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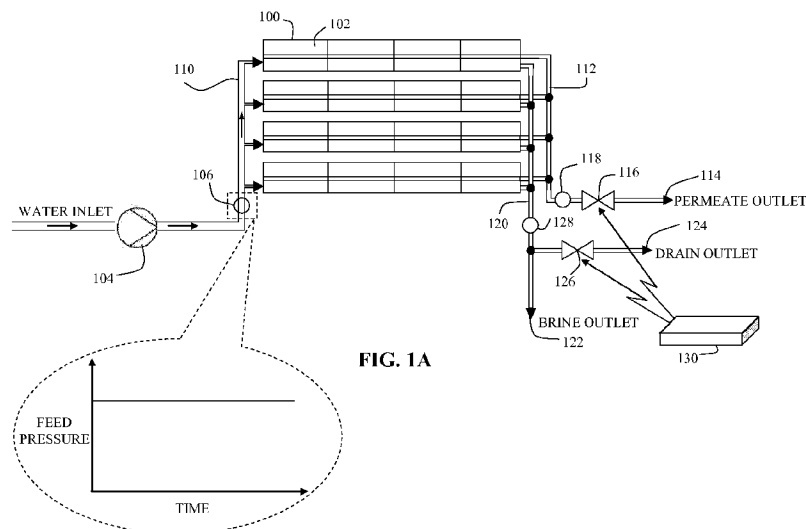


FIG. 1A

(57) **Abstract:** A system for water treatment, the system including at least one water treatment unit, including at least one membrane and having a feed water inlet at a feed side of the at least one membrane and a permeate outlet at a permeate side of the at least one membrane, and an intermittent cleaning control subsystem operative to provide intermittent cleaning of the at least one membrane by causing the permeate to pass through the at least one membrane from the permeate side to the feed side, thereby dislodging foulants from the at least one membrane, by at least one of at least one of narrowing and closing the permeate outlet, thereby causing an increase in the pressure of the permeate at the permeate side of the at least one membrane and reducing the feed pressure by at least 5% without significantly increasing the permeate pressure.

SYSTEM AND METHOD FOR TREATMENT OF WATER

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FIELD OF THE INVENTION

The present invention relates to water treatment generally.

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BACKGROUND OF THE INVENTION

The following patent publications are believed to represent the current state of the art: U.S. Patents 3,853,756 and 7,563,375.

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SUMMARY OF THE INVENTION

5 The present invention seeks to provide improved methods and systems for treatment of water.

There is thus provided in accordance with a preferred embodiment of the present invention a system for water treatment, the system including at least one water treatment unit including at least one membrane and having a feed water inlet at a feed side of the at least one membrane and a permeate outlet at a permeate side of the at least one membrane, the water treatment unit receiving feed water containing foulants via the feed water inlet at a feed pressure which exceeds the osmotic pressure of the feed water, thereby causing permeate to flow through the at least one membrane to the permeate side of the at least one membrane and the foulants to be trapped by the at least one membrane and an intermittent cleaning control subsystem operative to provide intermittent cleaning of the at least one membrane by causing the permeate to pass through the at least one membrane from the permeate side to the feed side, thereby dislodging the foulants from the at least one membrane into the feed water at the feed side of the at least one membrane, enabling the foulants to be flushed from the feed side to a location outside of the at least one water treatment unit, by at least one of at least one of narrowing and closing the permeate outlet, thereby causing an increase in the pressure of the permeate at the permeate side of the at least one membrane and reducing the feed pressure by at least 5% without significantly increasing the permeate pressure.

There is also provided in accordance with another preferred embodiment of the present invention a system for water treatment, the system including at least one water treatment unit including at least one membrane and having a feed water inlet at a feed side of the at least one membrane and a permeate outlet at a permeate side of the at least one membrane, the at least one water treatment unit receiving feed water containing foulants via the feed water inlet at a feed pressure at the feed side of the at least one membrane which exceeds the osmotic pressure of the feed water on the feed side of the at least one membrane, causing permeate to flow through the at least one membrane to the permeate side of the at least one membrane and the foulants to be trapped by the at least one membrane and an intermittent cleaning control subsystem

operative to provide intermittent cleaning of the at least one membrane by causing the permeate to pass through the at least one membrane from the permeate side to the feed side, thereby dislodging the foulants from the at least one membrane into the feed water at the feed side of the at least one membrane, enabling the foulants to be flushed from the feed side to a location outside of the at least one water treatment unit, by reducing the feed pressure at the feed side of the at least one membrane to be below the osmotic pressure at the feed side of the at least one membrane without significantly increasing the permeate pressure.

Preferably, the reducing the feed pressure includes reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water. Alternatively, the reducing the feed pressure includes reducing the feed pressure to a pressure required for desalination of feed water and the feed pressure exceeds the osmotic pressure of the feed water.

In accordance with a preferred embodiment of the present invention, the feed pressure is generally constant other than during the intermittent cleaning of the at least one membrane.

Alternatively, the feed pressure varies over time at times other than only during the intermittent cleaning of the at least one membrane. Additionally, the feed pressure varies over time as a function of salinity of the feed water at the feed side of the at least one membrane. Alternatively or additionally, the feed pressure varies over time proportionally to a rate of flow through the at least one membrane.

Preferably, a sum of the permeate pressure and the osmotic pressure of the feed water is generally at least equal to the feed pressure.

In accordance with a preferred embodiment of the present invention the at least one membrane is selected from at least one reverse osmosis membrane and at least one nanofiltration membrane.

There is further provided in accordance with yet another preferred embodiment of the present invention a method for water treatment including supplying at least one water treatment unit including at least one membrane and having a feed water inlet at a feed side of the at least one membrane and a permeate outlet at a permeate side of the at least one membrane, feeding feed water containing foulants to the at least one water treatment unit via the feed water inlet at a feed pressure which

exceeds the osmotic pressure of the feed water, thereby causing permeate to flow through the at least one membrane to the permeate side of the at least one membrane and the foulants to be trapped by the at least one membrane and intermittently cleaning the at least one membrane by causing the permeate to pass through the at least one
5 membrane from the permeate side to the feed side, thereby dislodging the foulants from the at least one membrane into the feed water at the feed side of the at least one membrane, enabling the foulants to be flushed from the feed side to a location outside of the at least one water treatment unit, by at least one of at least one of narrowing and closing the permeate outlet, thereby causing an increase of pressure of the permeate at
10 the permeate side of the at least one membrane to rise and reducing the feed pressure by at least 5% without significantly increasing the permeate pressure.

There is yet further provided in accordance with still another preferred embodiment of the present invention a method for water treatment including supplying at least one water treatment unit including at least one membrane and having a feed
15 water inlet at a feed side of the at least one membrane and a permeate outlet at a permeate side of the at least one membrane, feeding feed water containing foulants to the at least one water treatment unit via the feed water inlet at a feed pressure which exceeds the osmotic pressure of the feed water, thereby causing permeate to flow through the at least one membrane to the permeate side of the at least one membrane
20 and the foulants to be trapped by the at least one membrane and intermittently cleaning the at least one membrane by causing the permeate to pass through the at least one membrane from the permeate side to the feed side, thereby dislodging the foulants from the at least one membrane into the feed water at the feed side of the at least one membrane, enabling the foulants to be flushed from the feed side to a location outside of
25 the at least one water treatment unit, by reducing the feed pressure at the feed side of the at least one membrane to be below the osmotic pressure at the feed side of the at least one membrane without significantly increasing the permeate pressure.

Preferably, the reducing the feed pressure includes reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water.

30 In accordance with a preferred embodiment of the present invention the reducing the feed pressure includes reducing the feed pressure to a pressure required for

water treatment of the feed water and the feed pressure exceeds the osmotic pressure of the feed water.

Preferably, the feed pressure is generally constant other than during the intermittent cleaning of the at least one membrane. Alternatively, the feed pressure
5 varies over time at times other than only during the intermittent cleaning of the at least one membrane. In accordance with a preferred embodiment of the present invention the feed pressure varies over time as a function of salinity of the feed water at the feed side of the at least one membrane. Additionally or alternatively, the feed pressure varies over time proportionally to a rate of flow through the at least one water treatment unit up to a
10 predetermined threshold.

Preferably, a sum of the permeate pressure and the osmotic pressure of the feed water is generally at least equal to the feed pressure.

In accordance with a preferred embodiment of the present invention the intermittently cleaning includes the at least one of narrowing and closing the permeate
15 outlet and reducing the feed pressure.

