SYSTEM AND METHOD FOR WATER TREATMENT

TECHNOLOGICAL FIELD

The present application is directed to systems and method of water treatment, in particular, methods allowing operation of a treatment facility.

BACKGROUND ART

Desalination processes and/or treatment processes are well known in the art, and are configured for receiving feed water and, following proper treatment, to produce a first stream of 'product' water (usually clean/fresh water) also known as permeate, and a second stream of brine (usually highly saline water).

Different systems and methods were devised in order to increase the efficiency of such treatment processes, including more sophisticated membranes, water recirculation arrangements etc.

Some examples are provided below:

US 7,628,921 discloses an apparatus for consecutive sequential closed-circuit desalination of a salt water solution by reverse osmosis having at least one circuit and a single container (CN), wherein the circuit includes at least one RO module (M 1) connected in parallel;

US 7,695,614 discloses an apparatus for continuous closed-circuit consecutive sequential desalination of a salt water solution by reverse osmosis that comprises a closed circuit system comprising one or more desalination modules having their respective inlets and outlets connected in parallel by conducing lines, each of desalination modules comprising of one or more membrane elements, a pressurizing device for creating counter pressure to enable reverse osmosis desalination and replacement of released permeate, a circulation system for recycling the desalinated solution through the desalination modules, a conducting line systems for permeate collection from the desalination modules, a conducting line system for removing brine effluent a valve system to enable periodic discharge of brine from the closed circuit without stopping desalination, and monitoring and control systems to enable continuous

closed circuit desalination of desired recovery proceed in consecutive sequential steps under variable or constant pressure conditions;

US2008/217222 discloses a modular unit apparatus for continuous separation of suspended particles from feed solutions or fluids by a consecutive sequential process in closed circuit that comprises, a closed circuit system comprising cross flow membrane filter modules having their respective inlets and outlets connected in parallel with each said module comprising a cross flow membrane filter element within housing, a circulation system enabling recycling of the feed solution or fluid through the membrane, a conducting line system for supply of said fresh feed to the closed circuit, a conducting line system for permeate collection from the membrane modules, a conducting line system for removing concentrated suspended particles solutions or fluids from the closed circuit, two valve systems for enabling connection or disconnection of said fresh feed supply line to the closed circuit, and for enabling periodic discharge suspended solution from the closed circuit without stopping filtration, and a monitoring and control systems; and

US 8,025,804 discloses an apparatus for continuous closed-circuit consecutive sequential desalination of a salt water solution by reverse osmosis that comprises a closed circuit system comprising one or more desalination modules having their respective inlets and outlets connected in parallel by conducing lines, each of desalination modules comprising of one or more membrane elements, a pressurizing device for creating counter pressure to enable reverse osmosis desalination and replacement of released permeate by fresh, a circulation system for recycling the desalinated solution through the desalination modules, a conducting line systems for permeate collection from the desalination modules, a conducting line system for removing brine effluent a valve system to enable periodic discharge of brine from the closed circuit without stopping desalination, and monitoring and control systems to enable continuous closed circuit desalination of desired recovery proceed in consecutive sequential steps under variable or constant pressure conditions

Acknowledgement of the above references herein is not to be inferred as meaning that these are in any way relevant to the patentability of the presently disclosed subject matter.

GENERAL DESCRIPTION

The present invention seeks to provide improved water treatment systems and methods. There is thus provided in accordance with an embodiment of the present invention a method of treatment of liquid including supplying liquid to be treated to at least one liquid treatment module employing at least one of reverse osmosis and nanofiltration membranes, the at least one module having a liquid inlet, a permeate outlet and a brine outlet, monitoring liquid pressure within the at least one liquid treatment module and upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, reducing the liquid pressure in the at least one liquid treatment module by performing at least one of the following functions: opening a liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of a circulation pump which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside a liquid feed tank and opening a liquid pressure reducing valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses a liquid pressure increasing pump upstream of the liquid inlet.

In accordance with an embodiment of the present invention upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, the liquid pressure in the at least one liquid treatment module is reduced by performing at least two of the following functions: opening a liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of a circulation pump which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside a liquid feed tank and opening a liquid pressure reducing

valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses a liquid pressure increasing pump upstream of the liquid inlet.

In accordance with an embodiment of the present invention upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, the liquid pressure in the at least one liquid treatment module is reduced by performing at least three of the following functions: opening a liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of a circulation pump which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside a liquid feed tank and opening a liquid pressure reducing valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses a liquid pressure increasing pump upstream of the liquid inlet.

In accordance with an embodiment of the present invention upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, the liquid pressure in the at least one liquid treatment module is reduced by performing all of the following functions: opening a liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of a circulation pump which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside a liquid feed tank and opening a liquid pressure reducing valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses a liquid pressure increasing pump upstream of the liquid inlet.

There is also provided in accordance with another embodiment of the present invention a method of treatment of liquid including: supplying at least one water treatment module including at least one membrane and having a feed water inlet at a feed side of the at least one membrane, a permeate outlet at a permeate side of the at least one membrane and a brine outlet at a brine side of at least one membrane, pressurizing feed water supplied to the feed water inlet by employing a pump which normally maintains a fixed output feed water volume notwithstanding variations in water pressure at an outlet thereof, the energy consumption of the pump being a function of the variations in water pressure at the outlet, monitoring the water pressure at the outlet of the pump and when a predetermined high pressure threshold is reached at the outlet of the pump, immediately making changes in the water supply to the module, thereby to cause immediate lowering of the water pressure at the outlet of the pump, to a pressure below the osmotic pressure at the feed side of part but not all of the module, thereby immediately reducing the energy consumption of the pump, thereby providing an overall energy cost savings per unit of water treated.

There is further provided in accordance with yet another embodiment of the present invention a method for treatment of liquid in at least one liquid treatment module including at least a high pressure pump and a circulation pump, the method including upon occurrence of an operational threshold representing exceedence of a salinity threshold in the at least one liquid treatment module, effecting the following: removing brine from the at least one liquid treatment module and reducing, at an enhanced speed, pressure of the liquid in the at least one liquid treatment module by at least one of the following: opening a pressure reducing valve downstream of the high pressure pump, increasing the volume output of the circulation pump from its volume output when functioning as a concentrate circulation pump to a higher volume output when functioning as a feed water pump and passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump, and passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump includes passing the liquid via a flow restrictor arranged in parallel to the high pressure feed pump.

In accordance with an embodiment of the present invention the pressure of the liquid in the at least one liquid treatment module is reduced at an enhanced speed by at least two of the following: opening a pressure reducing valve downstream of the high

pressure pump, increasing the volume output of the circulation pump from its volume output when functioning as a concentrate circulation pump to a higher volume output when functioning as a feed water pump and passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump. Alternatively, the pressure of the liquid in the at least one liquid treatment module is reduced at an enhanced speed by all of the following: opening a pressure reducing valve downstream of the high pressure pump, increasing the volume output of the circulation pump from its volume output when functioning as a concentrate circulation pump to a higher volume output when functioning as a feed water pump and passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump.

The liquid treatment module is a water treatment module including at least one of at least one reverse osmosis membrane and at least one nanofiltration membrane and is operative for treatment of at least one of sea water, brackish water and waste water.

There is even further provided in accordance with another embodiment of the present invention a water treatment system including: at least one liquid treatment module operative to receive feed water at a water inlet thereof and to separate the feed water into permeate and concentrate, the permeate constituting treated water, the at least one liquid treatment module having a brine outlet for release of concentrate whose salinity is such that an operational threshold of the system is exceeded, a liquid pressure reducing valve at the brine outlet, a high pressure pump, operative to pressurize liquid to be treated received at a liquid feed inlet and to provide a pressurized feed water output to the at least one liquid treatment module, a feed water flow rate sensor located upstream of the high pressure pump and providing a feed water flow rate output, a pump controller receiving the feed water flow rate output and controlling the operation of the high pressure pump, a liquid pressure sensor for providing an output indication of liquid pressure at at least one of an inlet to the at least one liquid treatment module, an outlet from the at least one liquid treatment module and within the at least one liquid treatment module, a circulation pump which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet, a liquid feed tank, a system controller receiving at least the output indication of liquid pressure within the at least one liquid treatment module, the system controller being operative, upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, reducing the liquid pressure in

the at least one liquid treatment module by performing at least one of the following functions: opening the liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of the circulation pump, which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside the liquid feed tank and opening a liquid pressure reducing valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses the high pressure pump upstream of the liquid inlet.

