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## DESCRIPTION

SPIRAL MEMBRANE ELEMENT, REVERSE OSMOSIS MEMBRANE MODULE,  
AND REVERSE OSMOSIS MEMBRANE APPARATUS

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### TECHNICAL FIELD

The present invention relates to a spiral membrane element, reverse osmosis membrane module, and reverse osmosis membrane apparatus that can process feed water in a stable manner for a long period of time without pretreating the feed water even if the feed water is highly turbid water such as industrial water.

### BACKGROUND ART

15 Conventionally, as a method for desalinating seawater or for obtaining high purity water and various manufacturing process water, a method of separating ions and low molecular weight compounds from feed water using a spiral membrane element in which a reverse osmosis membrane (RO membrane) or a nano  
20 filtration membrane (NF membrane) is used as a permeable membrane has been known. As shown in Figure 9, a conventional spiral membrane element has an enveloped membrane 93 formed from sheets of permeate water spacer 92, each having a reverse osmosis membrane 91 layered on both surfaces, by closing off  
25 three sides of the permeate water spacer 92, thereby forming enveloped membrane 93. The open side of the enveloped membrane 93 is attached to a permeate water collecting pipe 94 and the

enveloped membrane being spirally wound around the external circumference of the permeate water collecting pipe 94 together with a net of feed water spacer 95. Feed water 96 is supplied from one end 9a of the spiral membrane element 90, flows along  
5 the feed water spacer 95, and is discharged from the other end 9b of the spiral membrane element 90 as concentrate water 98. While flowing along the feed water spacer 95, the feed water 96 permeates through the reverse osmosis membrane 91. The  
) permeate water 97 flows along the permeate water spacer 92 into  
10 the permeate water collecting pipe 94 and is discharged from the end of the permeate water collecting pipe 94. In this manner, a feed water passage is formed by the feed water spacer 95 provided between wound enveloped membranes 93.

When desalinating seawater or producing high purity  
15 water or process water for various manufacturing processes using such a spiral membrane element, feed water is pretreated for the purpose of eliminating turbidity and the like. The feed water spacer in the spiral membrane element has a small  
) thickness (usually 1 mm or less) to provide the feed water with  
20 as large an area in which the feed water comes in contact with the reverse osmosis membrane as possible, while ensuring the required feed water passage. This design allows turbid materials in the feed water to be accumulated in the feed water spacer, giving rise to clogging of the feed water passage. The  
25 pretreatment is performed in order to remove the turbid materials in the feed water to ensure a safe and long-term operation by avoiding an increase in the pressure drop due to

accumulated turbid materials and avoiding a decrease in the amount and quality of the permeate water. A pretreatment apparatus used for eliminating such turbid materials includes various process units such as a coagulator, filter, and membrane, which not only increase installation cost and operation cost, but also require a large installation area. Therefore, if a spiral membrane element with a structure for avoiding accumulation of turbid materials which can ensure a sufficient feed water passage for a conventionally used thin feed water spacer and can maintain a desalination efficiency equivalent to a conventional apparatus is developed, industrial water and tap water without pretreatment can be supplied as feed water to RO membrane. Such a spiral membrane element can simplify the system and decrease the installation area and operating cost, thus presenting an extremely high industrial value.

On the other hand, various methods for improving the conventional feed water spacer structure of grating net have been proposed to prevent clogging of the feed water passage in the spiral membrane element due to turbid materials. Japanese Patent Application Laid-open No. 64-47404 discloses a spiral membrane element using a feed water spacer in the form of a meandering corrugated board. Such a feed water spacer with a meandering corrugated form is not practical because not only it is difficult to mold such a meandering corrugated board, but also there is a every probability that the flowing passages will break down when the corrugated board is spirally wound.

Japanese Patent Application Laid-open No. 9-299770

discloses a net structure made from first wires and second wires crossing each other, wherein a feed water spacer is arranged so that either the first wires or the second wires run in parallel with the longitudinal direction of the permeate water

5 collecting pipe. Since the feed water flow is almost straight and parallel to the longitudinal direction of the permeate water collecting pipe, the feed water spacer of this structure exhibits a low pressure loss and allows feed water to flow at a high linear velocity, making it difficult for turbid materials  
10 to accumulate. However, because the wires that are present in the direction perpendicular to the longitudinal direction of the permeate water collecting pipe interrupt the feed water passage, turbid materials accumulate in the wires and clog the feed water passage.

