. 8 is a schematic diagram for explanation of a third step of processing of the negatively charged membrane method executed by the concentration apparatus illustrated in FIG. 5;

FIG. 9 is a schematic diagram for explanation of a fourth step of
20 processing of the negatively charged membrane method executed by the concentration apparatus illustrated in FIG. 5;

FIG. 10 is a schematic diagram for explanation of a fifth step of processing of the negatively charged membrane method executed by the
25 concentration apparatus illustrated in FIG. 5; and

FIG. 11 illustrates functional parts controlled by a controller in each step of the processing of the negatively charged membrane method executed by the concentration apparatus illustrated in FIG. 5.

30 DETAILED DESCRIPTION

[0021] An embodiment of the present disclosure is described below with reference to the drawings.

[0022] First, a Comparative Example is described of equipment that purifies concentrated solutions of microorganisms such as bacteria and viruses by a
35 negatively charged membrane method. As an example, the present disclosure describes purification of a virus concentrate, but similar equipment and

methods may be applied to other particulates such as bacteria. Microorganisms such as bacteria and viruses are negatively charged in neutral to alkaline waters. Sample water in which the processing of the negatively charged membrane method is performed is neutral to alkaline, and therefore
5 such microorganisms are negatively charged in the sample water.

[0023] FIG. 1 is a schematic diagram for explanation of the Comparative Example of the equipment capable of performing processing by the negatively charged membrane method. As illustrated in FIG. 1, equipment 1 of the Comparative Example includes a negatively charged membrane 2, an aspirator
10 3, and a suction bottle 4. In FIG. 1, solid lines joining each component indicate piping through which fluid flows.

[0024] The negatively charged membrane 2 is a negatively charged membrane, for example, a mixed cellulose membrane manufactured by Millipore Corporation (hereinafter also referred to simply as "HA membrane") may be
15 used. The negatively charged membrane 2 has pores able to capture viruses and allow molecules that make up a fluid, such as water molecules, to pass through. The pore diameter of the pores in the negatively charged membrane 2 may be determined according to the viruses and the like to be captured by the negatively charged membrane 2.

[0025] A pipe 5 is provided upstream of the negatively charged membrane 2 to supply fluid. In the Comparative Example illustrated in FIG. 1, three different pipes 5a, 5b, and 5c are manually reconnected for each step, and different fluids are supplied to the negatively charged membrane 2 via the pipe 5. Instead of the pipes 5a, 5b, and 5c being reconnected to the pipe 5,
25 different fluids may be supplied to the negatively charged membrane 2 via the pipe 5 by changing a solution fed into the pipe 5.

[0026] Of the three pipes 5a, 5b, and 5c, a first pipe 5a connects the pipe 5 to a sample water supply port 6. From the sample water supply port 6, sample water that may contain a virus is supplied to the first pipe 5a. The sample
30 water supply port 6 may be supplied with a defined solution mixed with sample water taken from a water treatment infrastructure facility. The defined solution may be, for example, a magnesium chloride solution. As the defined solution, an appropriate solution may be used depending on properties of the sample water. Further, the defined solution need not be used, depending on the
35 properties of the sample water.

[0027] Of the three pipes 5a, 5b, and 5c, a second pipe 5b connects the pipe 5

to an acidic solution storage tank 7 where an acidic aqueous solution is stored. The acidic aqueous solution is supplied to the second pipe 5b from the acidic solution storage tank 7. The acidic aqueous solution is described herein as a sulfuric acid solution as an example, but is not limited to this.

5 **[0028]** Of the three pipes 5a, 5b, and 5c, a third pipe 5c connects the pipe 5 to an alkaline solution storage tank 8 where an alkaline aqueous solution is stored. The alkaline aqueous solution is supplied to the third pipe 5c from the alkaline solution storage tank 8. The alkaline aqueous solution is described herein as a sodium hydroxide aqueous solution as an example, but is not
10 limited to this.

[0029] Fluid is supplied to the negatively charged membrane 2 via the pipe 5 from each of the three pipes 5a, 5b, and 5c connected in a given step. Only one of the sample water, the acidic aqueous solution, and the alkaline aqueous solution is supplied to the negatively charged membrane 2 at a given time. In
15 other words, the pipes 5a, 5b and 5c are manually reconnected for each step so that two or more of the sample water, the acidic aqueous solution, and the alkaline aqueous solution are not supplied at the same timing.

[0030] The aspirator 3 is disposed downstream of the negatively charged membrane 2. The aspirator 3 draws in the fluid supplied to the negatively charged membrane 2 by creating a reduced pressure condition. In the Comparative Example illustrated in FIG. 1, in cases where the sample water and the acidic aqueous solution are supplied to the negatively charged membrane 2, the aspirator 3 is driven and fluid is drawn into the aspirator 3 and discharged externally.
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[0031] The suction bottle 4 is disposed downstream of the negatively charged membrane 2 and in parallel with the aspirator 3. The suction bottle 4 draws in the fluid supplied to the negatively charged membrane 2 by creating a reduced pressure condition and collects the fluid in a concentrated fluid collection container 10 provided internally. In the Comparative Example illustrated in
30 FIG. 1, when the alkaline aqueous solution is supplied to the negatively charged membrane 2, the fluid is drawn into the suction bottle 4 and collected in the concentrated fluid collection container 10.