Preferably, the at least one membrane is selected from at least one reverse osmosis membrane and at least one nanofiltration membrane.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1A is a simplified illustration of a water treatment system constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 1B illustrates operation of the system of Fig. 1A wherein intermittent cleaning is achieved by narrowing or closing the permeate outlet;

Fig. 1C illustrates operation of the system of Fig. 1A wherein intermittent cleaning is achieved by reducing the feed water pressure to a pressure which is less than the osmotic pressure of the feed water, without significantly increasing the permeate pressure;

Fig. 1D illustrates operation of the system of Fig. 1A wherein intermittent cleaning is achieved by significantly increasing the permeate pressure by narrowing or closing the permeate outlet and reducing the feed water pressure to a pressure which is less than the osmotic pressure of the feed water;

Fig. 2A is a simplified illustration of a water treatment system constructed and operative in accordance with another preferred embodiment of the present invention;

Fig. 2B illustrates operation of the system of Fig. 2A wherein intermittent cleaning is achieved by narrowing or closing the permeate outlet and reducing the feed water pressure;

Fig. 2C illustrates operation of the system of Fig. 2A wherein intermittent cleaning is achieved by reducing the feed water pressure to a pressure which is less than the osmotic pressure of the feed water without significantly increasing the permeate pressure; and

Fig. 2D illustrates operation of the system of Fig. 2A wherein intermittent cleaning is achieved by significantly increasing the permeate pressure by

narrowing or closing the permeate outlet and reducing the feed water pressure to a pressure which is less than the osmotic pressure of the feed water.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to Fig. 1A, which is a simplified illustration of a water treatment system constructed and operative in accordance with a preferred embodiment of the present invention, and to Figs. 1B, 1C and 1D which are simplified time-line illustrations of cleaning operations of the system of Fig. 1A.

The water treatment system of Fig. 1A comprises at least one water treatment unit, preferably comprising reverse osmosis membranes and/or nanofiltration membranes, and is operative for water treatment of feed water, whose pressure is generally uniform over time, and intermittent cleaning of at least one membrane by causing permeate to pass through the at least one membrane from a permeate side to a feed side, thereby dislodging foulants from the at least one membrane into feed water at the feed side of the at least one membrane, enabling the foulants to be flushed from the feed side to a location outside of the at least one water treatment unit.

In the present description, the term “foulants” is used to describe both bio foulants and scale.

It is a particular feature of the present invention that the intermittent cleaning is achieved by at least one of:

narrowing or closing the permeate outlet, thereby causing an increase of pressure of the permeate at the permeate side of the membrane; and

reducing the feed pressure by at least 5%, preferably at least 10%, more preferably at least 20% and most preferably above 20%, without significantly increasing the permeate pressure. Preferably, when reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water without significantly increasing the permeate pressure, the permeate pressure is not increased at all.

Fig. 1B illustrates operation of the system of Fig. 1A wherein intermittent cleaning is achieved by narrowing or closing the permeate outlet.

Fig. 1C illustrates operation of the system of Fig. 1A wherein intermittent cleaning is achieved by reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water without significantly increasing the permeate

pressure. As shown in Fig. 1C, in the illustrated embodiment, the permeate pressure is not increased.

Fig. 1D illustrates operation of the system of Fig. 1A wherein intermittent cleaning is achieved by significantly increasing the permeate pressure by narrowing or closing the permeate outlet and reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water.

Turning initially to Fig. 1A, there is seen a simplified water treatment system comprising at least one water treatment unit including a plurality of pressure vessels 100 arranged in parallel. Each pressure vessel 100 preferably includes a plurality of membrane elements 102, typically eight in number, only four being shown in the drawing for the sake of conciseness. Pressure vessels 100 are commercially available from multiple vendors, such as BEL Composite Industries Ltd, Industrial Zone, Kiryat Yehudit, P.O.B. 4, 84100 Beer Sheva, Israel and membrane elements 102 are commercially available from multiple vendors, such as Hydranautics, 401 Jones Road, Oceanside, CA 92058.

Water to be treated is supplied at a water inlet and is pressurized by a pump 104, preferably operative to pressurize the water to be treated to typical pressures of approximately 15 bar for brackish water and up to approximately 65 bar for sea water. Pump 104 may be any suitable type of pump, such as a positive displacement pump. An example of a preferred positive displacement pump is a Danfoss APP 21-38 high pressure pump, commercially available from Danfoss A/S Nordborgvej 81, 6430 Nordborg, Denmark. Preferably, a pressure sensor 106 is provided downstream of pump 104. A typical graph of pressure as measured by pressure sensor 106 vs. time appears in an enlargement forming part of Fig. 1A.

The water to be treated, hereinafter referred to as feed water, wherein the definition of "feed water" also encompasses, inter alia, saline solution, brackish water, sea water and waste water, is supplied via a manifold 110 to the parallel pressure vessels 100. Treated water, hereinafter referred to as permeate, wherein the definition of "permeate" also encompasses, inter alia, "product water", from each of pressure vessels 100, is preferably supplied via a permeate manifold 112 to a permeate outlet 114 via a permeate outlet control valve 116. A permeate pressure sensor 118 is preferably located upstream of permeate outlet control valve 116. Concentrate from each of pressure

vessels 100 is preferably supplied via a manifold 120 to a brine outlet 122. An output of manifold 120 is also coupled to a drain outlet 124 via a drain outlet control valve 126. A pressure sensor 128 is provided downstream of manifold 120 and upstream of brine outlet 122 and drain outlet 124.

5 In accordance with a preferred embodiment of the present invention, there is provided a Closing Permeate Outlet Reducing Feed Pressure (CPORFP) Controller 130, which controls the operation of permeate outlet control valve 116 and also controls the operation of drain outlet control valve 126, for intermittently cleaning foulants from the membrane elements 102.

10 Further in accordance with a preferred embodiment of the invention, intermittent cleaning of the membrane elements 102 is achieved by:

narrowing or closing the permeate outlet 114 by at least partially closing permeate outlet control valve 116, thereby causing the pressure of the permeate, as measured by pressure sensor 118, at the permeate side of the membrane element 102, to increase and approach the differential pressure across the membrane element, which is closest to the inlet of the pressure vessel 100. This differential pressure is typically in the range of up to 35 bar in seawater desalination and possibly significantly lower in brackish water desalination; and

when the pressure, as measured by pressure sensor 118, of the permeate at the permeate side of the membrane elements 102 increases and approaches the differential pressure across the membrane element, which is closest to the inlet of the pressure vessel 100, by opening drain outlet control valve 126, thus reducing the feed pressure, as measured by pressure sensor 128, to a pressure which is less than the osmotic pressure of feed water, thereby causing the permeate to pass through the membrane elements 102 from the permeate side to the feed side thereof, thereby dislodging foulants from the membrane elements 102 into the feed water at the feed side of the membrane elements 102, thus enabling the foulants to be flushed from the feed side to the brine outlet 122 and out through the drain outlet 124.

A preferred methodology for intermittent cleaning of the membrane elements 102 is now described with reference to Figs. 1B, 1C and 1D. The cleaning process is preferably initiated when foulants accumulate inside a membrane element 102, which can be sensed in various ways. For example, a pressure drop across the

membrane elements 102 may be measured by pressure sensors 106 and 128 or by the use of other sensors which sense the presence of the foulants. When pressure sensors are employed, as described above, intermittent cleaning of the membrane elements 102 is initiated when the pressure drop exceeds a predetermined threshold.

5 Figs. 1B - 1D and 2B - 2D illustrate examples wherein seawater is being desalinated.

It is appreciated that the pressure values given for the embodiments described in the context of Figs. 1B-1D are values associated with membrane cleaning in a sea water desalination operation. While the embodiment shown specifically in Fig. 1B may be used in a sea water desalination operation, it is preferably used for
10 membrane cleaning in a brackish water desalination operation.

Prior to initiation of the cleaning process, permeate outlet control valve 116 is open and drain outlet control valve 126 is closed. Feed water is supplied to the membrane elements 102 and permeate is produced by conventional water treatment
15 techniques. The permeate flows out of the membrane elements 102 via permeate outlet control valve 116. Foulants accumulate on the feed side of the membrane elements. The feed pressure, as measured by pressure sensor 106, typically 65 bar, is indicated by trace 150. The permeate pressure, as measured by pressure sensor 118, typically 1 bar, is indicated by trace 160.

20 Fig. 1B illustrates an example where upon initiation of the cleaning process, as indicated at A and designated in time as $T = 0$ seconds, permeate outlet control valve 116 is at least partially closed by CPORFP controller 130, thereby limiting or preventing outflow of permeate from permeate manifold 112, thereby causing the permeate pressure, as measured by pressure sensor 118, to gradually increase and
25 approach the differential pressure across the membrane element which is closest to the inlet of the pressure vessel 100.

For example, in sea water desalination, if the feed pressure is 65 bar and the osmotic pressure in the membrane element which is closest to the inlet of the pressure vessel 100 is 30 bar, then the permeate pressure can rise up to 35 bar, as shown
30 at B. This increase in the permeate pressure causes the permeate to pass through the membrane elements 102 from the permeate side to the feed side thereof, thereby dislodging foulants from the membrane elements 102 into the feed water at the feed side

of the membrane elements 102, thereby enabling the foulants to be flushed from the feed side to the brine outlet 122.

Typically after stage B, the CPORFP controller 130 opens permeate outlet control valve 116, thereby producing a rapid reduction in the permeate pressure.

5 From this point forward until initiation of a further cleaning cycle, the system proceeds to produce permeate by conventional water treatment techniques.

Fig. 1C illustrates an example wherein upon initiation of the cleaning process, as indicated at A and designated in time as $T = 0$ seconds, drain outlet control valve 126 is operated by CPORFP controller 130 to drain brine not only via brine outlet
10 122 but also via drain outlet 124, thereby reducing the feed pressure to a level which is below the osmotic pressure.

Thereafter, typically shortly after stage A, the sum of the permeate pressure as measured by pressure sensor 118 and the osmotic pressure of the concentrate, which is a function of its salinity, exceeds the feed pressure, as measured
15 by pressure sensor 106. As this pressure difference increases, a backwards flow of permeate through the membrane elements 102 takes place, as indicated at B, thereby flushing foulants from the membrane elements 102 back into the concentrate and allowing them to be flushed out through both the brine outlet 122 and the drain outlet 124.