15 Japanese Patent Application Laid-open No. 10-156152 discloses a feed water spacer formed from wires running in a zigzag pattern from a feed water inlet side X to a feed water outlet side Y as shown in Figure 8. The wires consist of first  
20 wires 81 running along the surface of a separating membrane 80, one of the pair of opposing separating membranes, and second wires 82 running along the surface of another separating membrane. A water passage is formed respectively between the first wires that are present in juxtaposition and between the second wires that are present in juxtaposition, and  
25 continuously extends from the inlet side to the outlet side of the feed water along the surface of the separating membrane. Part of the first and second wires overlap at 81b and 82a and

are bonded there. Although clogging of the water passage due to turbid materials can be suppressed using the feed water spacer of this structure better than using a conventional grating net spacer, stagnation of feed water near the corner C of the first wire 81 shown in Figure 8 will continue to remain in spite of a high flow rate of the feed water stream close to the protrusion B of the second wire 82, for example. Because of this, turbid materials accumulate during operation over a long period of time.

In this manner, among the feed water spacers proposed heretofore, the net structure made of first and second wires has corners or bending portions in the feed water passage which cause stagnation of feed water, resulting in accumulation of turbid materials and an increase in the pressure difference through the membrane element during long term service. Thus, conventional pretreatment of feed water cannot be omitted. The structure formed only from straight wires or almost straight wires running from a feed water inlet side toward a feed water outlet side is ideal from the viewpoint of forming a flow path with no bending portions that can ensure steady flow of feed water. However, it is difficult to industrially fabricate such a structure because the wires are not connected with the other wires.

Accordingly, the present invention provides a spiral membrane element, reverse osmosis membrane module, and reverse osmosis membrane apparatus that do not accumulate turbid materials and can treat feed water in a stable manner for a long

period of time without pretreating feed water even if the feed water is highly turbid water such as industrial water.

#### DISCLOSURE OF THE INVENTION

5           In view of the above-mentioned situation, the inventors of the present invention have conducted extensive studies. As a result, the inventors have found that in a spiral membrane element of the type in which an enveloped separation membrane and a feed water spacer are wound around the external  
10 circumference of a permeate water collecting pipe, accumulation of turbid materials in the feed water spacer can be greatly suppressed if the feed water is caused to flow straight by designing the feed water spacer so that wires are not crossed and no bending parts are present since turbid materials in feed  
15 water accumulate mainly in intersections and bending parts of wires of the conventional feed water spacer. This find has led to the completion of the present invention.

          Accordingly, the present invention (1) provides a spiral  
20 membrane element, in which an enveloped separation membrane is wound around the external circumference of a permeate water collecting pipe together with a feed water spacer, wherein the feed water spacer is formed from first wires and second wires, each meandering with a gentle curve from a feed water inlet side toward a feed water outlet side, the first wires run along one  
25 of the opposing surfaces of the separating membrane, one first wire and the other adjacent first wire forming one of the feed water passages, the second wires run along the other membrane

surface of the separating membrane, one second wire and the other adjacent second wire forming the other feed water passage, and the first wires and second wires partly overlap and are bonded at the overlapping points. This structure ensures that feed water flows in a space between wires meandering with a gentle curve from a feed water inlet side to a feed water outlet side along the membrane surface while gently meandering or flowing almost straight. Therefore, accumulation of turbid materials in the feed water passage can be greatly controlled.

The present invention (2) provides the above spiral membrane element, wherein the meandering shape with a gentle curve has a regular pattern without a bending point, the pattern having a ratio of amplitude H to wavelength L ( $H/L$ ) of 0.02-2 and the number of waves of 1-100/m per wire. This requirement allows selection of appropriate parameters according to the intended application and use conditions, whereby the effect of the invention is ensured with certainty. The present invention (3) provides a reverse osmosis membrane module equipped with the above spiral membrane element. This reverse osmosis membrane module not only ensures the same effect as the above inventions, but also allows easy access to a water processing facility and can be installed in a process line as is. The present invention (4) provides a reverse osmosis membrane apparatus equipped with the above reverse osmosis membrane module. When desalinating seawater or producing high purity water or process water for various manufacturing processes using the reverse osmosis membrane apparatus of the present

invention, feed water with high turbidity such as industrial water and tap water can be supplied as feed water to RO membrane without pretreatment, whereby the water treatment system can be simplified, its installation area can be minimized, and its operating cost can be reduced. The reverse osmosis membrane apparatus of the present invention thus represents an extremely high industrial value.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a drawing showing a feed water spacer in one embodiment of the present invention.