[0032] The following is a description of a processing method according to the negatively charged membrane method using the equipment of the Comparative
35 Example illustrated in FIG. 1. FIG. 2 through FIG. 4 are schematic diagrams for explanation of processing steps of the negatively charged membrane

method performed by the equipment 1 illustrated in FIG. 1. Bold lines in FIG. 2 through FIG. 4 indicate fluid flow.

[0033] First, the first pipe 5a is connected to the pipe 5 and the aspirator 3 is driven to supply sample water from the sample water supply port 6 to the negatively charged membrane 2 via the first pipe 5a, as illustrated in FIG. 2. As the sample water passes through the negatively charged membrane 2, cations in the sample water have a positive charge and are therefore captured by the negatively charged membrane 2. Further, viruses in the sample water are larger than the pores of the negatively charged membrane 2 and are therefore captured by the negatively charged membrane 2. As the negatively charged membrane 2, one capable of capturing viruses at this time is used. For example, an HA membrane having a pore size of 0.45 μm and a diameter of 13 mm to 90 mm may be used as the negatively charged membrane 2. The sample water with captured cations and viruses is drained by the aspirator 3 through a pipe 11 and a pipe 11a disposed downstream of the negatively charged membrane 2.

[0034] Next, the second pipe 5b is connected to the pipe 5 instead of the first pipe 5a, and the aspirator 3 is driven to supply the sulfuric acid solution from the acidic solution storage tank 7 through the second pipe 5b to the negatively charged membrane 2, as illustrated in FIG. 3. This results in acid cleaning of the negatively charged membrane 2. In other words, by supplying the sulfuric acid solution to the negatively charged membrane 2 and flowing downstream via the aspirator 3, the cations captured in the negatively charged membrane 2 are stripped from the negatively charged membrane 2 and drained with the sulfuric acid solution through the pipe 11 and the pipe 11a. The sulfuric acid solution may be any acid washing solution, for example, 0.5 mM sulfuric acid solution at pH 3.0. The sulfuric acid solution may be supplied in an appropriate volume, for example, one-tenth the volume of the supplied sample water. Acid washing leaves the negatively charged membrane 2 with viruses adhering thereto.

[0035] Then, the third pipe 5c is connected to the pipe 5 instead of the second pipe 5b, and sodium hydroxide aqueous solution is supplied to the negatively charged membrane 2 from the alkaline solution storage tank 8 through the third pipe 5c, as illustrated in FIG. 4. As a result, the negatively charged virus captured by the negatively charged membrane 2 is stripped from the negatively charged membrane 2 and flows with the sodium hydroxide aqueous

solution through the pipe 11 and the pipe 11b to the suction bottle 4 and is collected in the concentrated solution collection container 10. The sodium hydroxide aqueous solution may be any solution from which viruses may be recovered, for example, a 1.0 mM sodium hydroxide aqueous solution at pH 10.5 to pH 10.8. The sodium hydroxide aqueous solution may be supplied in an appropriate volume, for example, 1 ml to 10 ml.

[0036] The concentrated solution collection container 10 is preferably pre-filled with a solution to neutralize the sodium hydroxide aqueous solution from which the virus is collected. For example, the concentrated solution collection container 10 is preferably pre-filled with 5 μ l to 50 μ l of 0.2 N sulfuric acid solution and 10 μ l to 100 μ l of pH 8.0 buffer solution.

[0037] Thus, the processing described with reference to FIG. 2 through FIG. 4 may purify a virus in the sample water into a concentrated solution collection container 10 by performing the negatively charged membrane method using the equipment 1.

[0038] The negatively charged membrane method using the equipment 1 described above may be applied to water treatment infrastructure such as water purification plants, sewage treatment plants, water reclamation facilities, seawater desalination facilities, and the like. However, when applying the negatively charged membrane method using the equipment 1 described above to water treatment infrastructure, for example, when the negatively charged membrane method is to be implemented at the water treatment infrastructure site, workers need to assemble the equipment 1 to be used in the treatment on site. Further, when using the equipment 1 to perform the processing according to the negatively charged membrane method, workers need to reconnect the piping as described above. Therefore, arranging for skilled workers capable of assembling and disassembling the equipment 1 and reconnecting the piping is necessary. Further, time and effort are required to assemble and disassemble the equipment 1. When the water treatment infrastructure to be sampled is located outdoors, additional equipment may be required, which could require additional time and effort. Further, workers must be on site at all times to respond to problems on site. Further, the number of people and the amount of time they have access to the facility may be limited at a water treatment infrastructure site, making it difficult to dispatch a large number of workers or to allow the workers to spend long periods of time working or taking water samples.

[0039] Further, when sample water is collected at the water treatment infrastructure site and then processed by the negatively charged membrane method in a laboratory away from the water treatment infrastructure site, additional tools such as containers, and transportation work, are required to properly store and transport the sample water to the laboratory. In this case, the water sampling site and the laboratory where the negatively charged membrane is processed are separated, and therefore changing a policy of use of the negatively charged membrane method according to the sampling conditions of the sample water at the water treatment infrastructure facility may be difficult.