20 Typically shortly after stage B, the CPORFP controller 130 closes drain outlet control valve 126, thereby restoring the initial feed pressure. From this point forward until initiation of a further cleaning cycle, the system proceeds to produce permeate by conventional water treatment techniques.

Fig. 1D illustrates an example wherein upon initiation of the cleaning
25 process, as indicated at A and designated in time as $T = 0$ seconds, permeate outlet control valve 116 is at least partially closed by CPORFP controller 130, thereby limiting or preventing outflow of permeate from permeate manifold 112 and causing the permeate pressure, as measured by pressure sensor 118, to gradually increase and approach the differential pressure across the membrane element which is closest to the
30 inlet of the pressure vessel 100.

Typically a few seconds after $T = 0$, as indicated at B, drain outlet control valve 126, is opened by CPORFP controller 130 to drain brine to drain outlet 124, thereby reducing the feed pressure to a level which is below the osmotic pressure.

Thereafter, typically shortly after B, the sum of the permeate pressure as measured by pressure sensor 118 and the osmotic pressure of the concentrate, which is a function of its salinity, exceeds the feed pressure, as measured by pressure sensor 106. As this pressure difference increases, a backwards flow of permeate through the membrane elements 102 takes place, as indicated at C, thereby flushing foulants from the membrane elements 102 back into the concentrate and allowing them to be flushed through both the brine outlet 122 and the drain outlet 124.

Typically a few seconds after stage C, the CPORFP controller 130 opens permeate outlet control valve 116 and closes drain outlet control valve 126, thereby producing a rapid reduction in the permeate pressure and restoring the initial feed pressure. From this point forward until initiation of a further cleaning cycle, the system proceeds to produce permeate by conventional techniques.

Reference is now made to Fig. 2A, which is a simplified illustration of a water treatment system constructed and operative in accordance with a preferred embodiment of the present invention and to Figs. 2B, 2C and 2D, which are simplified time-line illustrations of cleaning operations of the system of Fig. 2A.

The water treatment system of Fig. 2A comprises at least one water treatment unit, preferably comprising reverse osmosis membranes and/or nanofiltration membranes, and is operative for water treatment of feed water, whose pressure varies over time as shown in an enlargement, forming part of Fig. 2A, and intermittent cleaning of at least one membrane by causing permeate to pass through the at least one membrane from a permeate side to a feed side, thereby dislodging foulants from the at least one membrane into feed water at the feed side of the at least one membrane, enabling the foulants to be flushed from the feed side to a location outside of the at least one water treatment unit.

Variations in the required feed pressure are a positive function of the salinity of the feed water entering the membrane elements and thus, if the salinity of the feed water entering the membrane elements increases, the feed pressure must be increased. Periodic variations in the salinity of the feed water entering the membrane

elements, which result from periodic feedback of concentrate as will be described in detail hereinafter, thus result in periodic variation of the feed pressure.

The variation of feed pressure over time typically has a periodicity of a few minutes, typically between 3 - 30 minutes in seawater desalination and possibly longer in brackish water desalination. It is a particular feature of the embodiment of Figs. 2A - 2D that the variation of feed pressure is preferably utilized to provide enhanced energy efficiency in the intermittent cleaning of the membrane.

It is a particular feature of the present invention that the intermittent cleaning is achieved by at least one of:

at least partially closing the permeate outlet, thereby causing an increase of pressure of the permeate at the permeate side of the membrane to rise; and

reducing the feed pressure by at least 5%, preferably at least 10%, more preferably at least 20% and most preferably above 20%, without significantly increasing the permeate pressure. Preferably, when reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water without significantly increasing the permeate pressure, the permeate pressure is not increased at all.

Fig. 2B illustrates operation of the system of Fig. 2A wherein intermittent cleaning is achieved by at least one of narrowing and closing the permeate outlet and reducing the feed pressure according to the water treatment method illustrated in Fig. 2A.

Fig. 2C illustrates operation of the system of Fig. 2A, wherein intermittent cleaning is achieved by reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water without significantly increasing the permeate pressure. As shown in Fig. 2C, in the illustrated embodiment, the permeate pressure is not increased.

Fig. 2D illustrates operation of the system of Fig. 2A wherein intermittent cleaning is achieved by significantly increasing the permeate pressure by at least one of narrowing and closing the permeate outlet and reducing the feed pressure to a pressure which is less than the osmotic pressure of the feed water.

Turning initially to Fig. 2A, there is seen a simplified water treatment system comprising at least one water treatment unit including a plurality of pressure vessels 200 arranged in parallel. Each pressure vessel 200 preferably includes a plurality

of membrane elements 202, typically eight in number, only four being shown in the drawing for the sake of conciseness. pressure vessels 200 are commercially available from multiple vendors, such as BEL Composite Industries Ltd, Industrial Zone, Kiryat Yehudit P.O.B. 4, 84100 Beer Sheva, Israel and membrane elements 202 are
5 commercially available from multiple vendors, such as Hydranautics, 401 Jones Road, Oceanside, CA 92058.

Water to be treated is supplied at a water inlet and is pressurized by a pump 204, preferably operative to pressurize the water to be treated to typical pressures of approximately 20 bar for brackish water and up to approximately 65 bar for sea
10 water. Pump 204 may be any suitable type of pump, such as a positive displacement pump. An example of a preferred positive displacement pump is a Danfoss APP 21-38 high pressure pump, commercially available from Danfoss A/S Nordborgvej 81, 6430 Nordborg, Denmark. Preferably a pressure sensor 206 is provided downstream of pump 204. A typical graph of pressure as measured by pressure sensor 206 vs. time is
15 indicated in an enlargement forming part of Fig. 2A.

The water to be treated, hereinafter referred to as feed water, wherein the definition of “feed water” also encompasses, inter alia, “saline solution”, is supplied via a manifold 210 to the parallel pressure vessels 200. Treated water, hereinafter referred to as permeate, wherein the definition of “permeate” also encompasses, inter alia,
20 “product water”, from each of pressure vessels 200 is preferably supplied via a permeate manifold 212 to a permeate outlet 214 via a permeate outlet control valve 216.

A permeate pressure sensor 218 is preferably located upstream of permeate outlet control valve 216. Concentrate from each of pressure vessels 200 is preferably supplied via a manifold 220 to a recycle conduit 222, which directs
25 concentrate back to an input to manifold 210 downstream of pump 204, by employing a circulation pump 224. A pressure sensor 228 is preferably provided downstream of manifold 220. Concentrate from each of pressure vessels 200 may also be supplied from manifold 220 to a brine outlet 230 via a brine outlet control valve 232. An output of manifold 220 is also coupled to a drain outlet 234 via a drain outlet control valve 236.

30 In accordance with a preferred embodiment of the present invention there is provided a CPORFP (Closing Permeate Outlet Reducing Feed Pressure) Controller 240, which controls the operation of permeate outlet control valve 216, brine outlet

control valve 232 and drain outlet control valve 236 for intermittently cleaning foulants from the membrane elements 202.

The periodic variations in the required feed pressure during water treatment correspond to the periodic variations in the salinity of the feed water entering the membrane elements. The control over the variation of the feed pressure can be achieved in various ways, such as according to the flow rate or the salinity level of water being supplied to the membrane elements 202. Alternatively, the feed pressure may be varied in accordance with a predetermined time schedule. Other alternative algorithms for control over the variation of the feed pressure may be employed.

Controller 240 is operative to periodically open and close brine outlet control valve 232 in accordance with a predetermined time schedule or alternatively, for example, in response to either sensed salinity of the concentrate or exceedance of a predetermined maximum feed pressure threshold. Other alternative algorithms for control of opening and closing brine outlet control valve 232 may be employed.

Once the concentration of the concentrate increases to a predetermined level at which continued water treatment is deemed not to be practicable, the controller 240 opens brine outlet control valve 232 and the brine exits the system via brine outlet control valve 232 to brine outlet 230. New feed water enters the system, with significantly lower salinity. When brine outlet control valve 232 is closed, the concentrate is directed back to the input of the manifold 210 via the recycle conduit 222. In the manifold 210, the concentrate blends with fresh feed water and enters membrane elements 202 for further treatment.

Typically the predetermined level of concentrate concentration is based on one of a number of operational considerations, such as rate of accumulation of foulants and energy efficiency.

As a result of the entry of new feed water, the feed pressure, as measured by pressure sensor 206, is accordingly reduced. The feed pressure is thereafter gradually increased as the salinity of the water being supplied to the membrane elements 202 increases and the above-described recycling process is repeated.