In accordance with an embodiment of the present invention the system controller is operative, upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, reducing the liquid pressure in the at least one liquid treatment module by performing at least two of the following functions: opening the liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of the circulation pump, which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside the liquid feed tank and opening a liquid pressure reducing valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses the high pressure pump upstream of the liquid inlet.

Alternatively, the system controller is operative, upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, reducing the liquid pressure in the at least one liquid treatment module by performing at least three of the following functions: opening the liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds

osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of the circulation pump, which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside the liquid feed tank and opening a liquid pressure reducing valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses the high pressure pump upstream of the liquid inlet.

In another alternative embodiment, the system controller is operative, upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, to reduce the liquid pressure in the at least one liquid treatment module by performing all of the following functions: opening the liquid pressure reducing valve at the brine outlet, thereby reducing the liquid pressure at the brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of the liquid in the at least one liquid treatment module, increasing a liquid volume output of the circulation pump, which removes brine from the at least one liquid treatment module and supplies liquid to the water inlet from a liquid volume output at times other than upon and immediately following the exceedance, equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside the liquid feed tank and opening a liquid pressure reducing valve at the liquid inlet, thereby providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module which bypasses the high pressure pump upstream of the liquid inlet.

There is yet further provided in accordance with still another embodiment of the present invention aa water treatment system including at least one water treatment module including at least one membrane and having a feed water inlet at a feed side of the at least one membrane, a permeate outlet at a permeate side of the at least one membrane and a brine outlet at a brine side of at least one membrane, a high pressure pump, which normally maintains a fixed output feed water volume notwithstanding variations in water pressure at an outlet thereof, a system controller receiving at least the output indication of liquid pressure within the at least one liquid treatment module, the system controller being operative, upon exceedance of a liquid pressure threshold in the

at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, to reduce the liquid pressure in the at least one liquid treatment module by performing at least one of the following functions: pressurizing feed water supplied to the feed water inlet by employing the high pressure pump, the energy consumption of the high pressure pump being a function of the variations in water pressure at the outlet, monitoring the water pressure at the outlet of the high pressure pump and when a predetermined high pressure threshold is reached at the outlet of the high pressure pump, immediately making changes in the water supply to the at least one liquid treatment module, thereby to cause immediate lowering of the water pressure at the outlet of the high pressure pump, to a pressure below the osmotic pressure at the feed side of part but not all of the at least one liquid treatment module, thereby immediately reducing the energy consumption of the high pressure pump, thereby provide an overall energy cost savings per unit of water treated.

There is still further provided in accordance with yet another embodiment of the present invention a water treatment system including at least one water treatment module including at least one membrane and having a feed water inlet at a feed side of the at least one membrane, a permeate outlet at a permeate side of the at least one membrane and a brine outlet at a brine side of at least one membrane, a high pressure pump, which normally maintains a fixed output feed water volume notwithstanding variations in water pressure at an outlet thereof, a pressure reducing valve downstream of the high pressure feed pump, a circulation pump, a system controller receiving at least the output indication of liquid pressure within the at least one liquid treatment module, the system controller being operative, upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, to reduce the liquid pressure in the at least one liquid treatment module by performing at least one of the following functions: upon occurrence of an operational threshold representing exceedence of a salinity threshold in the at least one liquid treatment module, effecting the following: removing brine from the at least one liquid treatment module and reducing, at an enhanced speed, pressure of the liquid in the at least one liquid treatment module by at least one of the following: opening the pressure reducing valve downstream of the high pressure feed pump, increasing the volume output of the circulation pump from its volume output when functioning as a concentrate circulation pump to a higher volume output when

functioning as a feed water pump and passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump.

The water treatment system also includes a flow restrictor arranged in parallel to the high pressure feed pump and the passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump includes passing the liquid via the flow restrictor.

In accordance with an embodiment of the present invention the pressure of the liquid in the at least one liquid treatment module is reduced at an enhanced speed by at least two of the following: opening the pressure reducing valve downstream of the high pressure feed pump, increasing the volume output of the circulation pump from its volume output when functioning as a concentrate circulation pump to a higher volume output when functioning as a feed water pump and passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump. Alternatively, the pressure of the liquid in the at least one liquid treatment module is reduced at an enhanced speed by at least three of the following: opening the pressure reducing valve downstream of the high pressure feed pump, increasing the volume output of the circulation pump from its volume output when functioning as a concentrate circulation pump to a higher volume output when functioning as a feed water pump and passing liquid from downstream of the high pressure feed pump to upstream of the high pressure feed pump.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

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

Figs. 2A and **2B** are simplified illustrations of examples of periodic variations in feed water pressure and osmotic pressure in embodiments of the system of Fig. 1, each showing a distinction from the prior art;

Figs. 3A, **3B**, **3C** and **3D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and

osmotic pressure shown in Fig. 2A in accordance with one embodiment of the present invention;

Figs. 4A, **4B**, **4C** and **4D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and osmotic pressure shown in Fig. 2A in accordance with another embodiment of the present invention;

Figs. 5A, **5B** and **5C** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and osmotic pressure shown in Fig. 2A in accordance with still another embodiment of the present invention;

Figs. 6A, **6B**, **6C** and **6D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and osmotic pressure shown in Fig. 2B in accordance with yet another embodiment of the present invention;

Figs. 7A, **7B**, **7C** and **7D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and osmotic pressure shown in Fig. 2B in accordance with a further embodiment of the present invention;

Figs. 8A, **8B**, **8C** and **8D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and osmotic pressure shown in Fig. 2B in accordance with still a further embodiment of the present invention;

Figs. 9A, **9B**, **9C** and **9D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and osmotic pressure shown in Fig. 2A in accordance with yet a further embodiment of the present invention;

Figs. 10A, **10B**, **10C** and **10D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and osmotic pressure shown in Fig. 2A in accordance with an alternative embodiment of the present invention; and

Figs. 11A, **11B**, **11C** and **11D** are simplified illustrations of liquid flows in the system of Fig. 1 at various stages in the periodic variation in feed water pressure and

osmotic pressure shown in Fig. 2B in accordance with a further embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Reference is now made to Fig. 1, which is a simplified illustration of a liquid treatment system constructed and operative in accordance with an embodiment of the present invention, and to Figs. 2A and 2B, which are simplified time-line illustrations of examples of the operation of the system of Fig. 1, wherein seawater is being desalinated.

The liquid treatment system of Fig. 1 comprises at least one liquid treatment module, water treatment module **100,** comprising reverse osmosis membranes and/or nanofiltration membranes. The system of Fig. 1 is operative for treatment of liquid to be treated, such as feed water, which may be, for example, sea water, brackish water or waste water.

Water treatment module **100** is described in applicant's U.S. Patent Application No. 13/603,028, filed September 4, 2012 and entitled SYSTEM AND METHOD FOR DESALINATION OF WATER, and published as U.S. Published Patent Application No. 2014/0061129 on March 6, 2014, the disclosure of which is hereby incorporated by reference. Fig. 2A in U.S. Patent Application No. 13/603,028 illustrates a water treatment module, here designated by reference numeral **100.**

For the purposes of the description which follows, the following definitions will be employed:

feed water - water to be treated by the system, such as saline solution, sea water, brackish water or waste water;

mixed feed water - water supplied to water treatment module **100,** which may include feed water and water that was previously treated in the water treatment module **100** and is being resupplied to the water treatment module for further treatment;

module feed side water - water at a feed side, as distinguished from a permeate side, of module **100.** The salinity of the module feed side water increases as the module feed side water passes through the module from an initial salinity, which represents the salinity of the mixed feed water, to a concentrate salinity, which represents the salinity of the concentrate output at an output of the feed side, as distinguished from the permeate side, of module **100.**

It is an inherent feature of water treatment modules **100** that the osmotic pressure at the feed side thereof increases over time as the salinity at the feed side increases until such time as the salinity at the feed side is reduced, thereby reducing the osmotic pressure. As described hereinbelow, the salinity of the mixed feed water at the feed side is reduced by supplying only feed water instead of a mixture of feed water and recirculated concentrate.

An increase in osmotic pressure requires a corresponding increase in water pressure at the feed side of the module **100** in order to maintain permeate production. This increase is provided automatically by a high pressure pump **102,** operative to pressurize the liquid to be treated to typical pressures of approximately **15** bar for brackish water and up to approximately **70** bar for sea water.