[0040] Although the negatively charged membrane method is able to capture microorganisms such as bacteria and viruses with a high recovery rate, the work described in FIG. 2 through FIG. 4 has to be performed by workers using the equipment 1. This places a heavy burden on the workers. Further, accurately performing the tasks described with reference to FIG. 2 through FIG. 4 is not easy, and is complicated. In particular, when the need to control water quality arises during an emergency or unusual situation in the water treatment infrastructure, personnel who are not necessarily familiar with the operation of the equipment 1 that performs the negatively charged membrane method may have to operate the equipment 1, which may result in a lack of accurate work, and thus microorganisms might not be properly recovered.

[0041] Further, in practice, when managing the operation and quality of water treatment infrastructure, the facilities and environmental conditions may not always be suitable for the negatively charged membrane method, and being able to implement the negatively charged membrane method more conveniently is desirable. Due to the complicated nature of the processing by the negatively charged membrane method, especially in a water treatment infrastructure with strict entry restrictions, there is also a problem that the negatively charged membrane method might only be performed by taking only a single sample.

[0042] The following is a description of a concentration apparatus that is able to solve the problems described above.

[0043] FIG. 5 is a schematic diagram of a concentration apparatus 100 according to an embodiment of the present disclosure. As illustrated in FIG. 5, the concentration apparatus 100 includes a controller 101, a negatively charged membrane 102, a first suction pump 103, a second suction pump 104,

a mixing solution storage tank 105, a sample water supply 106, an acidic solution storage tank 107, an alkaline solution storage tank 108, a pressurization tank 109, and a concentrated solution collection container 110. In FIG. 5, solid lines joining each component indicate piping through which fluid flows. As illustrated in FIG. 5, the concentration apparatus 100 further includes a first pump P1, a second pump P2, a first flow meter M1, a second flow meter M2, a third flow meter M3, a pressure sensor S, a first solenoid valve V1, a second solenoid valve V2, a third solenoid valve V3, a fourth solenoid valve V4, a fifth solenoid valve V5, and a sixth solenoid valve V6. In FIG. 5, dashed lines joining each component indicate transmission paths of signals to be sent to and from the controller 101.

[0044] The controller 101 is a processor that controls and manages the concentration apparatus 100 overall, including each component included in the concentration apparatus 100. The controller 101 controls the first suction pump 103, the second suction pump 104, the first pump P1, the second pump P2, the first solenoid valve V1, the second solenoid valve V2, the third solenoid valve V3, the fourth solenoid valve V4, the fifth solenoid valve V5, and the sixth solenoid valve V6 by sending control signals. The controller 101 obtains information about measured flow rates from the first flow meter M1, the second flow meter M2, and the third flow meter M3, as well as information about measured pressure from the pressure sensor S. Processing executed by the controller 101 may be designed using a microcomputer, Raspberry Pi, Arduino, or the like, but is not limited to these examples. The controller 101 includes a processor such as a central processing unit (CPU) that executes a program that defines control steps. The program to be executed by the processor is stored, for example, in an internal or external storage medium or the like of the concentration apparatus 100.

[0045] The negatively charged membrane 102 is a negatively charged membrane, for example, an HA membrane may be used. The negatively charged membrane 102 may be constructed in the same way as the negatively charged membrane 2 of the Comparative Example illustrated in FIG. 1.

[0046] Upstream of the negatively charged membrane 102 is an upstream pipe 111 for supplying fluid. Three different pipes, a first pipe 111a, a second pipe 111b, and a third pipe 111c, are connected to the upstream pipe 111, and different fluids are supplied from these three pipes 111a, 111b, and 111c, respectively, to the negatively charged membrane 2 via the upstream pipe 111.

[0047] The first pipe 111a connects the upstream pipe 111 to the pressurization tank 109. The first solenoid valve V1 is provided to the first pipe 111a. The first solenoid valve V1 is disposed on a flow path from the sample water supply 106 to the negatively charged membrane 102 and
5 controls the supply of fluid stored in the pressurization tank 109 to the negatively charged membrane 102. Upstream of the pressurization tank 109 are the mixing solution storage tank 105 and the sample water supply 106.

[0048] The mixing solution storage tank 105 stores a solution to be mixed with sample water supplied from the sample water supply 106 (hereinafter
10 also simply referred to as "mixing solution"). The mixing solution may be magnesium chloride solution, but is not limited to this example. As the defined solution, an appropriate solution may be used depending on properties of the sample water. According to the present embodiment, the mixing solution is described below as a magnesium chloride solution. A fourth pipe
15 112a is connected to the mixing solution storage tank 105, which supplies the magnesium chloride solution to a mixing pipe 112, which leads to the pressurization tank 109 via the fourth pipe 112a. The first pump P1 that controls the flow rate of the magnesium chloride solution and the first flow meter M1 that measures the flow rate of the fluid flowing inside the fourth
20 pipe 112a are disposed in the fourth pipe 112a. Information about the flow rate measured by the first flow meter M1 is transmitted to the controller 101, which controls the pumping of liquid by the first pump P1 based on the obtained information about the flow rate.