In accordance with a preferred embodiment of the invention, intermittent cleaning of the membrane elements 202 is achieved by:

limiting or closing the permeate outlet 214 (CPO) by at least partially closing permeate outlet control valve 216, thereby causing the pressure of the permeate, as measured by pressure sensor 218, at the permeate side of the membrane element 202, to increase and approach the differential pressure across the membrane element which is closest to the inlet of the pressure vessel 200. This differential pressure is typically in the range of up to 25 bar in seawater desalination and possibly significantly lower in brackish water desalination; and

when the pressure, as measured by pressure sensor 218, of the permeate at the permeate side of the membrane elements 202 increases and approaches the differential pressure across the membrane element which is closest to the inlet of the pressure vessel 200, by opening the brine outlet control valve 232 and/or the drain outlet control valve 236, thus reducing the feed pressure, as measured by pressure sensor 206, to a pressure which is less than the osmotic pressure of feed water, thereby causing the permeate to pass through the membrane elements 202 from the permeate side to the feed side thereof, thus dislodging foulants from the membrane elements 202 into the feed water at the feed side of the membrane elements 202, thereby enabling the foulants to be flushed from the feed side to the brine outlet 230 and out through the drain outlet 234. The opening of the brine outlet control valve 232 is in accordance with a preferred embodiment of the invention as in Fig. 2A.

A preferred methodology for intermittent cleaning of the membrane elements 202 is now described with reference to Figs. 2B, 2C and 2D. The cleaning process is preferably initiated when foulants accumulate inside a membrane element 202, which can be sensed in various ways. For example, a pressure drop across the membrane elements 202 may be measured by pressure sensors 206 and 228 or by the use of other sensors which sense the presence of the foulants. When pressure sensors are employed, as described above, intermittent cleaning of the membrane elements 202 is initiated when the pressure drop exceeds a predetermined threshold.

Figs. 2B, 2C and 2D illustrate examples wherein seawater is being desalinated. Prior to initiation of the cleaning process, permeate outlet control valve 216 is open and brine outlet control valve 232 and drain outlet control valve 236 are closed. Feed water is supplied to the membrane elements 202 and permeate is produced by water treatment techniques as described hereinabove. The permeate flows out of the

membrane elements 202 via permeate outlet control valve 216. Foulants accumulate on the feed side of the membrane elements 202. The feed pressure, as measured by pressure sensor 206, typically increases up to 65 bar, is indicated by trace 250. The permeate pressure, as measured by pressure sensor 218, typically 1 bar, is indicated by trace 260.

Fig. 2B illustrates an example where upon initiation of the cleaning process, as indicated at A' and designated in time as $T = 0$ seconds, permeate outlet control valve 216 is at least partially closed by CPORFP controller 240, thereby limiting or preventing outflow of permeate from permeate manifold 212 and causing the permeate pressure, as measured by pressure sensor 218, to gradually increase and approach the differential pressure across the membrane element which is closest to the inlet of the pressure vessel 200.

For example, in sea water desalination, if the feed pressure is 65 bar and the osmotic pressure in the membrane element which is closest to the inlet of the pressure vessel 200 is 40 bar, then the permeate pressure can rise up to 25 bar, as shown in Fig. 2B at C'. This increase in the permeate pressure causes the permeate to pass through the membrane elements 202 from the permeate side to the feed side thereof, thereby dislodging foulants from the membrane elements 202 into the feed water at the feed side of the membrane elements 202, thus enabling the foulants to be flushed from the feed side to the brine outlet 230. At a permeate pressure of 25 bar, there is no production of permeate in any of membrane elements 202.

Typically a few seconds after $T=0$, as indicated at B', brine outlet control valve 232 is operated by CPORFP controller 240 to drain brine to brine outlet 230 and replace it with new feed water, with significantly lower salinity, and the feed pressure is thus reduced, as mentioned above.

Thereafter, typically shortly after B', the sum of the permeate pressure, as measured by pressure sensor 218, and the osmotic pressure of the brine, which is a function of its salinity, exceeds the reduced feed pressure, as measured by pressure sensor 206. As this pressure difference increases, a backwards flow of permeate through the membrane element 202 takes place, as indicated at D' thereby flushing foulants from the membrane elements 202 back into the concentrate and allowing them to be flushed to the brine outlet 230.

Typically and shortly after D', the CPORFP controller 240 opens permeate outlet control valve 216 and closes brine outlet control valve 232, thereby producing a rapid reduction in the permeate pressure. From this point forward until initiation of a further cleaning cycle, the system proceeds to produce permeate by the technique described hereinabove with reference to Fig. 2A.

Fig. 2C illustrates an example wherein upon initiation of the cleaning process, as indicated at A' and designated in time as $T = 0$ seconds, brine outlet control valve 232 and drain outlet control valve 236 are operated by CPORFP controller 240 to drain brine to drain outlet 234 and to brine outlet 230, thereby reducing the feed pressure to a level which is below the osmotic pressure.

Thereafter, typically shortly after A', the sum of the permeate pressure, as measured by pressure sensor 218, and the osmotic pressure of the concentrate, which is a function of its salinity, exceeds the feed pressure, as measured by pressure sensor 206. As this pressure difference increases, a backwards flow of permeate through the membrane elements 202 takes place, as indicated at B', thereby flushing foulants from the membrane elements 202 back into the concentrate and allowing them to be flushed to the brine outlet 230 and to the drain outlet 234.

Typically shortly after B', the CPORFP controller 240 closes brine outlet control valve 232 and drain outlet control valve 236, thereby restoring the initial feed pressure. From this point forward until initiation of a further cleaning cycle, the system proceeds to produce permeate by the technique described hereinabove with reference to Fig. 2A.

Fig. 2D illustrates an example wherein, upon initiation of the cleaning process, as indicated at A' and designated in time as $T = 0$ seconds, permeate outlet control valve 216 is at least partially closed by CPORFP controller 240, thereby limiting or preventing outflow of permeate from permeate manifold 212 and causing the permeate pressure, as measured by pressure sensor 218, to gradually increase and approach the differential pressure across the membrane element which is closest to the inlet of the pressure vessel 200.

Typically a few seconds after $T = 0$, as indicated at B', brine outlet control valve 232 and drain outlet control valve 236 are opened by CPORFP controller

240 to drain brine to drain outlet 234 and to brine outlet 230, thereby reducing the feed pressure to a level which is below the osmotic pressure.

Thereafter, typically shortly after B', the sum of the permeate pressure, as measured by pressure sensor 218, and the osmotic pressure of the concentrate, which is a function of its salinity, exceeds the feed pressure, as measured by pressure sensor 206. As this pressure difference increases, a backwards flow of permeate through the membrane elements 202 takes place, as indicated at C' thereby flushing foulants from the membrane elements 202 back into the concentrate and allowing them to be flushed to brine outlet 230 and to drain outlet 234.

Typically shortly after C', the CPORFP controller 240 opens permeate outlet control 216 and closes brine outlet control valve 232 and drain outlet control valve 236, thereby producing a rapid reduction in the permeate pressure and restoring the initial feed pressure. From this point forward until initiation of a further cleaning cycle, the system proceeds to produce permeate by the technique described hereinabove with reference to Fig. 2A.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather the scope of the present invention includes both combinations and sub-combinations of various features described hereinabove as well as variations and modifications thereof which would occur to a person skilled in the art upon reading the foregoing and which are not in the prior art.

CLAIMS

1. A system for water treatment, the system comprising:

5 at least one water treatment unit including at least one membrane and having a feed water inlet at a feed side of said at least one membrane and a permeate outlet at a permeate side of said at least one membrane, said water treatment unit receiving feed water containing foulants via said feed water inlet at a feed pressure which exceeds the osmotic pressure of said feed water, thereby causing permeate to
10 flow through said at least one membrane to said permeate side of said at least one membrane and said foulants to be trapped by said at least one membrane; and

an intermittent cleaning control subsystem operative to provide intermittent cleaning of said at least one membrane by causing said permeate to pass through said at least one membrane from said permeate side to said feed side, thereby
15 dislodging said foulants from said at least one membrane into said feed water at said feed side of said at least one membrane, enabling said foulants to be flushed from said feed side to a location outside of said at least one water treatment unit, by at least one of:

at least one of narrowing and closing said permeate outlet, thereby
20 causing an increase in the pressure of said permeate at said permeate side of said at least one membrane; and

reducing said feed pressure by at least 5% without significantly increasing the permeate pressure.

25 2. A system for water treatment, the system comprising:

at least one water treatment unit including at least one membrane and having a feed water inlet at a feed side of said at least one membrane and a permeate outlet at a permeate side of said at least one membrane, said at least one water treatment unit receiving feed water containing foulants via said feed water inlet at a feed pressure
30 at said feed side of said at least one membrane which exceeds the osmotic pressure of said feed water on said feed side of said at least one membrane, causing permeate to

flow through said at least one membrane to said permeate side of said at least one membrane and said foulants to be trapped by said at least one membrane; and

an intermittent cleaning control subsystem operative to provide intermittent cleaning of said at least one membrane by causing said permeate to pass
5 through said at least one membrane from said permeate side to said feed side, thereby dislodging said foulants from said at least one membrane into said feed water at said feed side of said at least one membrane, enabling said foulants to be flushed from said feed side to a location outside of said at least one water treatment unit, by reducing said feed pressure at said feed side of said at least one membrane to be below said osmotic
10 pressure at the feed side of said at least one membrane without significantly increasing the permeate pressure.

3. A system for water treatment according to claim 1 and wherein:
said reducing said feed pressure comprises reducing said feed pressure to
15 a pressure which is less than the osmotic pressure of said feed water.

4. A system for water treatment according to claim 1 and wherein:
said reducing said feed pressure comprises reducing said feed pressure to
a pressure required for desalination of feed water; and
20 said feed pressure exceeds the osmotic pressure of the feed water.