Figure 2 is a cross-sectional view, wherein (A) is a view along the line A-A and (B) is a view along the line B-B of Figure 1.

Figure 3 is an enlarged perspective view of part of the feed water spacer in Figure 1.

Figure 4 shows (A) first wires forming the feed water spacer and (B) second wires forming the feed water spacer.

Figure 5 is a drawing showing a feed water spacer in another embodiment of the present invention.

Figure 6 is a drawing showing a structure of the reverse osmosis membrane module in one embodiment of the present invention.

Figure 7 is a drawing showing a reverse osmosis membrane apparatus in one embodiment of the present invention.

Figure 8 is a drawing showing a conventional feed water spacer with a zigzag configuration.

Figure 9 shows an outline of a conventional reverse osmosis membrane module.

#### BEST MODE FOR CARRYING OUT THE INVENTION

5           The feed water spacer of the present invention is formed from a plurality of first wires and a plurality of second wires meandering with a gentle curve from a feed water inlet side to a feed water outlet side. There are no specific limitations to the cross-sectional configuration of the first and second  
10 wires. A circle, triangle, and quadrangle can be given as examples. Wires with same dimension and same cross-sectional configuration can be used for the first and second wires.

As the meandering shape with a gentle curve, a shape formed from a curve with turning points, but no bending points  
15 is given as an example. A bending point refers to a corner formed from two lines with an angle. The corner herein includes a shape in which the corner is cut or rounded. Therefore, a shape meandering with a gentle curve does not include a zigzag shape as shown in Figure 8. As the curved section, a half-circle  
20 and an arc (part of a circle) formed from a curve with the same constant curvature radius, a shape of which the curvature radius continuously changes such as a sine curve, and the like can be given. In the case of the half-circle or the arc (part of a  
25 radius, the curvature radius may be in the range of 10-10,000 mm, and preferably 20-5,000 mm. If the curvature radius is less than 10 mm, flow of feed water tends to stagnate and turbid

materials may be accumulated during long-term service; if more than 10,000 mm, formability is impaired, making it difficult to fabricate the feed water spacer. A shape meandering with a gentle curve may be either a regular pattern shape formed from a repetition of a wavelength and amplitude having a prescribed dimension or an irregular pattern shape of which the wavelength or amplitude gradually changes in the longitudinal direction of the water collecting pipe or the direction perpendicular thereto. The former shape is more preferable in view of ease of fabrication.

Preferable examples of the shape meandering with a gentle curve will now be described referring to Figures 1-4. Figure 1 is a drawing showing a feed water spacer of this embodiment. Figure 2 is a cross-sectional view, wherein (A) is a view along the line A-A and (B) is a view along the line B-B of Figure 1. Figure 3 is an enlarged perspective view of part of the feed water spacer in Figure 1. Figure 4 shows (A) first wires forming the feed water spacer and (B) second wires forming the feed water spacer. In the Figures, a feed water spacer 1 has a gently meandering shape formed from a curve with a regular pattern but no bending points, with the curvature radius of the curved section continuously changing. The curve has a wavelength  $L$  in the range of 10-1,000 mm, and preferably 20-500 mm, an amplitude  $H$  in the range of 2-200 mm, and preferably 10-100 mm, with the ratio of the amplitude  $H$  to the wavelength  $L$  being 0.02-2 and preferably 0.05-0.5. In this instance, a wire has 1-100 waves in one meter. If the ratio  $H/L$ , the amplitude  $H$ , and the

wavelength L are in the above ranges, feed water flows in the feed water passage gently meandering or almost straight from the inlet side toward the outlet side. The feed water spacer does not accumulate turbid materials in the feed water passage.

5           The feed water spacer 1 of this embodiment is formed from a plurality of first wires 11 and a plurality of second wires 12 extending in the above-described manner from a feed water inlet side X to a feed water outlet side Y. As shown in Figure ) 2, the first wires 11 extend along one membrane surface 21 of  
10           opposing surfaces of a separation membrane 20. A feed water passage 23 is formed between one first wire 11 and the other adjacent first wire 11 in the form of a gently meandering curve from the inlet side X to the outlet side Y. The water flows in this feed water passage 23 along a passage formed on the  
15           surface of the membrane 21. The second wires 12 extend along the other membrane surface 22 of the opposing surfaces of the separation membrane 20. A feed water passage 24 is formed between one second wire 12 and the other adjacent second wire )  
20           12 in the form of a gently meandering curve from the inlet side X to the outlet side Y. The water flows in this feed water passage 24 along a passage formed on the surface of the membrane 22. The actual flow in the feed water passage formed from one feed water passage 23 and the other feed water passage 24 is straight or almost straight since there are no bending points  
25           or corners obstructing a flow in the passage direction. In Figures 3 and 4, 231 indicates one of the feed water passages and 241 indicates the other feed water passage.