[0049] The sample water supply 106 supplies sample water taken from a water treatment plant. The sample water supply 106 may be configured as a mechanism to supply sample water collected from a water treatment plant by hose, tube, or the like, and may be configured as a tank to store sample water collected at a water treatment plant. A fifth pipe 112b is connected to the sample water supply 106, and sample water is supplied via the fifth pipe 112b
30 to the mixing pipe 112 leading to the pressurization tank 109. The second pump P2 that controls the flow rate of the sample water and the second flow meter M2 that measures the flow rate of the fluid flowing inside the fifth pipe 112b are disposed in the fifth pipe 112b. Information about the flow rate measured by the second flow meter M2 is transmitted to the controller 101,
35 which controls the pumping of liquid by the second pump P2 based on the obtained information about the flow rate.

[0050] The first pump P1 and the second pump P2 are pumps able to pump fluid downstream. The first pump P1 and the second pump P2 may be, for example, Perista® Pumps (Perista is a registered trademark in Japan, other countries, or both) that pump liquid by squeezing a soft tube with rollers. By
5 using the first pump P1 and the second pump P2, the amount of the mixing solution mixed with the sample water is automatically controlled by the controller 101.

[0051] The sample water and the magnesium chloride solution are simultaneously supplied to the mixing pipe 112, mixed in the mixing pipe 112,
10 and supplied to the pressurization tank 109. The pressurization tank 109 is a tank for storing the solution in which the sample water and magnesium chloride solution are mixed (hereinafter also simply referred to as "post-mixing solution"). The pressurization tank 109 is capable of hermetically storing the post-mixing solution at a pressure higher than
15 atmospheric pressure. The pressure sensor S is attached to the pressurization tank 109. The pressure sensor S measures the pressure inside the pressurization tank 109 and sends information about the measured pressure to the controller 101.

[0052] The second pipe 111b connects the upstream pipe 111 to the acidic solution storage tank 107. The acidic solution storage tank 107 is a tank that stores an acidic aqueous solution (acidic solution). The acidic aqueous solution is described herein as a sulfuric acid solution as an example, but is not limited to this. The second solenoid valve V2 is provided in the second pipe 111b. The second solenoid valve V2 is disposed on the flow path from
20 the acidic solution storage tank 107 to the negatively charged membrane 102 and controls the supply of the acidic aqueous solution stored in the acidic solution storage tank 107 to the negatively charged membrane 102.
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[0053] The third pipe 111c connects the upstream pipe 111 to the alkaline solution storage tank 108. The alkaline solution storage tank 108 is a tank that stores an alkaline aqueous solution (alkaline solution). The alkaline aqueous solution is described herein as a sodium hydroxide aqueous solution as an example, but is not limited to this. The third solenoid valve V3 is provided in the third pipe 111c. The third solenoid valve V3 is disposed on the flow path from the alkaline solution storage tank 108 to the negatively charged
30 membrane 102 and controls the supply of the alkaline aqueous solution stored in the alkaline solution storage tank 108 to the negatively charged membrane
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102.

[0054] Downstream of the negatively charged membrane 102 is a downstream pipe 113 for discharging fluid that has passed through the negatively charged membrane 102. Two different pipes, a sixth pipe 113a and a seventh pipe 113b,
5 are connected to the downstream pipe 113.

[0055] The sixth pipe 113a is provided with the fourth solenoid valve V4, the first suction pump 103, and the third flow meter M3. The sixth pipe 113a discharges fluid from an outlet 114. The fourth solenoid valve V4 is disposed on the flow path from the negatively charged membrane 102 to the outlet 114
10 and controls the discharge of fluid that has passed through the negatively charged membrane 102 from the sixth pipe 113a. The first suction pump 103 is a pump that draws fluid from the negatively charged membrane 102 to the sixth pipe 113a side. The first suction pump 103 includes, for example, an aspirator that draws in fluid by creating a reduced pressure condition. The
15 third flow meter M3 measures the flow rate of fluid flowing in the sixth pipe 113a. Information about the flow rate measured by the third flow meter M3 is transmitted to the controller 101, which controls the drawing of fluid by the first suction pump 103 based on the obtained information about the flow rate.

[0056] The seventh pipe 113b is provided with the fifth solenoid valve V5.
20 The seventh pipe 113b connects the downstream pipe 113 to the concentrated solution collection container 110. The fifth solenoid valve V5 is disposed on the flow path from the negatively charged membrane 102 to the concentrated solution collection container 110 and controls the drawing of fluid that has passed through the negatively charged membrane 102 into the concentrated
25 solution collection container 110. The concentrated solution collection container 110 is a container that collects fluid (concentrated solution) containing the virus captured by the negatively charged membrane 102. The concentrated solution collection container 110 includes a hermetically sealable container.

[0057] The outlet 114 is attached to the concentrated solution collection container 110. The outlet 114 is provided with the sixth solenoid valve V6 and the second suction pump 104. The outlet 114 is arranged such that one end of the outlet 114 is disposed in the interior space of the concentrated solution collection container 110. The second suction pump 104 is a pump that draws
35 gas from inside the concentrated solution collection container 110 and discharges externally. The sixth solenoid valve V6 controls the drawing of gas

from the inside of the concentrated solution collection container 110 to the outside.