5. A system for water treatment according to any of claims 1 - 4 and wherein said feed pressure is generally constant other than during said intermittent cleaning of said at least one membrane.
25

6. A system for water treatment according to any of claims 1 - 4 and wherein said feed pressure varies over time at times other than only during said intermittent cleaning of said at least one membrane.

30 7. A system for water treatment according to claim 6 and wherein said feed pressure varies over time as a function of salinity of said feed water at said feed side of said at least one membrane.

8. A system for water treatment according to claim 6 and wherein said feed pressure varies over time proportionally to a rate of flow through said at least one membrane.

5

9. A system for water treatment according to any of claims 1 - 8 and wherein a sum of said permeate pressure and said osmotic pressure of said feed water is generally at least equal to said feed pressure.

10 10. A system for water treatment according to any of claims 1 - 9 and wherein said at least one membrane is selected from at least one reverse osmosis membrane and at least one nanofiltration membrane.

11. A method for water treatment comprising:

15 supplying at least one water treatment unit including at least one membrane and having a feed water inlet at a feed side of said at least one membrane and a permeate outlet at a permeate side of said at least one membrane;

feeding feed water containing foulants to said at least one water treatment unit via said feed water inlet at a feed pressure which exceeds the osmotic pressure of said feed water, thereby causing permeate to flow through said at least one membrane to said permeate side of said at least one membrane and said foulants to be trapped by said at least one membrane; and

intermittently cleaning said at least one membrane by causing said permeate to pass through said at least one membrane from said permeate side to said feed side, thereby dislodging said foulants from said at least one membrane into said feed water at said feed side of said at least one membrane, enabling said foulants to be flushed from said feed side to a location outside of said at least one water treatment unit, by at least one of:

at least one of narrowing and closing said permeate outlet, thereby causing an increase of pressure of said permeate at said permeate side of said at least one membrane to rise; and

reducing said feed pressure by at least 5% without significantly increasing the permeate pressure.

12. A method for water treatment comprising:

5 supplying at least one water treatment unit including at least one membrane and having a feed water inlet at a feed side of said at least one membrane and a permeate outlet at a permeate side of said at least one membrane;

feeding feed water containing foulants to said at least one water treatment unit via said feed water inlet at a feed pressure which exceeds the osmotic pressure of
10 said feed water, thereby causing permeate to flow through said at least one membrane to said permeate side of said at least one membrane and said foulants to be trapped by said at least one membrane; and

intermittently cleaning said at least one membrane by causing said permeate to pass through said at least one membrane from said permeate side to said
15 feed side, thereby dislodging said foulants from said at least one membrane into said feed water at said feed side of said at least one membrane, enabling said foulants to be flushed from said feed side to a location outside of said at least one water treatment unit, by reducing said feed pressure at said feed side of said at least one membrane to be below said osmotic pressure at the feed side of said at least one membrane without
20 significantly increasing the permeate pressure.

13. A method for water treatment according to claim 11 and wherein:

said reducing said feed pressure comprises reducing said feed pressure to a pressure which is less than the osmotic pressure of said feed water.
25

14. A method for water treatment according to claim 11 and wherein:

said reducing said feed pressure comprises reducing said feed pressure to a pressure required for water treatment of said feed water; and

said feed pressure exceeds the osmotic pressure of said feed water.
30

15. A method for water treatment according to any of claims 11 - 14 and wherein said feed pressure is generally constant other than during said intermittent cleaning of said at least one membrane.

5 16. A method for water treatment according to any of claims 11 - 14 and wherein said feed pressure varies over time at times other than only during said intermittent cleaning of said at least one membrane.

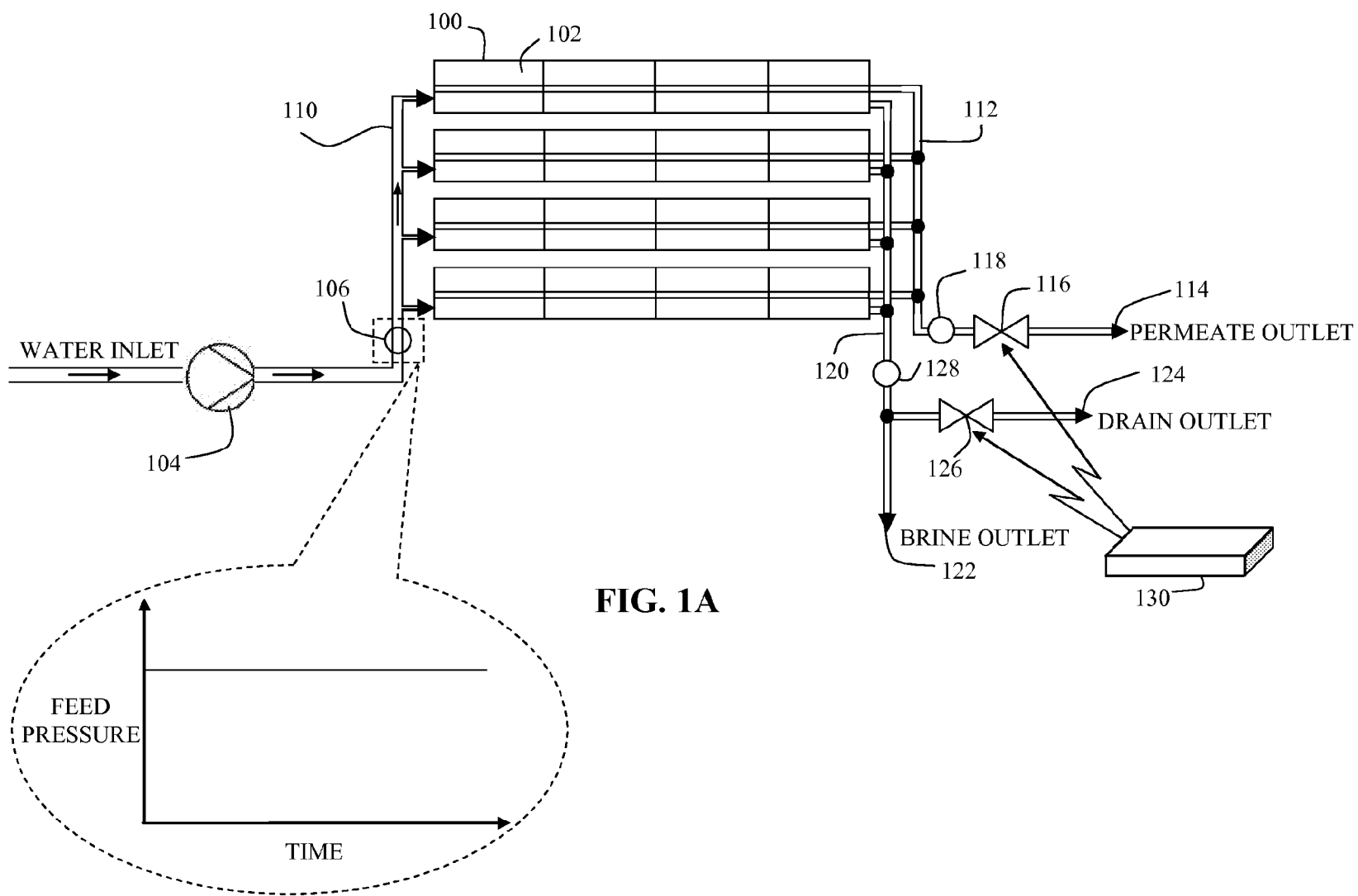
10 17. A method for water treatment according to claim 16 and wherein said feed pressure varies over time as a function of salinity of said feed water at said feed side of said at least one membrane.