High pressure pump **102** may be any suitable type of pump, such as a positive displacement pump. An example of a positive displacement pump is a Danfoss APP 21-43 high pressure pump, commercially available from Danfoss A/S Nordborgvej 81, 6430 Nordborg, Denmark. High pressure pump **102** is controlled by the output of a feed water flow rate sensor **104** upstream of pump **102,** which is received by a pump controller **106,** for example an ABB ACS800-U1 controller, commercially available from ABB Inc. MS 3L7 29801 Euclid Ave, Wickliffe, OH 44092-2530, USA.

A mixed feed water pressure sensor **108** is provided at the feed side of module **100.** A typical graph of mixed feed water pressure as measured by pressure sensor **108** over time and verses the osmotic pressure at the feed side of the module **100** appears in an enlargement forming part of Fig. 1 and in Figs. 2A and 2B. Alternatively or additionally, a water pressure sensor may be provided at a suitable location within module **100** or at a module outlet for measuring the pressure of liquid flowing therethrough.

The variation of feed water 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.

As seen in Fig. 1, water treatment module includes a plurality of pressure vessels **110** arranged in parallel. Each pressure vessel **110** includes, for example, a plurality of membrane elements **112,** typically eight in number, only four being shown in the drawing for the sake of conciseness. Pressure vessels **110** are commercially available from various vendors, for example BEL Composite Industries Ltd, Industrial Zone,

Kiryat Yehudit, P.O.B. 4, 84100 Beer Sheva, Israel, and membrane elements **112** are commercially available from various vendors, for example LG NanoH2O, 750 Lairport Street, El Segundo, CA 90245.

Liquid to be treated is supplied at a liquid feed inlet and is pressurized by high pressure pump **102,** operative to pressurize the liquid to be treated to typical pressures of approximately **15** bar for brackish water and up to approximately **70** bar for sea water.

The liquid to be treated, hereinafter referred to as feed water, wherein the definition of "feed water" encompasses, inter alia, saline solution, brackish water, sea water and waste water, is supplied via a feed manifold **114** to the parallel pressure vessels **110.** Treated water, hereinafter referred to as permeate, wherein the definition of "permeate" encompasses, inter alia, "product water", from each of pressure vessels **110,** is supplied via a permeate manifold **116** to a permeate outlet **118.**

Concentrate from each of pressure vessels **110** is supplied via a concentrate manifold **120** to a recirculation conduit **122,** which directs the concentrate back to feed manifold **114,** downstream of pump **102,** via a recirculation control valve **124** by employing a circulation pump **126.** A concentrate pressure sensor **128,** a concentrate conductivity sensor **129** and a concentrate flow rate sensor **130** are provided downstream of concentrate manifold **120.**

Concentrate from module **100** may also be provided from pressure vessels **110** via concentrate manifold **120** to a brine outlet **132** via a brine outlet control valve **134** for flushing. Concentrate that exits module **100** and is not recirculated is referred to herein as brine. The salinity of the brine that is flushed is greater than the salinity of the concentrate that is recirculated via conduit **122.**

In some embodiments of the present invention, brine from each of pressure vessels **110** may be supplied from concentrate manifold **120** via an auxiliary brine replacement conduit **136,** an auxiliary tank feed conduit **138** and an auxiliary brine replacement control valve **140** to an auxiliary feed water tank **142.** The salinity of the brine supplied to auxiliary feed water tank **142** exceeds the salinity of the concentrate that is recirculated via conduit **122.**

It is appreciated that, as described further hereinbelow, the decision to recirculate the liquid as concentrate or to flush the liquid as brine may be a function of the salinity of the liquid, a function of the pressure of the liquid, a function of a rate of

accumulation of foulants on membrane elements, a system energy efficiency rating, or may be based on a predetermined time schedule or any other suitable method. Additionally or alternatively, the selection of the threshold may be predetermined to be a suitable threshold which will avoid or minimize precipitation of foulants on the membrane elements **112** in module **100.**

During the flushing of brine, the recirculation control valve **124** is closed. The auxiliary feed water tank **142** is filled, prior to the opening of auxiliary brine replacement control valve **140,** with feed water by an auxiliary feed water pump **144.** Brine driven by circulation pump **126** drives the feed water from auxiliary feed water tank **142** to feed manifold **114** via an auxiliary feed water conduit **146** and an auxiliary feed water control valve **148.** An auxiliary water flow sensor **150** is provided upstream of auxiliary feed water tank **142.** After full replacement of brine by feed water in module **100,** the recirculation control valve **124** is opened and auxiliary brine replacement control valve **140** and auxiliary feed water control valve **148** are closed. Then auxiliary feed water pump **144** fills auxiliary feed water tank **142** with feed water, which drives the brine to an auxiliary brine outlet **152** via an auxiliary brine outlet tank control valve **154.**

It is appreciated that, alternatively, elements **136 - 154** may be obviated.

In some embodiments of the present invention, water pressure at the feed side of the module **100** may be quickly reduced at desired points in time by operation of a recycle conduit control valve **156** to redirect feed water from downstream of high pressure feed pump **102** to upstream of pump **102** through a conduit **158** and through a flow restrictor **160,** which limits the pressure reduction to a pressure above atmospheric pressure, which pressure exceeds the osmotic pressure of the feed water at the feed side of module **100.**

In accordance with an embodiment of the present invention there is provided a Feed Pressure Management (FPM) Controller **162,** which controls the operation of the high pressure feed pump **102,** circulation pump **126,** auxiliary feed water pump **144,** recirculation control valve **124,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148,** auxiliary brine outlet tank control valve **154,** and recycle conduit control valve **156** for adjusting the pressure at which desalination takes place at the at least one water treatment module.

As seen in Figs. **2A** and **2B**, which will be described in detail hereinbelow, and refer to examples wherein seawater is being desalinated, periodic variations in the feed water pressure during water treatment correspond to periodic variations in the osmotic pressure, which corresponds to the salinity of the feed water supplied to module **100,** as measurable by a conductivity sensor (not shown) typically downstream of pressure sensor **108.**

Control over the variation of the feed water pressure may be achieved in various ways, such as according to the flow rate measured by flow sensor **104** and, alternatively or additionally, according to the salinity of the water being supplied to the feed side of the module **100,** which may include feed water received from pump **102,** recirculated water received from recirculation conduit **122,** auxiliary feed water received via auxiliary conduit **146** and combinations thereof.

Alternatively, the feed pressure may be varied in accordance with a predetermined time schedule. As a further alternative, the desired feed pressure may be reached by employing recycle conduit **158** with or without flow restrictor **160.** Other alternative methodologies for control over the variation of the feed pressure may be employed.

FPM controller **162** is operative to periodically open and close recirculation control valve **124,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148,** auxiliary brine outlet tank control valve **154** and recycle conduit control valve **156** in accordance with a predetermined time schedule or alternatively, for example, in response to either sensed salinity of the concentrate, for example as per an output of sensor **129,** or exceedance of a predetermined maximum feed pressure threshold, for example as per an output of sensor **108** or sensor **128.**

FPM controller **162** is also operative to periodically activate auxiliary feed water pump **144** and may also be operative to change the flow rate of circulation pump **126.** Other alternative algorithms for control of opening and closing recirculation control valve **124,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148,** auxiliary brine outlet tank control valve **154** and recycle conduit control valve **156,** and for control of the operation of the high pressure feed pump **102,** circulation pump **126** and auxiliary feed water pump **144** may be employed.

In some embodiments of the invention, once the concentration of the concentrate increases to a predetermined level at which continued water treatment is deemed not to be practicable, the FPM controller **162** opens auxiliary brine replacement control valve **140** and allows brine to flow from concentrate manifold **120,** via auxiliary brine replacement conduit **136** and auxiliary tank feed water conduit **138,** to auxiliary feed water tank **142.** In some embodiments of the invention, FPM controller **162** also closes recirculation control valve **124** at about the same time. The volume of the brine flowing out of the system may be measured by concentrate flow rate sensor **130.** Feed water that was in auxiliary feed water tank **142** is driven by circulation pump **126** to flow via auxiliary feed water conduit **146** and auxiliary feed water control valve **148** to feed manifold **114.** Feed water, having salinity which is significantly lower than that of the brine, thus enters module **100.**

Various methodologies for ensuring that the feed water pressure is above atmospheric pressure and above the osmotic pressure of the feed water at the feed side of module **100** at all times are described hereinbelow with reference to Figs. 2A & 2B and to Figs. 3A - 11D. Ensuring that the feed water pressure remains above atmospheric pressure and above the osmotic pressure of the feed water at the feed side of module **100** prevents overshooting of the feed pressure when feed water from high pressure feed pump **102** enters the module **100,** which overshooting commonly occurs in prior art systems.