[0058] The concentration apparatus 100 is configured as a single integrated (packaged) device. The concentration apparatus 100 may be configured as an integrated device as a whole, with each functional part fixed to a structure formed using an L-shaped angle or other frame, for example.

[0059] The concentration apparatus 100 may be configured as an integrated device by being entirely housed inside an enclosure 120, such as a duralumin case, for example, as schematically illustrated in FIG. 5. The housing in the enclosure 120 facilitates transportation of the concentration apparatus 100 and protects each mechanism inside the concentration apparatus 100. The concentration apparatus 100 may further be provided with an electric power cable to obtain electric power from outside the enclosure 120. The concentration apparatus 100 may be provided with a battery or other electric power source inside the enclosure 120 that is able to supply electric power. The concentration apparatus 100 may be provided with a handle on the outside of the enclosure 120 that is graspable by a user. By providing the concentration apparatus 100 with the handle, a user may grasp the handle and carry the concentration apparatus 100.

[0060] The concentration apparatus 100 integrated by a frame or the enclosure 120 may be provided with wheels. The wheels may be provided on the enclosure 120, for example. The wheels allow a user to transport the concentration apparatus 100 by traveling on the wheels on the ground.

[0061] Next, processing steps of the negatively charged membrane method using the concentration apparatus 100 illustrated in FIG. 5 are described with reference to FIG. 6 through FIG. 11. FIG. 6 through FIG. 10 are schematic diagrams for explanation of steps of processing the negatively charged membrane method executed by the concentration apparatus 100. Bold lines in FIG. 6 through FIG. 10 indicate fluid flow. FIG. 11 illustrates a list of functional parts controlled by the controller 101 in each step of the processing of the negatively charged membrane method executed by the concentration apparatus 100. In FIG. 11, "open" indicates that the solenoid valve is open, and "closed" indicates that the solenoid valve is closed. In FIG. 11, "on" indicates that the first pump P1, the second pump P2, the first flow meter M1 through to the third flow meter M3, the pressure sensor S, the first suction pump 103 and the second suction pump 104 are driven, and "off" indicates

that the first flow meter M1 through to the third flow meter M3, the pressure sensor S, the first suction pump 103, and second suction pump 104 are stopped.

[0062] The processing of the negatively charged membrane method by the concentration apparatus 100 is realized by control by the controller 101. In other words, in the concentration apparatus 100, the processing of the negatively charged membrane method is automated. Specifically, the controller 101 executes the processing of the negatively charged membrane method by controlling the first solenoid valve V1 through to the sixth solenoid valve V6, the first pump P1, the second pump P2, the first flow meter M1 through to the third flow meter M3, the pressure sensor S, the first suction pump 103 and the second suction pump 104.

[0063] FIG. 6 is a schematic diagram for explanation of a first step of the processing of the negatively charged membrane method executed by the concentration apparatus 100 illustrated in FIG. 5. In the first step, as illustrated in FIG. 11, the controller 101 opens the first solenoid valve V1 and the fourth solenoid valve V4 and closes the other solenoid valves. The controller 101 also causes the first pump P1, the second pump P2, the first flow meter M1 through to the third flow meter M3, the pressure sensor S, and the first suction pump 103 to be driven, and the second suction pump 104 to be stopped.

[0064] The controller 101 thereby obtains information about the flow rates of the fourth pipe 112a and the fifth pipe 112b from the first flow meter M1 and the second flow meter M2, respectively. The controller 101 controls the first pump P1 and the second pump P2 based on the information about the obtained flow rates.

[0065] In the first step, the first solenoid valve V1 and the fourth solenoid valve V4 are opened and the first suction pump 103 is driven, so that the sample water and the magnesium chloride solution are mixed in the mixing pipe 112 and supplied from the pressurization tank 109 to the negatively charged membrane 102 as illustrated in FIG. 6. The controller 101 is able to cause mixing of the sample water and the magnesium chloride solution in the mixing pipe 112 by coordinated control of the first flow meter M1, the second flow meter M2, the first pump P1, and the second pump P2.

[0066] The controller 101 obtains information about the pressure in the pressurization tank 109 from the pressure sensor S. When the controller 101

causes supply of a defined amount or more of the post-mixing solution mixed in the mixing pipe 112 to the negatively charged membrane 102, the controller 101 may cause pressurization of the pressurization tank 109 to supply the post-mixing solution to the negatively charged membrane 102. This allows the post-mixing solution to be supplied to the negatively charged membrane 102 at a defined pressure or more. When the specifications of the concentration apparatus 100 do not require pressurization of the post-mixing solution, the concentration apparatus 100 need not be provided with the pressurization tank 109.

[0067] The post-mixing solution mixed in the mixing pipe 112 is supplied to the negatively charged membrane 102, where cations and viruses in the solution are captured. The liquid from the negatively charged membrane 102, after the cations and virus have been captured, is discharged externally from the sixth pipe 113a. The flow rate of the discharged liquid is measured by the third flow meter M3, and information about the measured flow rate is transmitted to the controller 101. The controller 101 is able to control the suction amount of the first suction pump 103 based on the information about the obtained flow rate.

[0068] The controller 101 terminates the first step and transitions to a second step at an appropriately defined timing, for example, after a defined time has elapsed since the start of the first step, after a defined amount of fluid has been discharged in the first step, or the like.