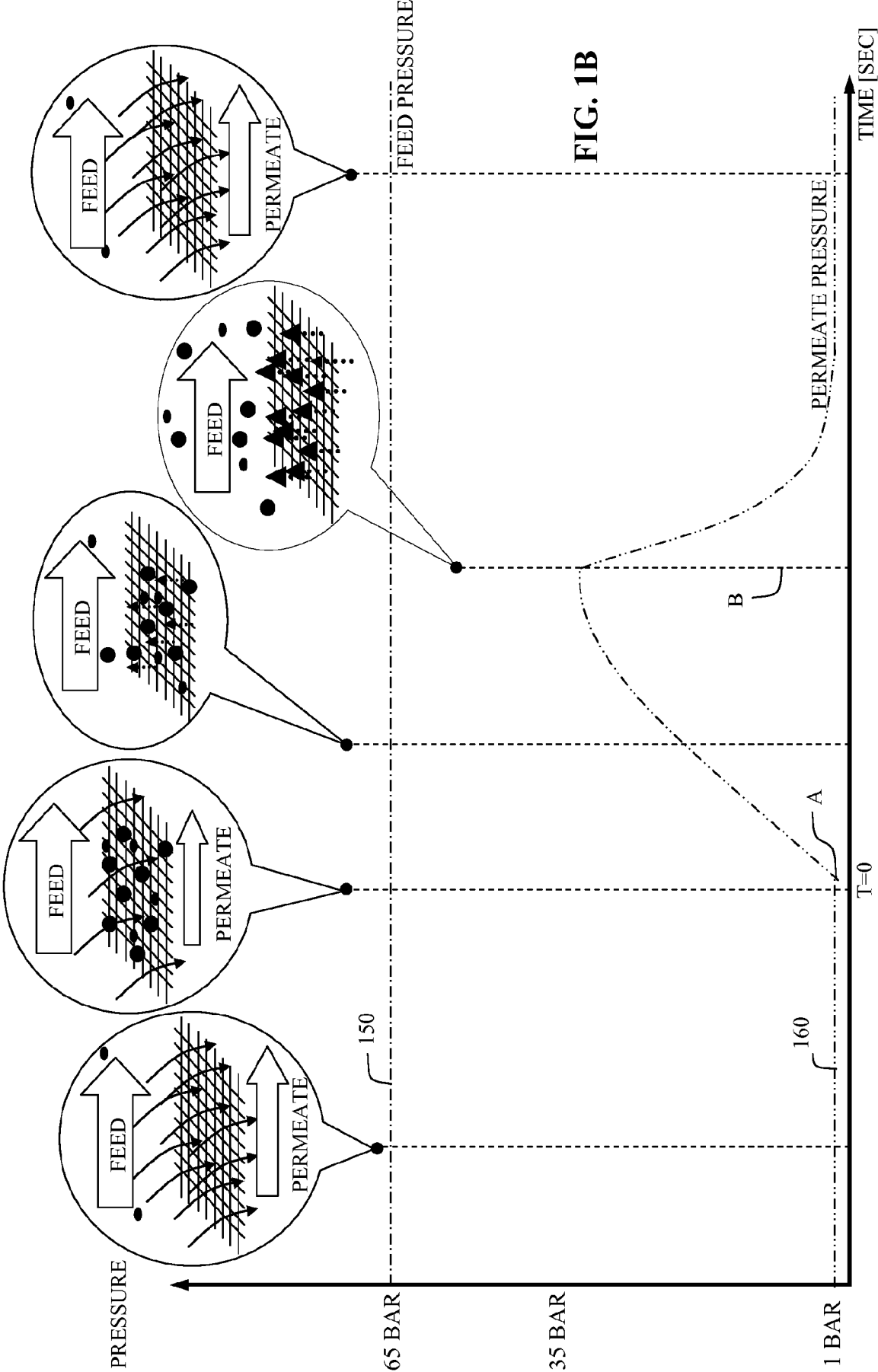
15 18. A method for water treatment according to claim 16 and wherein said feed pressure varies over time proportionally to a rate of flow through said at least one water treatment unit up to a predetermined threshold.

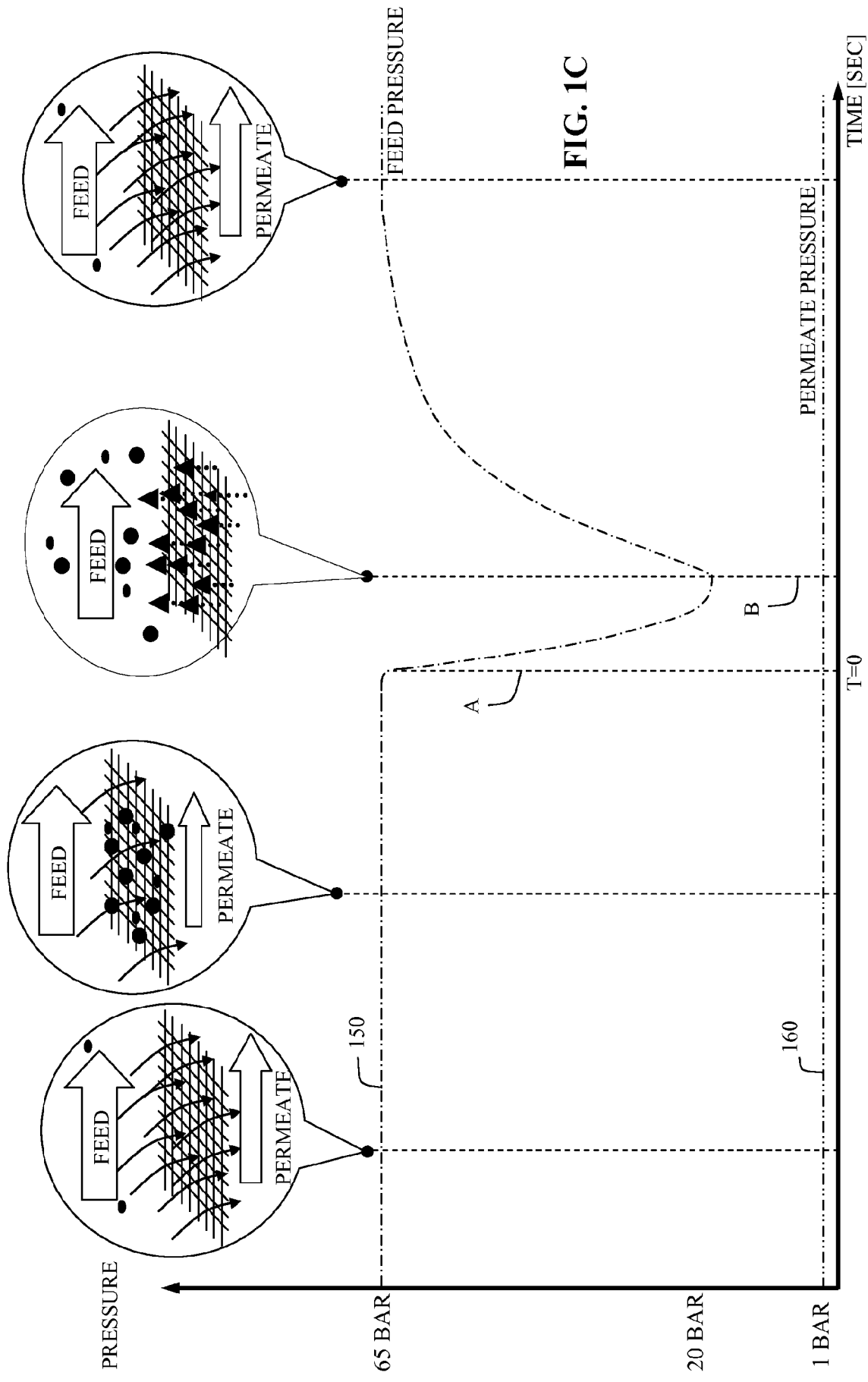
20 19. A method for water treatment according to any of claims 11 - 18 and wherein a sum of said permeate pressure and said osmotic pressure of said feed water is generally at least equal to said feed pressure.

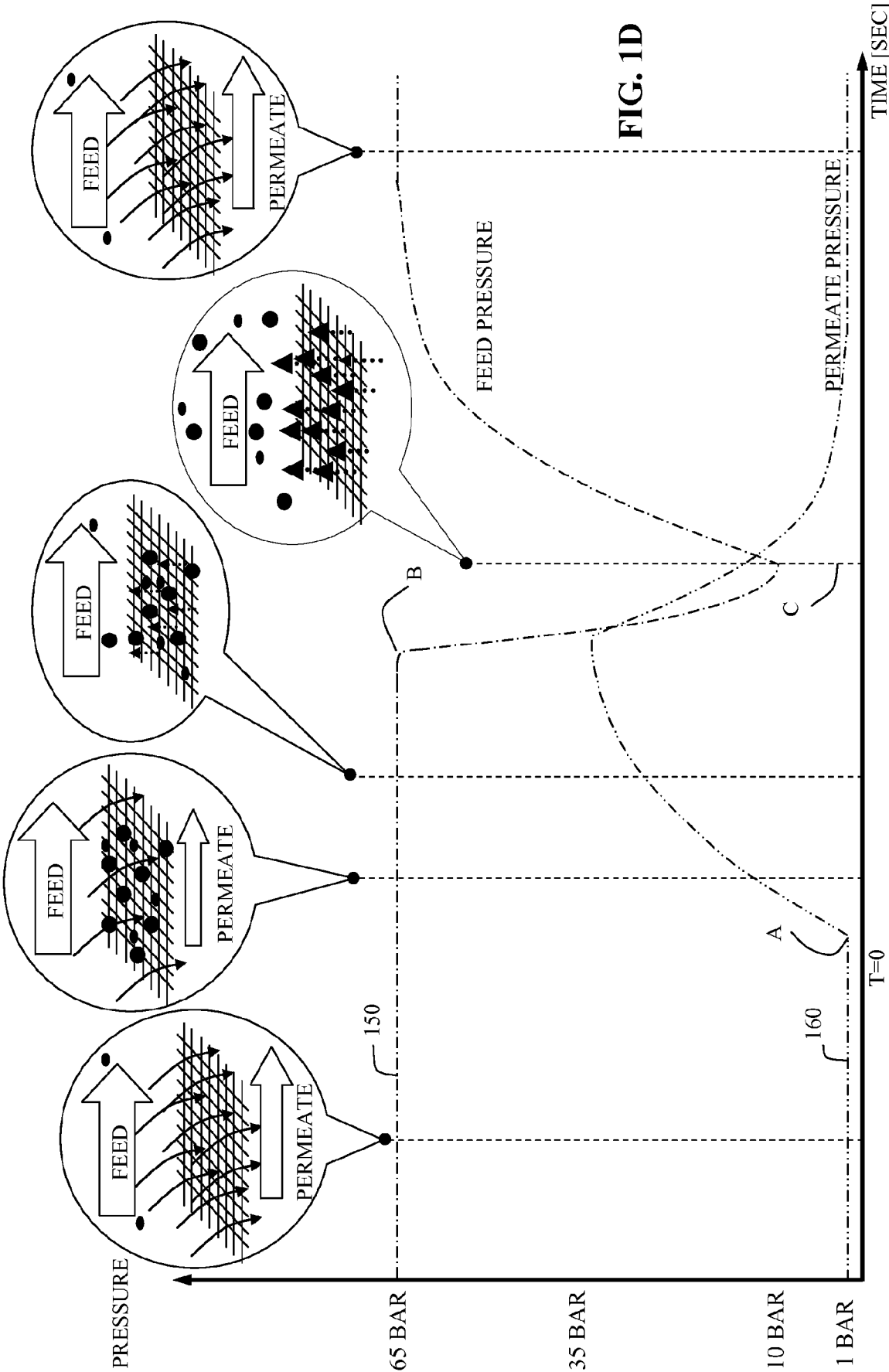
20. A method for water treatment according to any of claims 11 - 19 and wherein said intermittently cleaning comprises:
said at least one of narrowing and closing said permeate outlet; and
reducing said feed pressure.