It is appreciated that the term ‘overshooting’ as used herein refers to operating the high pressure feed pump **102** at an excessively high pressure relative to the osmotic pressure of the feed water, which is typically caused when the controller causes the system to supply feed water, as from auxiliary feed water tank **142,** instead of recirculated concentrate to modules **100,** without modifying the pressure of feed water supplied via high pressure feed pump **102.** The operation of the high pressure feed pump **102** at an excessively high pressure relative to the osmotic pressure of the feed water, increases the energy required to operate the system.

In the description which follows, it is to be appreciated that the pressure values given for the various embodiments described hereinbelow and shown in Figs. 2A & 2B are values associated with membrane sea water desalination. Different pressure values will apply to desalination of brackish water and other types of feed water.

In steady state normal operation of the system, prior to initiation of a periodic process of replacing the concentrate in the water treatment module **100** with feed water, brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148,** auxiliary brine outlet tank control valve **154** and recycle conduit control valve **156** are all closed and recirculation control valve **124** is open.

In this steady state normal operation, concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown in Fig. **1** by an arrow labeled CONCENTRATE representing the recirculation flow in recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown in Fig. **1** by an arrow labeled MIXED, representing the mixed flow in the feed manifold **114,** and the mixed flow enters pressure vessels **110** of module **100** for treatment. The above-described flow in steady state normal operation is represented in solid black lines in Figs. 3A, 4A, 5A, 6A, 7A, 8A, 9A, 10A and 11A, not including the permeate flow via permeate manifold **116** to a permeate outlet **118**.

The feed pressure gradually increases as the salinity of the mixed water being supplied to the membrane elements **112** increases. Once the concentration of the concentrate increases to a predetermined level at which continued water treatment is deemed not to be practicable, the periodic process of replacing the concentrate in the water treatment module **100** with feed water is initiated. Figs. 3A - 11D illustrate various techniques for replacing the concentrate in the water treatment module **100** with feed water at a pressure above atmospheric pressure, which exceeds the osmotic pressure of the feed water at the feed side of module **100** without causing overshooting.

Typically, the predetermined level of concentrate concentration deemed not to be practicable to continue treating, is based on one of a number of operational considerations, such as rate of accumulation of foulants and energy efficiency.

Reference in now made to Fig. 2A, which illustrates the periodic variations in mixed feed water pressure as measured by pressure sensor **108,** and in the mixed feed water osmotic pressure estimated to exist at pressure sensor **108** when circulation pump **126** is operating at a normal pumping rate. The estimated mixed feed water osmotic pressure at pressure sensor **108** is generally a function of the salinity of the water at the feed side of the membranes **112** in module **100.**

Periodic variations in the mixed feed water pressure during water treatment correspond to periodic variations in the salinity of the feed water entering module **100,** as measurable by the conductivity sensor, typically located downstream of pressure sensor **108.** The y-axis represents pressure in seawater desalination, and the x-axis represent time. Dashed vertical lines 'A' represent points in time where a threshold, such as a maximum feed water pressure threshold, is reached.

When the threshold is reached, pressure vessels **110** are still filled with concentrate, whose salt concentration continues to increase as it moves through the pressure vessel. Therefore, both mixed feed water osmotic pressure and mixed feed water pressure continue to increase, until feed water enters the pressure vessels **110** replacing the concentrate therein. Typically, reaching the threshold causes the system to begin the brine flushing process.

In Figs. 2A and 2B, the mixed feed water osmotic pressure line **170** represents the estimated osmotic pressure of the mixed feed water. Thus, when feed water from pump **102** is mixed with concentrate from recirculation conduit **122,** the mixed osmotic pressure gradually increases as seen in the gradual slope of line **170.** Once a threshold, such as a salinity threshold or a pressure threshold, is reached the controller **162** begins the flushing process. During the flushing process, concentrate is not recirculated back to feed manifold **114,** thus only feed water enters feed manifold **114** and the mixed osmotic pressure decreases sharply, as shown in the sharp decline in line **170.**

Line **175** in Fig. 2A illustrates the behavior of the mixed feed water pressure in the prior art, represented by the teaching of U.S. Patent No. 8,025,804. As can be observed, the mixed feed water pressure line 175 begins its drop (denoted by the dotted line to the right of dotted line A) only after the osmotic pressure already dropped below a certain threshold.

In contrast, line **180** illustrates the mixed feed water pressure of the present application, being controlled by the controller such that the mixed feed water pressure needed for reverse osmosis desalination process is maintained not only during the gradual increase of mixed feed water pressure, when concentrate is being recirculated back to feed manifold **114,** but also at times of flushing the brine in pressure vessels **110** by feeding only feed water without recirculated concentrate.

The difference between line **175** and line **180**, illustrates the energy benefit of operation at lower pressures for desalination of sea water, thus saving energy.

In both Figs. 2A and 2B, line **190** illustrates the osmotic pressure of the module feed side water.

As described further hereinbelow, Fig. 2B is similar to Fig. 2A, except that the values are provided for the embodiment where circulation pump **126** is operating at a higher than normal pumping rate, generating a higher flow.

Reference is now made to Figs. 3A - 3D, which are simplified illustrations of water flows in a first embodiment of a water treatment system of the type shown in Fig. **1.**

Fig. 3A shows the flow during normal steady state operation of the system in solid black.

Fig. 3B shows, in solid black lines, the flow that takes place, once the concentration of the concentrate increases to a predetermined level. At this stage, the FPM controller **162** opens auxiliary brine replacement control valve **140,** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** Brine from concentrate manifold **120** flows through auxiliary brine replacement conduit **136** and auxiliary brine replacement control valve **140** via auxiliary tank feed conduit **138** to auxiliary feed water tank **142.** The auxiliary feed water tank **142** is filled with feed water prior to the opening of auxiliary brine replacement control valve **140,** as described hereinbelow. The brine enters the auxiliary feed water tank **142** and drives feed water from tank **142** to feed manifold **114** via auxiliary feed water conduit **146** and auxiliary feed water control valve **148.**

It is noted that water in auxiliary feed water tank **142** may be maintained at the same pressure as that of the brine, such as by maintaining auxiliary brine replacement control valve **140** in an open state as the water pressure in the system gradually increases. Alternatively, the water in the auxiliary feed water tank **142** may be maintained at a pressure which is much lower than the pressure of the brine but above atmospheric pressure by operation of auxiliary feed water pump **144,** as described hereinbelow.

During flushing, FPM controller **162** opens recycle conduit control valve **156,** resulting in a water flow from a location downstream of pump **102** to a location upstream of pump **102,** optionally thorough a restrictor **160,** thus lowering the feed water pressure at manifold **114** to a pressure above atmospheric pressure, which pressure exceeds the osmotic pressure of the feed water at the feed side of module **100.**

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120** and thus measures the cumulative volume of feed water entering feed manifold **114** via auxiliary feed water conduit **146** and auxiliary feed water control valve **148,** which replaces the brine in module **100.**

After complete replacement of brine with feed water in module **100,** FPM controller **162** reopens recirculation control valve **124** and closes auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156,** providing a liquid flow as shown in Fig. **3C**, which may be identical to the liquid flow illustrated in Fig. 3A, in which the operation of circulation pump **126** and of high pressure pump **102** supplies mixed feed water to module **100.**

Thereafter, FPM controller **162** periodically activates auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a location outside of the at least one water treatment system, and to fill the auxiliary feed tank **142** with feed water for future replacement of the brine in module **100.** This flow is shown in solid black lines in Fig. 3D.

Following full replacement of brine with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow sensor **150,** FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of auxiliary feed water pump **144.**

Reference is now made to Figs. 4A - 4D, which are simplified illustrations of water flows in a second embodiment of a water treatment system of the type shown in Fig. **1.**

Prior to initiation of removal of the concentrate from the module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is open. The concentrate from concentrate manifold **120** is directed back to input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. 1), representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1), representing the mixed flow in the feed manifold **114.** Thus, a mixed flow

enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 4A.