[0069] FIG. 7 is a schematic diagram for explanation of the second step of the processing of the negatively charged membrane method executed by the concentration apparatus 100 illustrated in FIG. 5. In the second step, as illustrated in FIG. 11, the controller 101 opens the second solenoid valve V2 and the fourth solenoid valve V4 and closes the other solenoid valves. The controller 101 also causes the third flow meter M3 and the first suction pump 103 to be driven, while the first pump P1, the second pump P2, the first flow meter M1, the second flow meter M2, the pressure sensor S and the second suction pump 104 are stopped.

[0070] This supplies the sulfuric acid solution from the acidic solution storage tank 107 to the negatively charged membrane 102, as illustrated in FIG. 7. This results in acid cleaning of the negatively charged membrane 102, and the cations trapped in the negatively charged membrane 102 are stripped from the negatively charged membrane 2 and flow downstream with the

sulfuric acid solution. The liquid after being acid washed is discharged externally from the sixth pipe 113a. The flow rate of the discharged liquid is measured by the third flow meter M3, and information about the measured flow rate is transmitted to the controller 101. The controller 101 is able to control the suction amount of the first suction pump 103 based on the information about the obtained flow rate.

[0071] After the controller 101 has caused external discharge of all supplied sulfuric acid solution in the second step, the controller 101 terminates the second step and transitions to a third step.

[0072] FIG. 8 is a schematic diagram for explanation of the third step of the processing of the negatively charged membrane method executed by the concentration apparatus 100 illustrated in FIG. 5. In the third step, as illustrated in FIG. 11, the controller 101 opens the third solenoid valve V3 and closes the other solenoid valves. The controller 101 also causes the first pump P1, the second pump P2, the first flow meter M1 through to the third flow meter M3, the pressure sensor S, the first suction pump 103, and the second suction pump 104 to be stopped.

[0073] This supplies the sodium hydroxide aqueous solution from the acidic solution storage tank 107 to the negatively charged membrane 102, as illustrated in FIG. 8. The sodium hydroxide aqueous solution flows onto a membrane surface of the negatively charged membrane 102. The concentration apparatus 100 may be provided with a mechanism for venting air from piping at this time, as necessary. The sodium hydroxide aqueous solution is preferably supplied in an amount that becomes some millimeters thick on the negatively charged membrane 102.

[0074] When the controller 101 supplies the sodium hydroxide aqueous solution to the negatively charged membrane 102, the controller 101 terminates the third step and transitions to a fourth step.

[0075] FIG. 9 is a schematic diagram for explanation of the fourth step of the processing of the negatively charged membrane method executed by the concentration apparatus 100 illustrated in FIG. 5. In the fourth step, as illustrated in FIG.11, the controller 101 opens the sixth solenoid valve V6 and closes the other solenoid valves. The controller 101 also causes the second suction pump 104 to be driven, and causes the first pump P1, the second pump P2, the first flow meter M1 through to the third flow meter M3, the pressure sensor S, and the first suction pump 103 to be stopped.

[0076] This causes gas to be discharged externally from the space inside the concentrated solution collection container 110, resulting in negative pressure inside the concentrated solution collection container 110.

5 **[0077]** The controller 101, for example, terminates the fourth step and transitions to a fifth step after a predefined time has elapsed since the start of the fourth step.

[0078] FIG. 10 is a schematic illustration for explanation of the fifth step of the processing of the negatively charged membrane method executed by the concentration apparatus 100 illustrated in FIG. 5. In the fifth step, as
10 illustrated in FIG. 11, the controller 101 opens the fifth solenoid valve V5 and closes the other solenoid valves. The controller 101 also causes the first pump P1, the second pump P2, the first flow meter M1 through to the third flow meter M3, the pressure sensor S, the first suction pump 103, and the second suction pump 104 to be stopped.

15 **[0079]** The inside of the concentrated solution collection vessel 110 is under negative pressure due to the fourth step, and therefore the opening of the fifth solenoid valve V5 causes the sodium hydroxide aqueous solution supplied to the negatively charged membrane 102 in the third step to be drawn into the concentrated solution collection container 110 along with the virus captured
20 in the negatively charged membrane 102, and the concentrated solution of the virus is properly collected in the collection container. In this way, the processing of the negatively charged membrane method is executed and the concentrated solution of the virus in the sample water may be purified into the concentrated solution collection container 110.

25 **[0080]** Thus, in the concentration apparatus 100 according to the present embodiment, the controller 101 controls the opening and closing of the first solenoid valve V1 through to the sixth solenoid valve V6 to execute the processing according to the negatively charged membrane method. In other words, in the concentration apparatus 100, the processing according to the
30 negatively charged membrane method is automated. This reduces the labor burden on workers when processing according to the negatively charged membrane method. For example, in the concentration apparatus 100, the controller 101 controls solenoid valves and various pumps to execute the processing according to the negatively charged membrane method, eliminating
35 the need for workers to visually check or manually manipulate solution flow paths. This increases the convenience of processing by the negatively charged

membrane method according to the concentration apparatus 100. Automation also reduces human error that may occur when workers perform operations and stabilizes the efficiency of recovery of bacteria, viruses, and other microorganisms at a certain level.