As shown in Figures 1 and 3, projections 11a, 11a, .....  
on the one side of the gentle curve of the first wire 11 overlap  
projections 12a, 12a, ..... on the other side of the gentle  
curve of the second wire 12, the two wires being joined at the  
5 overlapping points. In the same manner, projections 11b, 11b,  
..... on the one side of the gentle curve of the first wire  
11 overlap projections 12b, 12b, ..... on the other side of  
the gentle curve of the second wire 12, the two wires being joined  
at the overlapping points. Therefore, the distance between one  
10 first wire 11 and the adjacent first wire 11 and the distance  
between one second wire 12 and the adjacent second wire 12, each  
representing the width  $V$  of the flow passage, are equivalent  
to two times the amplitude  $H$  in the embodiment shown in Figure  
1. For this reason, if the width of amplitude  $H$  is determined  
15 the width of flow passage  $V$  can be determined.

Another preferable embodiment of the shape meandering  
with a gentle curve will be described referring to Figure 5.  
Figure 5 is a drawing showing a feed water spacer in another  
embodiment. Features of the feed water spacer shown in Figure  
20 5 that are different from the feed water spacer of Figure 1 will  
be mainly explained. Specifically, unlike the feed water  
spacer shown in Figure 1, the distance between one first wire  
51 and the adjacent first wire 51 and the distance between one  
second wire 52 and the adjacent second wire 52, each  
25 representing the width  $V$  of the flow passage, are equivalent  
to the amplitude  $H$  in the embodiment shown in Figure 5. The  
first wire 51 and second wire 52 in Figure 5 are provided with

projections 51a, 52a respectively on the lower side of the gentle curve and projections 51b, 52b respectively on the upper side. The midsection of projections 51b, 51b on the one side of the gentle curve of the first wire 51 intersect and overlap  
5 the midsection of projections 52b, 52b on the other side of the gentle curve of the second wire 52. The projection 51a on the lower side of the first wire 51 overlaps the projection 52b on the upper side of the second wire 52. In addition, the  
10 projection 51b on the upper side of the first wire overlaps the projection 52a on the lower side of the second wire 52. The wires are joined in these overlapping points, whereby an integral feed water spacer 1a is formed. In the same manner as the embodiment shown in Figure 1, in the spiral membrane element using this feed water spacer 1a, which differs from the feed  
15 water spacer shown in Figure 1 in the flow passage width V (half that shown in Figure 1), one feed water passage is formed between one first wire 51 and the other adjacent first wire 51 in the form of a gently meandering curve from the inlet side X to the outlet side Y, and another feed water passage is formed between  
20 one second wire 52 and the other adjacent second wire 52 in the form of a gently meandering curve from the inlet side X to the outlet side Y. Although the flow in the feed water passage formed from one feed water passage and the other feed water passage in this embodiment tends to meander to a larger extent  
25 as compared with the feed water spacer 1 shown in Figure 1, the extent of meander is not so significant as causing accumulation of turbid materials.

The thickness of the feed water spacer is equivalent to or slightly smaller than the sum of the diameters of the first wire and the second wire, which is in the range of 0.4-3.0 mm. If the thickness is less than 0.4 mm, the pressure difference of flowing water increases and turbid materials tend to accumulate. On the other hand, if the thickness is more than 3.0 mm, the membrane area per one spiral element made from the feed water spacer is too small to use the element in practice. Although there are no specific limitations to the flow passage width V of the feed water spacer, an appropriate width is twice the amplitude H in the embodiment of Figure 1 and the same as the amplitude H in the embodiment of Figure 5. Although there are no specific limitations to the material for the feed water spacer, polypropylene and polyethylene are preferable from the viewpoint of formability and cost. Methods known in the art can be used with no specific limitations for manufacturing the feed water spacer. Fabrication using a metal mold is preferable from the viewpoint of cost and fabrication precision.