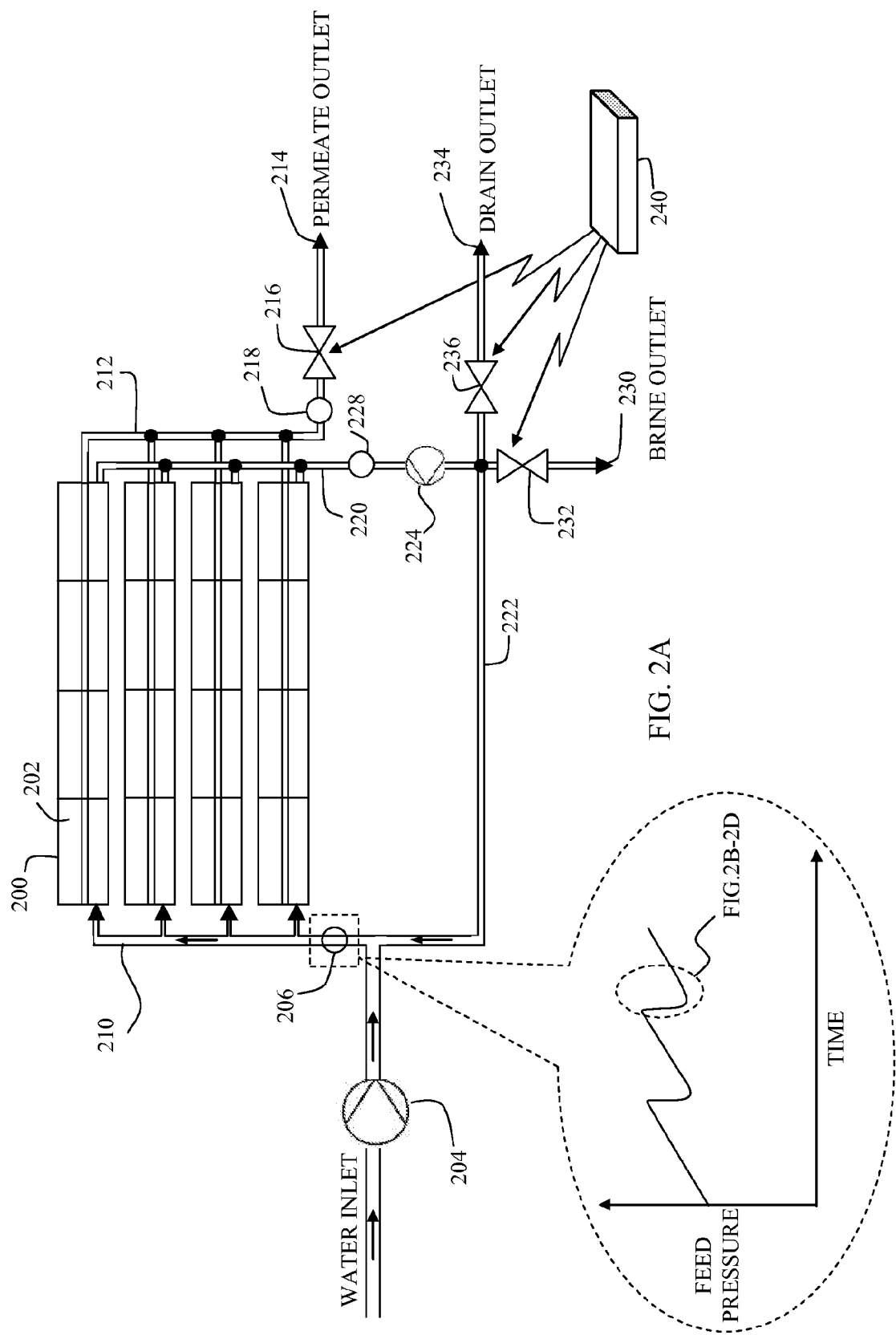
25 21. A method for water treatment according to any of claims 11 - 20 and wherein said at least one membrane is selected from at least one reverse osmosis membrane and at least one nanofiltration membrane.