5 **[0081]** Further, the concentration apparatus 100 is configured as a single integrated device, and therefore may be transported to locations where executing the processing according to the negatively charged membrane method is necessary. In other words, the concentration apparatus 100 itself is portable. Therefore, by transporting the concentration apparatus 100, sample
10 water may be collected and processed according to the negatively charged membrane method at various water treatment plant sites. This allows the concentration apparatus 100 to be transported to a location as required to execute the processing according to the negatively charged membrane method for various purposes, such as, for example, when there is an emergency,
15 unusual situation, or temporary requirement to perform the processing. The concentration apparatus 100 may be transported to execute the processing according to the negatively charged membrane method even in environments where facilities for processing according to the negatively charged membrane method are not available. Thus, according to the concentration apparatus 100,
20 the convenience of processing according to the negatively charged membrane method is increased. In particular, transportation is facilitated when the enclosure 120 has a handle or wheels.

[0082] The above embodiment describes an example in which the concentration apparatus 100 automatically controls purification of a
25 concentrated solution of microorganisms such as bacteria and viruses, but the concentration apparatus 100 is equally applicable to particulate and colloidal dispersion systems that are negatively charged and suspended in a liquid.

[0083] The concentration apparatus 100 described above may be used in a variety of fields and applications. For example, the concentration apparatus
30 100 described above may be used to monitor water quality management and treatment performance of water treatment infrastructure such as water purification plants, sewage treatment plants, water reclamation facilities, and seawater desalination facilities. The concentration apparatus 100 described above may also be used, for example, to conduct dynamic surveys of the
35 environment in water bodies such as rivers, oceans, water features, swimming pools, bathing areas, and the like. The concentration apparatus 100 described

above may also be used, for example, for water quality testing to determine the risk of microbial infection in a city covering water bodies and environmental infrastructure. The concentration apparatus 100 described above may also be used for the purpose of qualitative risk, safety monitoring, or quality control of liquids used for beverages or in the production of processed foods, to quantify risk or to verify a comparison with a threshold value to determine safety. The concentration apparatus 100 described above may also be used for testing the quality of water for industrial, irrigation, and agricultural use. The concentration apparatus 100 described above may be used, for example, to manage qualitative risk, safety monitoring, or quality control of liquids used for temperature and humidity management, such as in mist spraying, humidification devices, or water sprinkling. The concentration apparatus 100 described above may also be used with respect to water for which the use of permanent water quality research facilities is restricted, such as water for emergency or disaster situations. The concentration apparatus 100 described above may also be used to test the quality of water used in vehicles or transportation systems with attached living facilities, such as campers, large buses, ships, submarines, aircraft, space stations, and the like. The concentration apparatus 100 described above may also be used for quality control testing of water related to medical care such as water used in pharmaceutical manufacturing, dialysis therapy, and the like.

[0084] The concentration apparatus 100 described above may further have a function to detect problems such as fluid leakage in the concentration apparatus 100, for example, by measuring the flow rate of sample water supplied from the sample water supply 106 and the flow rate of wastewater discharged from the outlet 114, and comparing these flow rates.

[0085] The concentration apparatus 100 described above may have a mechanism for automatically starting and stopping water sampling, such as a timer. The concentration apparatus 100 described above may also have a mechanism to start and stop water sampling by remote control. Thus, when the concentration apparatus 100 has a timer and remote control functions, the processing according to the negatively charged membrane method may be executed without requiring workers to be present at the site where the concentration apparatus 100 is active.

[0086] The present disclosure is not limited to the configuration specified in the embodiment described above, and various variations are possible without

departing from the scope of the claims. For example, functions included in each component, each step, and the like may be reconfigured and multiple components or steps may be combined into one or divided, as long as no logical inconsistency results.

5 REFERENCE SIGNS LIST

	[0087]	1	Equipment
		2, 102	Negatively charged membrane
		3	Aspirator
		4	Suction bottle
10		5, 11, 11a, 11b, 114	Pipe
		5a, 111a	First pipe
		5b, 111b	Second pipe
		5c, 111c	Third pipe
		6	Sample water supply port
15		7, 107	Acid solution storage tank
		8, 108	Alkaline solution storage tank
		10, 110	Concentrated solution collection container
		100	Concentration apparatus
		101	Controller
20		103	First suction pump
		104	Second suction pump
		105	Mixing solution storage tank
		106	Sample water supply
		109	Pressurization tank
25		111	Upstream pipe
		112	Mixing pipe
		112a	Fourth pipe
		112b	Fifth pipe
		113	Downstream pipe
30		113a	Sixth pipe
		113b	Seventh pipe
		114	Outlet
		120	Enclosure
		M1	First flow meter
35		M2	Second flow meter
		M3	Third flow meter

	P1	First pump
	P2	Second pump
	S	Pressure sensor
	V1	First solenoid valve
5	V2	Second solenoid valve
	V3	Third solenoid valve
	V4	Fourth solenoid valve
	V5	Fifth solenoid valve
	V6	Sixth solenoid valve
10		

CLAIMS

[Claim 1] A concentration apparatus comprising:

a negatively charged membrane that is negatively charged;