The spiral membrane element of the present invention is made by winding an enveloped separation membrane and the feed water spacer around the external circumference of a permeate water collecting pipe. Either one sheet or two or more sheets of enveloped separation membranes may be used for winding. The spiral membrane element of the present invention can be used in a membrane separation apparatus such as a microfiltration apparatus, ultrafiltration apparatus, and reverse osmosis membrane separation apparatus. As the reverse osmosis

membrane, a common reverse osmosis membrane capable of eliminating 90% or more sodium chloride from a brine and a nano filtration membrane or loose reverse osmosis membrane with a lower desalinating capacity can be given. The nano filtration  
5 membrane and loose reverse osmosis membrane have a lower desalinating capacity than common reverse osmosis membranes, but can separate out hard components particularly such as calcium and magnesium. The nano filtration membrane and loose reverse osmosis membrane are also referred to as an NF membrane.

10 Any reverse osmosis membrane module that is equipped with the above-described spiral membrane element may be used without any specific limitations. For example, a reverse osmosis membrane module having the structure shown in Figure 6 can be given. As shown in Figure 6, an enveloped reverse osmosis  
15 membrane 61 is spirally wound around the external circumference of the permeate water collecting pipe 60 together with the feed water spacer. The surface is then covered with a cover 62. A telescope stopper 64 having a several radial ribs 63 is secured at both ends of the spirally wound reverse osmosis membrane 61  
20 to prevent it from being pushed out. One spiral membrane element 65 is formed from the permeate water collecting pipe 60, reverse osmosis membrane 61, cover 62, and telescope stopper 64. Several spiral membrane elements 65 are connected by connecting the permeate water collecting pipe 60 in each spiral  
25 membrane element 65 using a connector (not shown in the Drawing) and are packed in a housing 66. A clearance 67 between the external circumference of the spiral membrane element 65 and

the internal circumference of the housing 66 is blocked with a brine seal 68. A feed water feed pipe (not shown) for feeding feed water to the housing 66 is installed at one end of the housing 66. At the other end of the housing 66, a treated water  
5 pipe (not shown) connected with the permeate water collecting pipe 60 and a concentrate water pipe (not shown) is installed. The reverse osmosis membrane module 69 is formed from the housing 66, its internal components, pipes (nozzles), and the like.

10 When treating feed water using the reverse osmosis membrane module 69 of this type of structure, the feed water is introduced under pressure using a pump at one end of the housing 66. As shown by arrows in Figure 6, the feed water passes through the spaces of radial ribs 63 of the telescope  
15 stopper 64 and is introduced into a first spiral membrane element 65. A part of the feed water passes through a feed water passage partitioned by a feed water spacer between the membranes of the first spiral membrane element 65 and is introduced into the next spiral membrane element 65. The other part of the feed  
20 water permeates through a reverse osmosis membrane 61 and is collected in the permeate water collecting pipe 60 as permeate water. Feed water passes through the spiral membrane elements 65 continuously. The feed water not permeated through a reverse osmosis membrane is removed from the other end of the housing  
25 66 as a concentrate waste containing turbid materials and ionic impurities at high concentrations. Water permeated through a reverse osmosis membrane is removed from the housing 66 via the

permeate water collecting pipe 60 as permeate water. The reverse osmosis membrane module of the present invention includes, in addition to the module equipped with a plurality of spiral membrane elements as shown in Figure 6, a module  
5 equipped with one spiral membrane element, for example.

Although not specifically limited, the reverse osmosis membrane apparatus of the present invention comprises at least one or more above-mentioned reverse osmosis membrane modules, a feed water supply means such as a pump, a feed water inlet  
10 pipe, a concentrate water discharge pipe, and a permeate water discharge pipe. As the feed water directly supplied to the reverse osmosis membrane apparatus of the present invention, industrial water, tap water, and reclaimedwater can be given. Although the turbidity of feed water treated by the reverse  
15 osmosis membrane apparatus of the present invention is not specifically limited, the reverse osmosis membrane apparatus will not cause a problem such as pressure drop due to clogging of turbid materials when treated highly turbid feed water with a coefficient of turbidity of about 2. Feed water includes  
20 water pretreated with a coarse filter to remove large particles such as sand grains and water containing a dispersant for preventing scale and fouling. The addition of a dispersant increases the effect of suppressing accumulation of turbid materials in the feed water spacer and membrane surface. As  
25 the dispersant, commercially available products, Hypersperse MSI300 and Hypersperse MDC200 (both manufactured by Argo Scientific), for example, can be cited. If the reverse osmosis

membrane apparatus of the present invention is used, a pretreatment means such as a coagulator, filter, and membrane need not be installed. Therefore, the system is simplified, the installation area is minimized, and the costs can be reduced. The effect of the reverse osmosis membrane apparatus is thus innovative.