The feed pressure thereafter gradually increases, as the salinity of the mixed water being supplied to membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined salinity level at which continued water treatment is deemed not to be practicable, FPM controller **162** opens auxiliary brine replacement control valve **140,** which is approximately at atmospheric pressure, thus reducing the water pressure within module **100** to a pressure between the pressure of the concentrate at module **100** and the pressure of the feed water in the auxiliary feed tank **142.**

Immediately thereafter, FPM controller **162** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** Feed water from auxiliary feed tank **142** flows via auxiliary feed water conduit **146** and feed water control valve **148** to feed manifold **114,** as shown in Fig. **4B**, thus supplying feed water to module **100** at a pressure above the osmotic pressure of the feed water and slightly higher than the pressure required for reverse osmosis to occur.

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120,** and thus measures the cumulative volume of feed water entering feed manifold **114** via the auxiliary feed water conduit **146** and the auxiliary feed water control valve **148,** which replaces the brine in module **100.**

After full replacement of the brine with feed water in module **100,** FPM controller **162** reopens recirculation control valve **124,** and closes auxiliary brine replacement control valve **140** and auxiliary feed water control valve **148,** providing a liquid flow as shown in Fig. 4C, which may be identical to the liquid flow illustrated in Fig. 4A, in which the operation of high pressure pump **102** and the circulation pump **126** supplies mixed feed water to module **100.**

Thereafter, the FPM controller **162** periodically activates the auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a location outside of the at least one water treatment system and fill the auxiliary feed tank **142** with feed water for further replacement of the brine in module **100** with feed water as described hereinabove, as seen in Fig. 4D. Following full replacement of brine

with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow sensor **150,** FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of auxiliary feed water pump **144.**

Reference is now made to Figs. 5A-5C, which are simplified illustrations of water flows in another embodiment of a water treatment system of the type shown in Fig. **1.**

Prior to initiation of removal of the concentrate from module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is opened. The concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. 1), representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1) representing the mixed flow in the feed manifold **114.** Thus, a mixed flow enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 5A.

The feed pressure thereafter gradually increases as the salinity of the mixed water being supplied to the membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined salinity level at which continued water treatment is deemed not to be practicable, FPM controller **162** closes concentrate recirculation control valve **124** and at least partially opens brine outlet control valve **134,** thus allowing brine to flow via brine outlet **132** to a location outside of the at least one water treatment system, thus reducing the system pressure to a pressure above the atmospheric pressure, which pressure exceeds the osmotic pressure of the feed water at the feed side of module **100.** The brine is all flushed through brine outlet **132** from the at least one water treatment system, while high pressure feed pump **102** continues to pump feed water to feed side of module **100,** as shown in Fig. 5B. It is possible to increase the flow rate of pump **102** at this stage in order to speed the flushing of the brine.

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120,** and thus measures when the full flushing of the brine out of module **100** has been completed.

After fully flushing the brine from module **100,** FPM controller **162** reopens recirculation control valve **124** and closes brine outlet control valve **134,** providing a liquid flow as shown in Fig. 5C, which may be identical to the liquid flow illustrated in Fig. 5A, in which the operation of high pressure pump **102** and the circulation pump **126** supplies mixed feed water to module **100.**

Reference is now made to Figs. 6A – 6D, which are simplified illustrations of water flows in yet another embodiment of a water treatment system of the type shown in Fig. 1.

Prior to initiation of removal of the concentrate from module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is open. The concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. 1), representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1), representing the mixed flow in the feed manifold **114.** Thus, a mixed flow enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 6A.

The feed pressure thereafter gradually increases, as the salinity of the mixed liquid being supplied to the membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined pressure level, FPM controller **162** opens auxiliary brine replacement control valve **140,** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** Brine from concentrate manifold **120** flows through auxiliary brine replacement conduit **136,** auxiliary brine replacement control valve **140** and auxiliary tank feed conduit **138** to auxiliary feed water tank **142.**

The auxiliary feed water tank **142** is filled with feed water prior to the opening of brine replacement control valve **140,** as described hereinbelow. Brine entering the

auxiliary feed water tank **142** drives feed water in it to feed manifold **114** via an auxiliary feed water conduit **146** and an auxiliary feed water control valve **148.**

The water flow for this stage is shown in a solid black line in Fig. **6B**.

It is appreciated that the water in auxiliary feed water tank **142** may be maintained at a pressure generally the same as the pressure of the brine, such as by maintaining auxiliary opening brine replacement control valve **140** in an open state as the pressure in the system gradually increases. Alternatively, the water in the auxiliary feed water tank **142** may be maintained at a pressure which is much lower than the pressure of the brine but above the atmospheric pressure by operation of the auxiliary feed water pump **144** as described hereinbelow.

In the embodiment of Figs. 6A - 6D, FPM controller **162** increases the flow rate of circulation pump **126** during flushing to achieve faster replacement of the brine from module **100** with feed water from auxiliary feed tank **142,** hence, reducing the time required for the brine to be flushed from module **100** and replaced by feed water. A typical graph of flow rate over time, as measured by concentrate flow rate sensor **130,** located downstream of circulation pump **126,** appears in an enlargement forming part of Fig. 6B, in which line **200** represents the flow rate over time.

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120** and thus measures the cumulative volume of feed water entering feed manifold **114** via the auxiliary feed water conduit **146** and the auxiliary feed water control valve **148,** which replaces the brine in module **100.**

After complete replacement of the brine with feed water in module **100,** FPM controller **162** reopens recirculation control valve **124,** closes auxiliary brine replacement control valve **140** and auxiliary feed water control valve **148,** and reduces the flow rate of circulation pump **126** to the flow rate prior to opening concentrate recirculation control valve **124,** providing a liquid flow as shown in Fig. 6C, which may be identical to the liquid flow illustrated in Fig. 6A, in which the operation of high pressure pump **102** and the circulation pump **126** supplies mixed feed water to module **100.**

Thereafter, FPM controller **162** periodically activates auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a location outside of the at least one water treatment system, and fill the auxiliary feed tank **142** with feed

water for further replacement of the brine in module **100** with feed water as described hereinabove, as seen in Fig. 6D.

Following full replacement of brine with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow rate sensor **150,** FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of auxiliary feed water pump **144.**

Reverting now to Fig. 2B, wherein periodic variations in the feed water pressure during water treatment correspond to periodic variations in the salinity of the feed water entering module **100,** as measurable by a conductivity sensor (not shown), typically located downstream of pressure sensor **108.** As in Fig. 2A described hereinabove, the y-axis represents the pressure variations in seawater desalination, and the x-axis represent the time. Dashed vertical line 'A' represents the time where a threshold, such as a maximum feed water pressure threshold, is reached

When the threshold is reached, pressure vessels **110** are still filled with concentrate and both mixed osmotic pressure and mixed feed water pressure continue to increase, until feed water enters the pressure vessels **110** replacing the concentrate therein. Typically, reaching the threshold causes the system to begin the brine flushing process.

As described hereinabove, the mixed feed water osmotic pressure line **170** represents the estimated osmotic pressure of mixed feed water at module **100** inlet. Thus, when feed water from pump **102** is mixed with concentrate from recirculation conduit **122,** the mixed osmotic pressure gradually increases as seen in the gradual slope of line **170.** Once a threshold, such as a salinity threshold or a pressure threshold, is reached the controller **162** begins the flushing process. During the flushing process, concentrate is not recirculated back to feed manifold **114,** thus only feed water enters feed manifold **114** and the mixed osmotic pressure decreases sharply, as shown in the sharp decline in line **170.**

Line **175** in Fig. 2B illustrates the behavior of the mixed feed water pressure in the prior art, represented by the teaching of U.S. Patent No. 8,025,804. Line **180** illustrates the pressure being controlled by the controller such that the delta pressure needed for reverse osmosis desalination process is maintained not only during the gradual increase of mixed feed water pressure, when concentrate is being recirculated back to feed manifold **114,** but also at times of flushing the brine in pressure vessels **110**

by feeding only feed water without recirculated concentrate. As seen in Fig. 2B, increasing of flow rate of circulation pump **126,** vis-à-vis the flow rate of circulation pump **126** used in the example of Fig. 2A, causes the mixed osmotic pressure line **170,** as well as the mixed feed water pressure line **180,** to decrease even more rapidly than in the example shown in Fig. 2A. In Fig. 2B, the increased difference between line **175** and line **180,** vis-à-vis the difference between the two lines in Fig. 2A, illustrates the increased benefit of operation at lower pressures when the flow rate is increased, thus saving additional energy beyond the additional energy required to operate the circulation pump **126** at a higher flow rate.