5 a sample water supply disposed upstream of the negatively charged membrane and operable to supply sample water;

a first solenoid valve disposed on a flow path from the sample water supply to the negatively charged membrane;

10 an acidic solution storage tank disposed upstream of the negatively charged membrane in parallel with the sample water supply and storing an acidic solution;

a second solenoid valve disposed on a flow path from the acidic solution storage tank to the negatively charged membrane;

15 an alkaline solution storage tank disposed upstream of the negatively charged membrane in parallel with the sample water supply and the acidic solution storage tank and storing an alkaline solution;

a third solenoid valve disposed on a flow path from the alkaline solution storage tank to the negatively charged membrane;

20 an outlet disposed downstream of the negatively charged membrane and operable to discharge fluid externally;

a fourth solenoid valve and a first suction pump each disposed on a flow path from the negatively charged membrane to the outlet;

a collection container disposed downstream of the negatively charged membrane in parallel with the outlet and in which fluid is collected;

25 a fifth solenoid valve disposed on a flow path from the negatively charged membrane to the collection container; and

a controller that controls opening and closing of the first solenoid valve, the second solenoid valve, the third solenoid valve, the fourth solenoid valve, and the fifth solenoid valve.

30

[Claim 2] The concentration apparatus of claim 1, further comprising a mixing solution storage tank disposed upstream of the first solenoid valve in parallel with the sample water supply that stores a mixing solution to be mixed with the sample water.

35

[Claim 3] The concentration apparatus of claim 2, further comprising:

a first pump operable to pump the mixing solution downstream; and
a second pump operable to pump the sample water downstream,
wherein

the controller controls the pumping by the first pump and the second
5 pump.

[Claim 4] The concentration apparatus of any one of claims 1 to 3,
further comprising a pressurization tank upstream of the first solenoid valve
that stores the sample water supplied from the sample water supply.

10

[Claim 5] The concentration apparatus of any one of claims 1 to 4,
wherein

the controller is operable to execute a sequence of:

a first step of opening the first solenoid valve and the fourth solenoid
15 valve, closing the second solenoid valve, the third solenoid valve, and the
fifth solenoid valve, and causing the first suction pump to be driven;

a second step of opening the second solenoid valve and the fourth
solenoid valve, closing the first solenoid valve, the third solenoid valve, and
the fifth solenoid valve, and causing the first suction pump to be driven; and

20 a third step of opening the third solenoid valve and closing the first
solenoid valve, the second solenoid valve, the fourth solenoid valve, and the
fifth solenoid valve.

[Claim 6] The concentration apparatus of any one of claims 1 to 5,
25 further comprising a second suction pump operable to create negative pressure
inside the collection container.

[Claim 7] The concentration apparatus of claim 6, wherein

the controller is operable to execute a sequence of:

30 a fourth step of closing the fifth solenoid valve and causing the second
suction pump to be driven to create negative pressure inside the collection
container; and

a fifth step of closing the first solenoid valve, the second solenoid
valve, the third solenoid valve and the fourth solenoid valve, and opening the
35 fifth solenoid valve.

[Claim 8] The concentration apparatus of any one of claims 1 to 7, wherein the concentration apparatus is configured as one integrated device.

[Claim 9] The concentration apparatus of claim 8, wherein the
5 concentration apparatus is configured as an integrated device by being entirely housed inside an enclosure.

[Claim 10] The concentration apparatus of claim 9, wherein the enclosure is provided with a handle that is graspable by a user.

10

[Claim 11] The concentration apparatus of any one of claims 1 to 10, wherein the concentration apparatus further comprises wheels.

[Claim 12] A concentration method executed by a concentration apparatus
15 comprising:

a negatively charged membrane that is negatively charged;

a sample water supply disposed upstream of the negatively charged membrane and operable to supply sample water;

a first solenoid valve disposed on a flow path from the sample water
20 supply to the negatively charged membrane;

an acidic solution storage tank disposed upstream of the negatively charged membrane in parallel with the sample water supply and storing an acidic solution;

a second solenoid valve disposed on a flow path from the acidic
25 solution storage tank to the negatively charged membrane;

an alkaline solution storage tank disposed upstream of the negatively charged membrane in parallel with the sample water supply and the acidic solution storage tank and storing an alkaline solution;

a third solenoid valve disposed on a flow path from the alkaline
30 solution storage tank to the negatively charged membrane;

an outlet disposed downstream of the negatively charged membrane and operable to discharge fluid externally;

a fourth solenoid valve and a first suction pump each disposed on a flow path from the negatively charged membrane to the outlet;

35 a collection container disposed downstream of the negatively charged membrane in parallel with the outlet and in which fluid is collected; and

a fifth solenoid valve disposed on a flow path from the negatively charged membrane to the collection container,

the concentration method comprising:

5 a first step of opening the first solenoid valve and the fourth solenoid valve, closing the second solenoid valve, the third solenoid valve, and the fifth solenoid valve, and causing the first suction pump to be driven;

a second step of opening the second solenoid valve and the fourth solenoid valve, closing the first solenoid valve, the third solenoid valve, and the fifth solenoid valve, and causing the first suction pump to be driven; and

10 a third step of opening the third solenoid valve and closing the first solenoid valve, the second solenoid valve, the fourth solenoid valve, and the fifth solenoid valve.