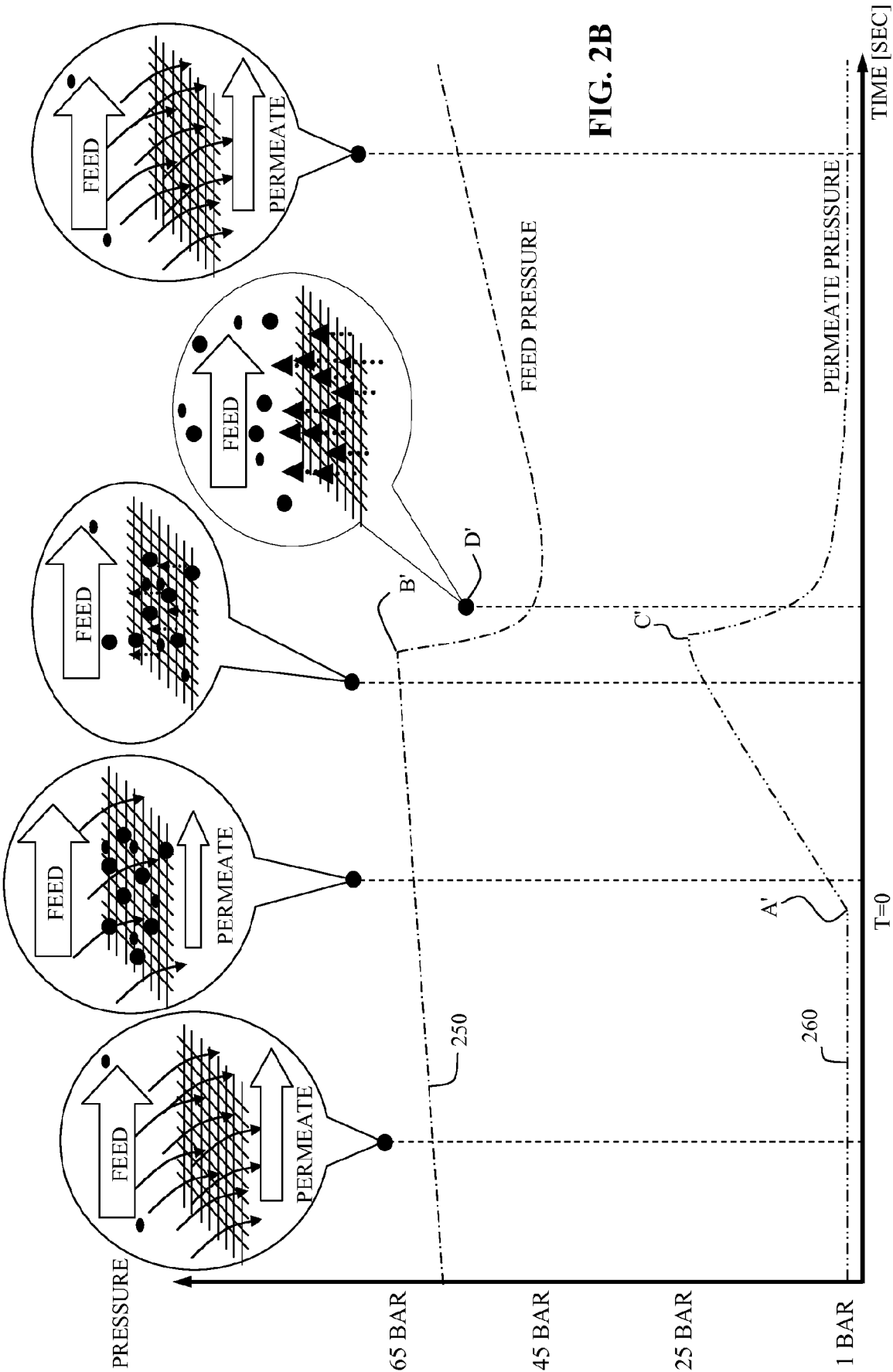


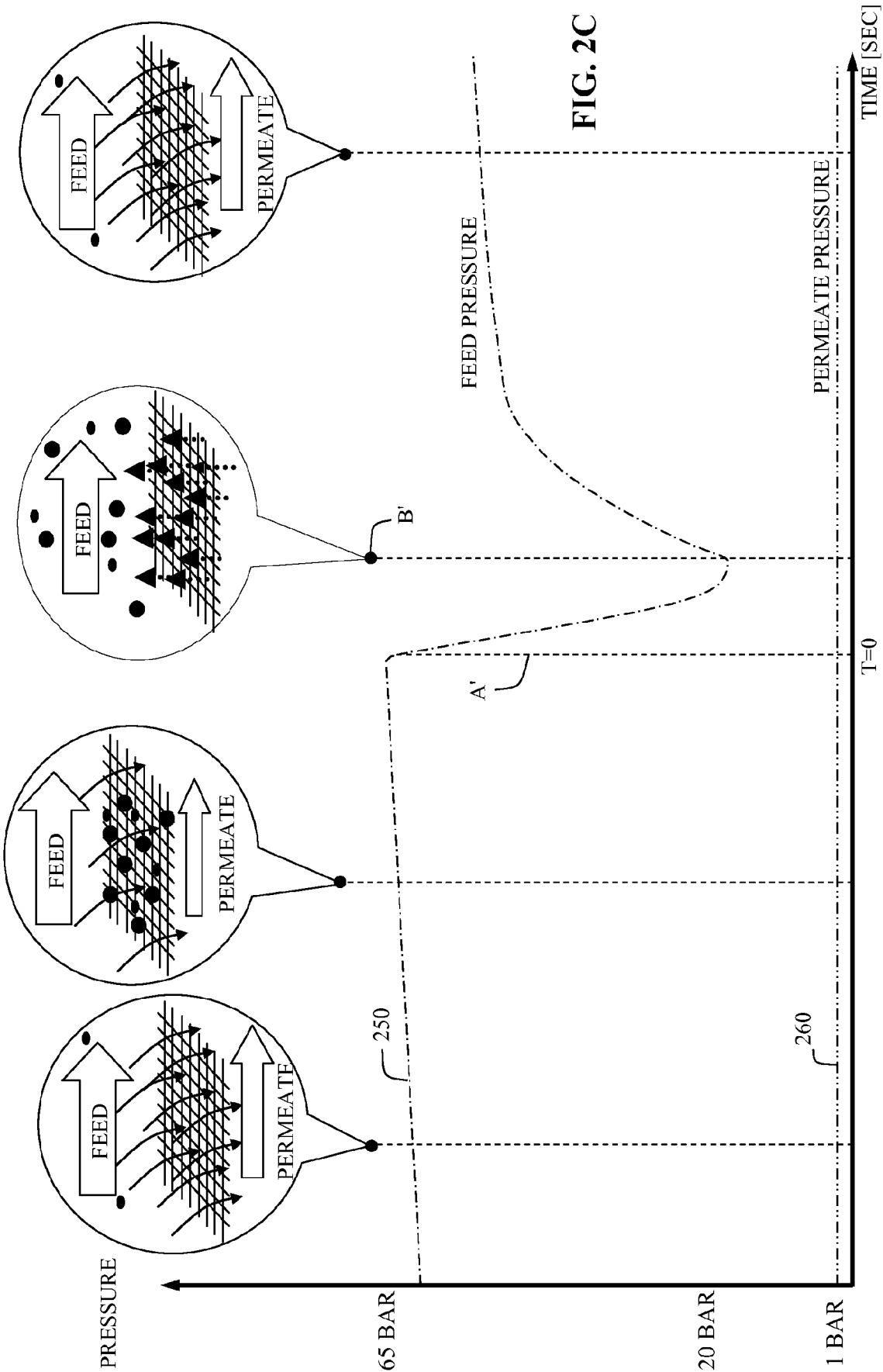


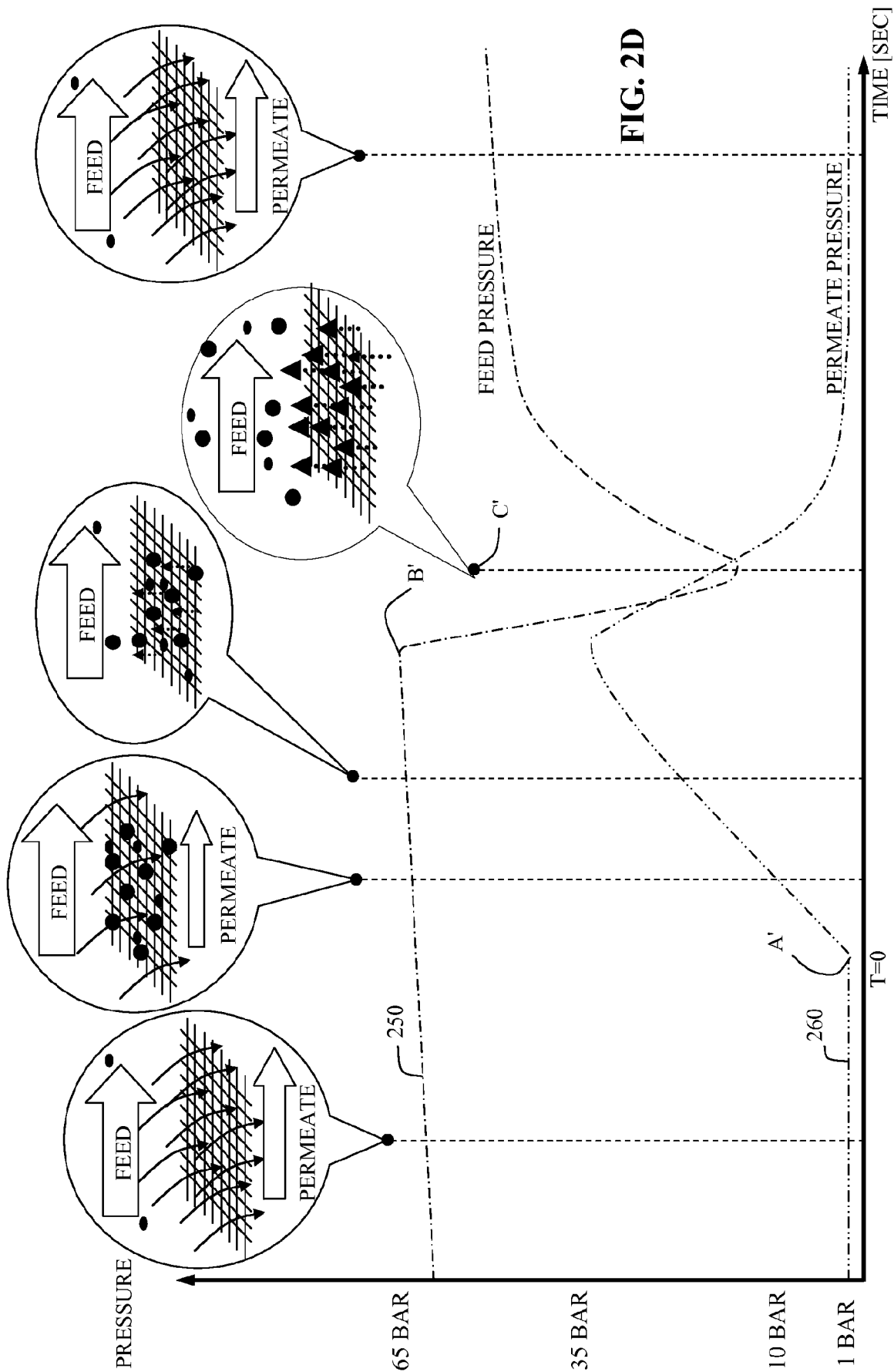












INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2013/050744

A. CLASSIFICATION OF SUBJECT MATTER IPC (2013.01) B01D 46/04, B01D 61/02, B01D 65/02, C02F 1/44 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC (2013.01) B01D 61/02, B01D 65/02 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Databases consulted: THOMSON INNOVATION, Esp@cenet, Google Patents Search terms used: flush, backwash, counter current, back pressure, back flush, regenerat , clean, treatment, osmo, RO, reverse osmosis, reverse pressure, DO, direct osmosis, forward osmosis, membran, differential pressure, pressure differential, transmembrane, trans-membrane.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007181497 A1 MEMBRANE RECOVERY LTD et al 09 Aug 2007 (2007/08/09) Fig.2-8,11,12; Paragraphs: 0026, 0030-0071, 0124- 0137, 0149, 0156-0171, 0187-0200.	1-21
X	US 3654148 A PUREDESAL INC. et al 04 Apr 1972 (1972/04/04) Figure 2; Column 5 lines 35-46, Column 6 line 52 - 57, Column 7 lines 31 - 71.	1,2,11,12
A	US 3853756 A WESTINGHOUSE ELECTRIC CORP et al 10 Dec 1974 (1974/12/10) Fig.2; Column 2 lines 1-14, Column 3 line 40 - Coumn 4 line 26.	1-21
A	US 2004134521 A1 LIBERMAN BORIS 15 Jul 2004 (2004/07/15) Paragraphs 0072-0117	1-21
A	WO 2012104684 A1 I.D.E. TECHNOLOGIES LTD. et al 09 Aug 2012 (2012/08/09) Figure 1; Paragraphs 0046-0052	1,2,11,12
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 19 Dec 2013		Date of mailing of the international search report 23 Dec 2013
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616		Authorized officer Aamidor Josh Telephone No. 972-2-5651722

INTERNATIONAL SEARCH REPORT
Information on patent family members

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