Reference is now made to Figs. 7A - 7D, which are simplified illustrations of water flows in a further embodiment of a water treatment system of the type shown in Fig. 1.

Prior to initiation of removal of the concentrate from module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is open. The concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. **1)**, representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1), representing the mixed flow in the feed conduit **114.** Thus, a mixed flow enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 7A.

The feed pressure thereafter gradually increases as the salinity of the mixed water being supplied to the membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined salinity level at which continued water treatment is deemed not to be practicable, FPM controller **162** opens auxiliary brine replacement control valve **140,** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** The FPM controller also increases flow rate produced by circulation pump **126.** Brine from concentrate manifold **120** flows through auxiliary brine replacement conduit **136,** auxiliary tank feed conduit **138** and auxiliary brine replacement control valve **140** to

auxiliary feed water tank **142.** The auxiliary feed water tank **142** is filled with feed water prior to the opening of auxiliary brine replacement control valve **140,** as described hereinbelow. The brine enters the auxiliary feed water tank **142** and drives feed water from tank **142** to feed manifold **114** via auxiliary feed water conduit **146** and auxiliary feed water control valve **148.** It is appreciated that water in auxiliary feed water tank **142** may be at the same pressure as the pressure of the brine, such as by maintaining auxiliary brine replacement control valve **140** in an open state as the water pressure in the system gradually increases. Alternatively, the water in the auxiliary feed water tank **142** may be maintained at a pressure which is much lower than the pressure of the brine but above the atmospheric pressure by operation of the auxiliary feed water pump **144** as described hereinbelow.

In this embodiment, during flushing the FPM controller **162** opens recycle conduit control valve **156,** resulting in a water flow from a location downstream of pump **102** to a location upstream of pump **102,** thorough a restrictor **160,** thus lowering the feed water pressure at manifold **114** to a pressure above atmospheric pressure, which pressure exceeds the osmotic pressure of the feed water at the feed side of module **100.** The water flow for this stage is shown in a solid black line in Fig. **7B**.

A typical graph of flow rate over time, as measured by concentrate flow rate sensor **130,** located downstream of circulation pump **126,** appears in an enlargement forming part of Fig. 7B, in which line **200** represents the flow rate over time.

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120,** and thus measures the cumulative volume of feed water entering feed manifold **114** via the auxiliary feed water conduit **146** and the auxiliary feed water control valve **148**, which replaces the brine in module **100.**

After complete replacement of brine with feed water in module **100,** FPM controller **162** reopens recirculation control valve **124,** and closes auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156,** providing a liquid flow as shown in Fig. 7C, which may be identical to the liquid flow illustrated in Fig. 7A, in which the operation of high pressure pump **102** and the circulation pump **126** supplies mixed feed water to module **100.**

Thereafter, the FPM controller **162** periodically activates the auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a

location outside of the at least one water treatment system, and fill the auxiliary feed tank **142** with feed water for further replacement of brine in module **100.** This flow is shown in solid black lines in Fig. 7D.

Following full replacement of brine with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow sensor **150,** the FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of the auxiliary feed water pump **144.**

Reference is now made to Figs. 8A-8D, which are simplified illustrations of water flows in yet another embodiment of a water treatment system of the type shown in Fig. **1.**

Prior to initiation of removal of the concentrate from module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is open. The concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. 1), representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1), representing the mixed flow in the feed manifold **114.** Thus, a mixed flow enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 8A.

The feed pressure thereafter gradually increases as the salinity of the mixed water being supplied to the membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined salinity level at which continued water treatment is deemed not to be practicable, FPM controller **162** opens auxiliary brine replacement control valve **140,** which is approximately at atmospheric pressure, thus reducing the water pressure within module **100** to a pressure between the pressure of the concentrate at module **100** and the pressure of the feed water in the auxiliary feed tank **142.**

Immediately thereafter, FPM controller **162** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** Feed water from auxiliary feed tank **142** flows via auxiliary feed water conduit **146** and feed water control valve **144** to

feed manifold **114,** as shown in Fig. **8B**, thus supplying feed water to module **100** at a pressure above the osmotic pressure of the feed water and slightly higher than the pressure required for reverse osmosis to occur.

In the embodiment illustrated in Figs. 8A-8D, FPM controller **162** also increases the flow rate of circulation pump **126** during flushing to achieve faster replacement of the brine from module **100** with feed water from auxiliary feed tank **142,** hence, reducing the time required for the brine to be flushed from module **100** and replaced by feed water. A typical graph of flow rate over time, as measured by concentrate flow rate sensor **130,** located downstream of circulation pump **126,** appears in an enlargement forming part of Fig. 8B, in which line **200** represents the flow rate over time.

The water flow for this stage is shown in a solid black line in Fig. 8B.

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120** and thus measures the cumulative volume of feed water entering feed manifold **114** via the auxiliary feed water conduit **146** and the auxiliary feed water control valve **148,** which replaces the brine in module **100.**

After complete replacement of the brine with feed water in module **100,** FPM controller **162** reopens recirculation control valve **124,** closes auxiliary brine replacement control valve **140** and auxiliary feed water control valve **148** and reduces the flow rate of circulation pump **126** to the flow rate prior to opening concentrate recirculation control valve **124,** providing a liquid flow as shown in solid black lines in Fig. 8C, which may be identical to the liquid flow illustrated in Fig. 8A, in which the operation of high pressure pump **102** and circulation pump **126** supplies mixed feed water to module **100.**

Thereafter, the FPM controller **162** periodically activates the auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a location outside of the at least one water treatment system, and fill the auxiliary feed tank **142** with feed water for further replacement of the brine in module **100.** This flow is shown in solid black lines in Fig. 8D.

Following full replacement of brine with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow rate sensor **150,** the FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of the auxiliary feed water pump **144.**

Reference is now made to Figs. 9A-9D, which are simplified illustrations of water flows in yet another embodiment of a water treatment system of the type shown in Fig. **1.**

Prior to initiation of removal of the concentrate from module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is open. The concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. 1), representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1), representing the mixed flow in the feed conduit **114.**Thus, a mixed flow enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 9A.

The feed pressure thereafter gradually increases as the salinity of the mixed water being supplied to the membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined salinity level at which continued water treatment is deemed not to be practicable, FPM controller **162** at least partially opens brine outlet control valve **134,** thus allowing brine to flow to via brine outlet **132** to a location outside of the at least one water treatment system, thus reducing the system pressure in module **100.**

Additionally, in the embodiment shown in Figs. 9A-9D, during flushing the FPM controller **162** opens recycle conduit control valve **156,** resulting in a water flow from a location downstream of pump **102** to a location upstream of pump **102,** thorough a restrictor **160,** thus maintaining the feed water pressure at manifold **114** at a pressure above atmospheric pressure, which pressure exceeds the osmotic pressure of the feed water at the feed side of module **100,** as seen in Fig. 9B.

Immediately thereafter, FPM controller also opens auxiliary brine replacement control valve **140,** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** Brine from concentrate manifold **120** flows through auxiliary brine replacement conduit **136,** auxiliary tank feed conduit **138** and auxiliary brine replacement control valve **140** to auxiliary feed water tank **142.** The auxiliary feed

water tank **142** is filled with feed water prior to the opening of auxiliary brine replacement control valve **140,** as described hereinbelow. The brine enters the auxiliary feed water tank **142** and drives feed water from tank **142** to feed manifold **114** via auxiliary feed water conduit **146** and auxiliary feed water control valve **148.** It is appreciated that water in auxiliary feed water tank **142** may be at the same pressure as the pressure of the brine, such as by maintaining auxiliary brine replacement control valve **140** in an open state as the water pressure in the system gradually increases. Alternatively, the water in the auxiliary feed water tank **142** may be maintained at a pressure which is much lower than the pressure of the brine but above the atmospheric pressure by operation of the auxiliary feed water pump **144** work as described hereinbelow. The water flow for this stage is shown in a solid black line in Fig. 9B.