One embodiment of the reverse osmosis membrane apparatus of the present invention will be explained with reference to Figure 7. The reverse osmosis membrane apparatus 70 shown in Figure 7 comprises a feed water supply unit 71, a front reverse osmosis membrane module 70A, and a rear reverse osmosis membrane module 70B arranged in that order. The feed water supply unit 71 and the front reverse osmosis membrane module 70A are connected by a feed water inlet pipe 72. The front reverse osmosis membrane module 70A and the rear reverse osmosis membrane module 70B are connected by a primary permeate water discharge pipe 73 which feeds the permeate water of the front reverse osmosis membrane module 70A to the rear reverse osmosis membrane module 70B to further treat the primary permeate water. The rear reverse osmosis membrane module 70B is equipped with a permeate water discharge pipe 74 that discharges the permeate water and a recycle pipe 75 that returns condensed water to the feed water inlet pipe 72. The front reverse osmosis membrane module 70A is equipped with a concentrate water discharge pipe 76. The reverse osmosis membrane apparatus of the present invention in which no turbid materials are accumulated is used as the front reverse osmosis membrane module 70A, whereas a

conventional reverse osmosis membrane apparatus is used as the rear reverse osmosis membrane module 70B.

Next, a method for treating feed water using the reverse osmosis membrane apparatus 70 of this embodiment will be described. First, feed water is supplied to the front reverse osmosis membrane module 70A by the feed water supply unit 71. The feed water is treated in the front reverse osmosis membrane module 70A into primary condensed water that is discharged via the condensed water discharge pipe 76 and primary permeate water that is discharged via the primary permeate water discharge pipe 73. The primary permeate water is treated in the rear reverse osmosis membrane module 70B into secondary permeate water that is discharged via the permeate water discharge pipe 74 and secondary concentrate water that is returned to the feed water inlet pipe 72 via the recycling pipe 75. The secondary condense water, obtained by concentrating the primary permeate water that has already been desalinated in the front reverse osmosis membrane module 70A using the rear reverse osmosis membrane module 70B, has a lower conductivity than feed water. For this reason, all the secondary concentrate water can be recycled, whereby the water recovery rate can be increased. Since the reverse osmosis membrane apparatus 70 employs the reverse osmosis membrane module of the present invention by which accumulation of turbid materials is greatly suppressed in the front end instead of a conventional pretreatment unit of which the target is only removing turbid materials, the apparatus substantially utilizes reverse osmosis membranes in two stages.

The reverse osmosis membrane apparatus 70 produces permeate water of remarkably excellent quality as compared with permeate water from a conventional reverse osmosis membrane apparatus that is not equipped with a pretreatment unit having a  
5 desalination function.

## EXAMPLES

### Example 1

Industrial water with a turbidity of 2 and conductivity  
10 of 20 mS/m was processed in a 2,000 hour durability test run under the following operating conditions using a reverse osmosis membrane module A of the following specification. Performance of the reverse osmosis membrane module A was evaluated by measuring the pressure drop (MPa), the amount of  
15 permeate water (l/min), and the conductivity of the permeate water (mS/m) at the initial stage of operation and at 2,000 hours thereafter. After the 2,000 hour operation, the reverse osmosis membrane module was dismantled to observe conditions  
of turbid material adhesion to the feed water passage. The  
20 results of measurement are shown in Table 1 and the results of naked eye observation of the feed water passage are shown in Table 2. In Table 1, the pressure drop and the conductivity of the permeate water are indicated by the values converted to those at 25°C.

25 (Reverse osmosis membrane module A)

A feed water spacer A with a structure shown in Figures 1 and 2 with a ratio of amplitude H to wavelength L: 0.66,

wavelength L: 15 mm, amplitude H: 10 mm, feed water passage width V: 20 mm, thickness: 1.0 mm, was prepared. A spiral membrane element A was prepared using this feed water spacer A, then the reverse osmosis membrane module A with the structure shown in Figure 6 was fabricated. The reverse osmosis membrane module A was fabricated as one module having one spiral membrane element.

(Operating conditions)

Pressure: 0.75 Mpa, concentrate water flow rate: 2.7 m<sup>3</sup>/hour, water temperature: 25°C, flushing operation: one flushing for 60 seconds per 8 hours. The flushing operation herein refers to an operation comprising fully opening the valves installed in the concentrate water discharge pipe, jetting feed water to the reverse osmosis membrane module in an amount three times the feed water feed rate in the permeation treatment, and discharging flushing waste water from the concentrate water discharge pipe.