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120** and thus measures when the full flushing of the brine from module **100** has been completed. After fully flushing the brine from module **100,** FPM controller **162** reopens recirculation control valve **124,** and closes brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156,** providing a liquid flow as shown in Fig. 9C, which may be identical to the liquid flow illustrated in Fig. 9A, in which the operation of high pressure pump **102** and circulation pump **126** supplies mixed feed water to module **100.**

Thereafter, the FPM controller **162** periodically activates the auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a location outside of the at least one water treatment system, and fill the auxiliary feed tank **142** with feed water for further replacement of the brine in module **100.** This flow is shown in solid black lines in Fig. 9D.

Following full replacement of brine with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow sensor **150,** the FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of the auxiliary feed water pump **144.**

It is appreciated that in the embodiment shown in Fig. 9B, as described hereinabove, a portion of the brine exits via brine outlet **132** and thus is not replaced with water from auxiliary feed water tank **142.** The volume of water in module **100** may

be replenished by increasing the flow rate of high pressure pump **102** or by any other suitable method.

Reference is now made to Figs. 10A-10D, which are simplified illustrations of water flows in still another embodiment of a water treatment system of the type shown in Fig. 1.

Prior to initiation of removal of the concentrate from module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is open. The concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. 1), representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1), representing the mixed flow in the feed conduit **114.** Thus, the mixed flow enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 10A.

The feed pressure thereafter gradually increases as the salinity of the mixed water being supplied to the membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined salinity level at which continued water treatment is deemed not to be practicable, FPM controller **162** opens auxiliary brine replacement control valve **140,** which is approximately at atmospheric pressure, thus reducing the water pressure within module **100** to a pressure between the pressure of the concentrate at module **100** and the pressure of the feed water in the auxiliary feed tank **142.**

Immediately thereafter, FPM controller **162** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** Brine from concentrate manifold **120** flows through auxiliary brine replacement conduit **136,** auxiliary tank feed conduit **138** and auxiliary brine replacement control valve **140** to auxiliary feed water tank **142.** The auxiliary feed water tank **142** is filled with feed water prior to the opening of auxiliary brine replacement control valve **140,** as described hereinbelow. The brine entering the auxiliary feed water tank **142** drives feed water in it to feed manifold **114** via auxiliary feed water conduit **146** and auxiliary feed water control valve **148.** It is

appreciated that water in auxiliary feed water tank **142** may be maintained at a pressure generally the same as the pressure of the brine, such as by maintaining auxiliary brine replacement control valve **140** in an open state as the pressure in the system gradually increases. Alternatively, the water in the auxiliary feed water tank **142** may be maintained at a pressure which is much lower than the pressure of the brine but above the atmospheric pressure by operation of the auxiliary feed water pump **144** as described hereinbelow.

Additionally, in the embodiment of Figs. 10A-10D, during flushing the FPM controller **162** opens recycle conduit control valve **156,** resulting in a water flow from a location downstream of pump **102** to a location upstream of pump **102,** thorough a restrictor **160,** thus lowering the feed water pressure at manifold **114** to a pressure above atmospheric pressure, which pressure exceeds the osmotic pressure of the feed water at the feed side of module **100.**

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120** and thus measures the cumulative volume of feed water entering feed manifold **114** via the auxiliary feed water conduit **146** and the auxiliary feed water control valve **148,** which replaces the brine in module **100.**

After complete replacement of the brine with feed water in module **100,** FPM controller **162** reopens recirculation control valve **124,** and closes auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156,** providing a liquid flow as shown in Fig. 10C, which may be identical to the liquid flow illustrated in Fig. 10A hereinabove.

Thereafter, the FPM controller **162** periodically activates the auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a location outside of the at least one water treatment system, and fill the auxiliary feed tank **142** with feed water for further replacement of the brine in module **100.** This flow is shown in solid black lines in Fig. 10D.

Following full replacement of brine with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow sensor **150,** the FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of the auxiliary feed water pump **144.**

Reference is now made to Figs. 11A-11D, which are simplified illustrations of water flows in another water treatment system of the type shown in Fig. **1.**

Prior to initiation of removal of the concentrate from module **100,** brine outlet control valve **134,** auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156** are closed and recirculation control valve **124** is open. The concentrate from concentrate manifold **120** is directed back to the input of feed manifold **114** via recirculation conduit **122** and recirculation control valve **124,** as shown by an arrow labeled CONCENTRATE (Fig. 1), representing the recirculation flow in the recirculation conduit **122.** In feed manifold **114,** the concentrate is mixed with feed water, as shown by an arrow labeled MIXED (Fig. 1), representing the mixed flow in the feed conduit **114.** Thus, a mixed flow enters pressure vessels **110** for further treatment. The water flow for this stage is shown in a solid black line in Fig. 11A.

The feed pressure thereafter gradually increases as the salinity of the mixed water being supplied to the membrane elements **112** increases, and the above-described recirculation process continues.

Once the concentration of the concentrate reaches a threshold, such as a predetermined salinity level at which continued water treatment is deemed not to be practicable, FPM controller **162** opens auxiliary brine replacement control valve **140** that is connected to auxiliary feed water tank **142** through auxiliary brine replacement conduit **136** and auxiliary tank feed conduit **138.** In this embodiment, the water in auxiliary feed water tank **142** is approximately at atmospheric pressure, thus opening auxiliary brine replacement control valve **140** reduces the water pressure within module **100** to a pressure between the pressure of the concentrate at module **100** and the pressure of the feed water in the auxiliary feed tank **142.**

Immediately thereafter, FPM controller **162** closes recirculation control valve **124** and opens auxiliary feed water control valve **148.** Brine from concentrate manifold **120** flows through auxiliary brine replacement conduit **136,** auxiliary tank feed conduit **138** and auxiliary brine replacement control valve **140** to auxiliary feed water tank **142.** The auxiliary feed water tank **142** is filled with feed water prior to the opening of auxiliary brine replacement control valve **140,** as described hereinbelow. The brine entering the auxiliary feed water tank **142** drives feed water from auxiliary feed tank **142** via auxiliary feed water conduit **146** and auxiliary feed water control valve **148** to

feed manifold **114,** thus supplying feed water to module **100** at a pressure above the osmotic pressure of the feed water and not much higher than the pressure required for a reverse osmosis to occur.

In this embodiment, during flushing, the FPM controller **162** also opens recycle conduit control valve **156,** resulting in a water flow from a location downstream of pump **102** to a location upstream of pump **102,** through a restrictor **160,** thus lowering the feed water pressure at manifold **114** to a pressure above atmospheric pressure, which pressure exceeds the osmotic pressure of the feed water at the feed side of module **100.** In this embodiment illustrated in Figs. 11A-11D, FPM controller also increases the flow rate produced by circulation pump **126** during flushing to achieve a faster replacement of the brine from module **100** with feed water from auxiliary feed tank **142,** hence, reducing the time required for the brine to be flushed from module **100** and replaced by feed water. A typical graph of flow rate over time, as measured by concentrate flow rate sensor **130,** located downstream of circulation pump **126,** appears in an enlargement forming part of Fig. 11B, in which line **200** represents the flow rate over time.

The water flow for this stage is shown in a solid black line in Fig. 11B.

Concentrate flow rate sensor **130** measures the cumulative volume of brine flowing from concentrate manifold **120** and thus measures the cumulative volume of feed water entering feed manifold **114** via the auxiliary feed water conduit **146** and the auxiliary feed water control valve **148,** which replaces the brine in module **100.**

After complete replacement of brine with feed water in module **100,** FPM controller **162** reopens recirculation control valve **124,** closes auxiliary brine replacement control valve **140,** auxiliary feed water control valve **148** and recycle conduit control valve **156,** and reduces the flow rate of circulation pump **126** to the flow rate prior to opening recirculation control valve **124,** providing a liquid flow as shown in solid black lines in Fig. 11C, which may be identical to the liquid flow illustrates in Fig. 11A, in which the operation of high pressure pump **102** and circulation pump **126** supplies water to module **100.**

Thereafter, the FPM controller **162** periodically activates the auxiliary feed water pump **144** and opens auxiliary brine outlet tank control valve **154** to flush all brine from auxiliary feed water tank **142** through an auxiliary brine outlet **152** to a location outside of the at least one water treatment system, and fill the auxiliary feed

tank **142** with feed water for further replacement of brine in module **100.** This flow is shown in a solid black line in Fig. 11D.