Example 2

The same 2,000 hour durability run as in Example 1 was carried out under the same conditions as in Example 1, except for using a reverse osmosis membrane module B with the following specification instead of the reverse osmosis membrane module A. The results of performance evaluation of the reverse osmosis membrane module B are shown in Tables 1 and 2.

(Reverse osmosis membrane module B)

Instead of the feed water spacer A, a feed water spacer B with the structure shown in Figure 5 with a ratio of amplitude

H to wavelength L: 0.66, wavelength L: 15 mm, amplitude H: 10 mm, feed water passage width V: 10mm, and thickness: 1.0 mm, was prepared in the same manner as the feed water spacer A.  
Example 3

5 Industrial water with a turbidity of 2 and conductivity of 20 mS/m was treated in a 2,000 hour permanent run using a reverse osmosis membrane apparatus of the following specification according to the flow scheme shown in Figure 7 under the following operating conditions. The results of  
10 performance evaluation of the reverse osmosis membrane apparatus are shown in Tables 1 and 2, wherein Table 1 shows the results of the rear reverse osmosis membrane apparatus. (Reverse osmosis membrane apparatus)

The reverse osmosis membrane module B of Example 2 was  
15 used as the front reverse osmosis membrane module. As the rear reverse osmosis membrane module, one module having one 8-inch element, ES-10 (manufactured by Nitto Denko Co, Ltd.), was used. The ES-10 employs a feed water spacer with a structure of grating net.

20 (Operating conditions)

Pressure: 0.75 Mpa, concentrate water flow rate: 2.7 m<sup>3</sup>/hour, water temperature: 25°C (for both the front and rear reverse osmosis membrane modules), flushing operation (for the front reverse osmosis membrane module): one flushing for 60  
25 seconds per 8 hours.

Example 4

The same 2,000 hour durability run as in Example 1 was

carried out under the same conditions as in Example 1, except for using a reverse osmosis membrane module C with the following specification instead of the reverse osmosis membrane module A. The results of performance evaluation of the reverse osmosis membrane module C are shown in Tables 1 and 2.

(Reverse osmosis membrane module C)

The reverse osmosis membrane module C was prepared in the same manner as the reverse osmosis membrane module A by using a feed water spacer C with the structure shown in Figure 1 with a ratio of amplitude H to wavelength L: 0.2, wavelength L: 100 mm, amplitude H: 20 mm, feed water passage width V: 40 mm, and thickness: 1.0 mm, instead of the feed water spacer A.

#### Comparative Example 1

Feed water was treated in the same manner as in Example 1, except that a known membrane pretreatment unit was installed in the front end and an 8 inch element, ES-10 (manufactured by Nitto Denko Co., Ltd.), was used instead of the spiral membrane element A. Industrial water with a turbidity of 2 and conductivity of 20 mS/m was treated in the pretreatment unit and the pretreated water was further treated in a commercially available conventional reverse osmosis membrane module. The results are shown in Tables 1 and 2.

#### Comparative Example 2

Feed water was treated in the same manner as in Example 1, except that the 8 inch element ES-10 (manufactured by Nitto Denko Co., Ltd.) was used instead of the spiral membrane element A. Industrial water with a turbidity of 2 and conductivity of

20 mS/m was directly treated in a commercially available conventional reverse osmosis membrane module without using any pretreatment. The results are shown in Tables 1 and 2. In the experiment of Comparative Example 2, since the pressure drop  
5 reached too high a level to obtain permeate water at about 800 hours, the operation was stopped at this point.

### Comparative Example 3

The same 2,000 hour durability run as in Example 1 was carried out under the same conditions as in Example 1, except  
10 for using a reverse osmosis membrane module D with the following specification instead of the reverse osmosis membrane module A. The results are shown in Table 1. The reverse osmosis membrane module D was fabricated as one module having one spiral membrane element.

### 15 (Reverse osmosis membrane module D)

A reverse osmosis membrane module was prepared in the same manner as the reverse osmosis membrane module A, except that instead of using the feed water spacer A, a feed water spacer  
20 E having a structure shown in Figure 1 of Japanese Patent Application Laid-open No. 10-156152, specifically, a feed water spacer with a structure shown in Figure 8 with a thickness: 1.0 mm, angle ( $\theta$ ) at a bending point:  $60^\circ$ , and distance between bending points: 5 mm, was used.