Following full replacement of brine with feed water in auxiliary feed water tank **142,** as measured by auxiliary flow sensor **150,** the FPM controller **162** closes auxiliary brine outlet tank control valve **154** and terminates operation of the auxiliary feed water pump **144.**

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

CLAIMS:

1. A liquid treatment system for treatment of feed liquid, the liquid treatment system comprising:

at least one liquid treatment module comprising at least one membrane and in communication with a liquid inlet, with a concentrate outlet, and with a permeate outlet;

a high pressure pump which normally maintains a fixed output liquid volume notwithstanding variations in liquid pressure at an outlet of the high pressure pump, the high pressure pump exhibiting an energy consumption that is a function of the variations in liquid pressure at the outlet of the high pressure pump, the high pressure pump being operative to pressurize a feed liquid to be supplied to the at least one liquid treatment module via said liquid inlet;

a circulation pump for circulating a concentrate from said concentrate outlet to said liquid inlet for the pressurized feed liquid to be mixed with the concentrate, to result into a mixed liquid to be supplied to said ~~to the~~ at least one liquid treatment module via said liquid inlet; and

a controller configured for:

controlling the high pressure pump;

monitoring the liquid pressure downstream from the high pressure pump;

determining that the liquid pressure downstream from the high pressure pump has reached a predetermined high pressure threshold representing exceedance of a salinity threshold of the concentrate; and

immediately after said determination, lowering the liquid pressure downstream from the high pressure pump to a level which exceeds an osmotic pressure of the feed liquid, thereby immediately reducing the energy consumption of the high pressure pump.

2. The liquid treatment system of claim 1, wherein the controller is configured for lowering the liquid pressure downstream from the high pressure pump to a pressure below osmotic pressure of the mixed liquid at said liquid inlet at the time of the exceedance.

3. The liquid treatment system of claim 1, further comprising:

a liquid pressure reducing valve at a brine outlet, wherein the at least one liquid treatment module is in communication with the brine outlet;

a liquid feed tank; and

a recycle conduit control valve which provides a pressure reducing backflow liquid path from the outlet of the high pressure pump to an inlet of the high pressure pump, the backflow liquid path bypassing the high pressure pump;

wherein for lowering the liquid pressure downstream from the high pressure pump, the controller is configured to perform at least one of the following operations:

opening said liquid pressure reducing valve, thereby removing said concentrate from said liquid treatment system;

stopping said circulation and increasing a liquid volume output of the circulation pump from volume output of the circulation pump when the circulation pump circulates said concentrate from the at least one liquid treatment module to the liquid inlet at times other than upon and immediately following the exceedance;

equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside said liquid feed tank; or

opening said recycle conduit control valve.

4. The liquid treatment system of claim 1, further comprising:

wherein the controller is configured for lowering the liquid pressure downstream from the high pressure pump to a pressure below osmotic pressure of the mixed liquid at said liquid inlet at the time of the exceedance;

a liquid pressure reducing valve at a brine outlet, wherein the at least one liquid treatment module is in communication with the brine outlet;

a liquid feed tank; and

a recycle conduit control valve which provides a pressure reducing backflow liquid path from the outlet of the high pressure pump to an inlet of the high pressure pump, the backflow liquid path bypassing the high pressure pump;

wherein for lowering the liquid pressure downstream from the high pressure pump, the controller is configured to perform at least one of the following operations:

opening said liquid pressure reducing valve, thereby removing said concentrate from said liquid treatment system;

stopping said circulation and increasing a liquid volume output of the circulation pump from volume output of the circulation pump when the circulation pump circulates said concentrate from the at least one liquid treatment module to the liquid inlet at times other than upon and immediately following the exceedance;

equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside said liquid feed tank; or

opening said recycle conduit control valve.

5. The liquid treatment system of claim 1, further comprising:

a liquid pressure reducing valve at a brine outlet, wherein the at least one liquid treatment module is in communication with the brine outlet;

a liquid feed tank; and

a recycle conduit control valve which provides a pressure reducing backflow liquid path from the outlet of the high pressure pump to an inlet of the high pressure pump, the backflow liquid path bypassing the high pressure pump;

wherein for lowering the liquid pressure downstream from the high pressure pump, the controller is configured to perform at least one of the following operations:

opening said liquid pressure reducing valve, thereby removing said concentrate from said liquid treatment system;

stopping said circulation and increasing a liquid volume output of the circulation pump from volume output of the circulation pump when the circulation pump circulates

said concentrate from the at least one liquid treatment module to the liquid inlet at times other than upon and immediately following the exceedance;

equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside said liquid feed tank; or

opening said recycle conduit control valve;

wherein for lowering the liquid pressure downstream from the high pressure pump, the controller is configured for:

removing said concentrate from the liquid treatment system; and

reducing pressure of the mixed liquid in the at least one liquid treatment module by at least one of the following operations:

opening a pressure reducing valve downstream from the high pressure pump;

stopping said circulation and increasing a liquid volume output of the circulation pump from volume output of the circulation pump when the circulation pump circulates said concentrate from the at least one liquid treatment module to the liquid inlet at times other than upon and immediately following the exceedance; or

passing the pressurized feed liquid from downstream from the high pressure pump to upstream from the high pressure pump.

6. The liquid treatment system of claim 1, wherein for lowering the liquid pressure downstream from the high pressure pump, the controller is configured for:

removing said concentrate from the liquid treatment system; and

reducing pressure of the mixed liquid in the at least one liquid treatment module by at least one of the following operations:

opening a pressure reducing valve downstream from the high pressure pump;

stopping said circulation and increasing a liquid volume output of the circulation pump from volume output of the circulation pump when the circulation pump circulates said concentrate from the at least one liquid treatment module to the liquid inlet at times other than upon and immediately following the exceedance; or

passing the pressurized feed liquid from downstream from the high pressure pump to upstream from the high pressure pump.

7. The liquid treatment system of claim 1, wherein the controller is configured for lowering the liquid pressure downstream from the high pressure pump to a pressure below osmotic pressure of the mixed liquid at said liquid inlet at the time of the exceedance; wherein for lowering the liquid pressure downstream from the high pressure pump, the controller is configured for:

removing said concentrate from the liquid treatment system; and

reducing pressure of the mixed liquid in the at least one liquid treatment module by at least one of the following operations:

opening a pressure reducing valve downstream from the high pressure pump;

stopping said circulation and increasing a liquid volume output of the circulation pump from volume output of the circulation pump when the circulation pump circulates said concentrate from the at least one liquid treatment module to the liquid inlet at times other than upon and immediately following the exceedance; or

passing the pressurized feed liquid from downstream from the high pressure pump to upstream from the high pressure pump.

8. The liquid treatment system of claim 1, further comprising:

wherein for lowering the liquid pressure downstream from the high pressure pump, the controller is configured for:

removing said concentrate from the liquid treatment system; and

reducing pressure of the mixed liquid in the at least one liquid treatment module by at least one of the following operations:

opening a pressure reducing valve downstream from the high pressure pump;

stopping said circulation and increasing a liquid volume output of the circulation pump from volume output of the circulation pump when the circulation pump circulates said concentrate from the at least one liquid treatment module to the liquid inlet at times other than upon and immediately following the exceedance; and

passing the pressurized feed liquid from downstream from the high pressure pump to upstream from the high pressure pump;

a flow restrictor arranged in parallel with the high pressure pump; and

wherein said passing the pressurized feed liquid from downstream from the high pressure pump to upstream from the high pressure pump includes passing the pressurized feed liquid via said flow restrictor.

9. The liquid treatment system of claim 1, further comprising:

a recirculation control valve disposed between said concentrate outlet and said liquid inlet;

wherein said circulation pump is configured for circulating the concentrate via the recirculation control valve, and a system controller is configured for, immediately after said determination, closing the recirculation control valve.

ABSTRACT

A method of treatment of liquid comprising steps of: supplying feed liquid to be treated to at least one liquid treatment module employing at least one membrane, the at least one module having a liquid inlet at a feed side of the at least one membrane, a permeate outlet at a permeate side of the at least one membrane and a brine outlet at a brine side of the at least one membrane; and monitoring liquid pressure within the at least one liquid treatment module and upon exceedance of a liquid pressure threshold in the at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, reducing the liquid pressure in the at least one liquid treatment module to a level which exceeds osmotic pressure of the liquid in the at least one liquid treatment module by making changes in the liquid supply to the module.