TABLE 1

|                       | Pressure difference (Mpa) |                   | Permeate water (l/min) |                   | Conductivity of permeate water (mS/m) |                   |
|-----------------------|---------------------------|-------------------|------------------------|-------------------|---------------------------------------|-------------------|
|                       | Initial                   | After 2,000 hours | Initial                | After 2,000 hours | Initial                               | After 2,000 hours |
| Example 1             | 0.015                     | 0.021             | 18                     | 15                | 0.40                                  | 0.55              |
| Example 2             | 0.015                     | 0.022             | 18                     | 15                | 0.40                                  | 0.55              |
| Example 3             | 0.020                     | 0.020             | 20                     | 20                | 0.03                                  | 0.03              |
| Example 4             | 0.013                     | 0.018             | 18                     | 15                | 0.40                                  | 0.55              |
| Comparative Example 1 | 0.020                     | 0.022             | 20                     | 20                | 0.30                                  | 0.30              |
| Comparative Example 2 | 0.020                     | -                 | 20                     | -                 | 0.30                                  | -                 |
| Comparative Example 3 | 0.020                     | 0.075             | 19                     | 8                 | 0.35                                  | 1.90              |

TABLE 2

|                       | Results of naked eye observation of feed water passage after 2,000 hours |
|-----------------------|--------------------------------------------------------------------------|
| Example 1             | Turbid materials are slightly attached.                                  |
| Example 2             | Turbid materials are slightly attached.                                  |
| Example 3 (front RO)  | Almost no turbid materials are attached.                                 |
| Example 3 (rear RO)   | No turbid materials are attached.                                        |
| Example 4             | Turbid materials are slightly attached (less than Examples 1-2).         |
| Comparative Example 1 | Almost no turbid materials are attached.                                 |
| Comparative Example 2 | Turbid materials entirely block the feed water passage.                  |
| Comparative Example 3 | Turbid materials accumulate mainly at bending points.                    |

5            In Examples 1-4, there was almost no increase in the pressure drop and no decrease in the amount of water permeated, and quality of the permeate water was high. The apparatus of Comparative Example 1 was provided with a pretreatment unit that required an installation area and installation cost, although

10   the results of performance evaluation after 2,000 hours were comparative to the result of Examples. The apparatus of Comparative Example 2 had turbid materials attached thereto in

such a large amount that the amount of permeate water decreased to zero in about 800 hours. In Comparative Example 3, there was a significant increase in the pressure drop and a decrease in the amount of water permeated at the point of 2,000 hour operation. The apparatus was estimated to become unusable in about 3,000 to 4,000 hours.

#### INDUSTRIAL APPLICABILITY

) The spiral membrane element of the present invention ensures feed water to flow a space between wires meandering with a gentle curve from a feed water inlet side to a feed water outlet side along the membrane surface while gently meandering or almost straight. Therefore, accumulation of turbid materials in the feed water passage can be greatly controlled. If the reverse osmosis membrane module or reverse osmosis membrane apparatus of the present invention is used, any pretreatment means conventionally used for removing turbidity need not be installed. Therefore, the system is simplified, the installation area is minimized, and the costs can be reduced. The effect of the reverse osmosis membrane apparatus is thus innovative. Even if the feed water is highly turbid water such as industrial water, the system does not accumulate turbid materials and can treat the feed water in a stable manner for a long period of time without pretreating the feed water.

## CLAIMS

1. A spiral membrane element, in which an enveloped separation membrane is wound around the external circumference of a permeate water collection pipe together with a feed water spacer, wherein the feed water spacer is formed from first wires and second wires, each meandering with a gentle curve from a feed water inlet side toward a feed water outlet side, the first wires run along one of the opposing surfaces of the separating membrane, one first wire and the other adjacent first wire forming one of the feed water passages, the second wires run along the other membrane surface of the separation membrane, one second wire and the other adjacent second wire forming the other feed water passage, and the first wires and second wires partly overlap and are bonded at the overlapping points.

2. The spiral membrane element according to claim 1, wherein the meandering shape with a gentle curve has a regular pattern without a bending point, the pattern having a ratio of amplitude H to wavelength L ( $H/L$ ) of 0.02-2 and the number of wave of 1-100/m per wire.

3. A reverse osmosis membrane module equipped with the spiral membrane element of claim 1 or 2.

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4. A reverse osmosis membrane apparatus equipped with the reverse osmosis membrane module of claim 3.