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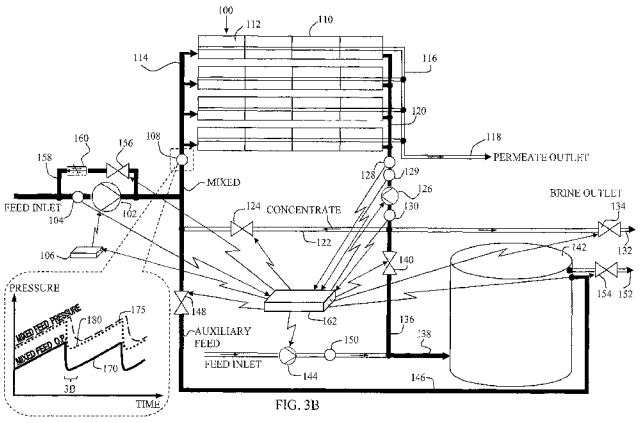


FIG. 3B

(57) Abstract: A method of treatment of liquid in a liquid treatment facility comprising 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; The method comprises (a) supplying liquid to be treated to the liquid treatment module through the liquid inlet; (b) providing at least some of the liquid from the brine outlet back to the liquid inlet; (c) monitoring liquid pressure within the at least one liquid treatment module; and (d) upon detecting that the liquid pressure exceeds a predetermined liquid pressure threshold, closing off circulation of liquid from the brine outlet back to the liquid inlet in order to reduce the liquid pressure in the at least one liquid treatment module and simultaneously performing at least one of the following: (i) 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; (ii) increasing liquid inlet at the liquid inlet using a designated liquid volume at times other than upon and immediately following the exceedance; (iii) equilibrating liquid pressures between a liquid pressure inside the at least one liquid treatment module and inside a liquid feed tank; and (iv) providing a pressure reducing backflow liquid path from the liquid inlet of the at least one liquid treatment module to bypasses a liquid pressure increasing pump upstream of the liquid inlet.

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SYSTEM AND METHOD FOR WATER TREATMENT

TECHNOLOGICAL FIELD

The present application is directed to systems and method of water treatment, in particular, methods allows continuous 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 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;

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.

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, the 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.

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.

One of the advantages of the present arrangement is conservation of energy since the feed pump is not required to keep increasing pressure (it can reduce pressure

earlier) – the pump in the arrangement of the present application begins its drop at dotted line A, considerably earlier with respect to the osmotic pressure compared to line 175 of the prior art. The difference, represented by the area delimited 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 method of treatment of liquid in a liquid treatment facility comprising at least one liquid treatment module employing at least one of reverse osmosis and nanofiltration membranes, said at least one module having a liquid inlet, a permeate outlet and a brine outlet, said method comprising:

- supplying liquid to be treated to said liquid treatment module through said liquid inlet;
- providing at least some of the liquid from the brine outlet back to the liquid inlet;
- monitoring liquid pressure within said at least one liquid treatment module; and
- upon detecting that said liquid pressure exceeds a predetermined liquid pressure threshold, closing off circulation of liquid from the brine outlet back to the liquid inlet in order to reduce said liquid pressure in said at least one liquid treatment module and simultaneously performing at least one of the following:
  - i. reducing said liquid pressure at said brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of said liquid in said at least one liquid treatment module;
  - ii. increasing liquid inlet at the liquid inlet using a designated liquid volume at times other than upon and immediately following said exceedance;
  - iii. equilibrating liquid pressures between a liquid pressure inside said at least one liquid treatment module and inside a liquid feed tank; and
  - iv. providing a pressure reducing backflow liquid path from said liquid inlet of said at least one liquid treatment module to bypasses a liquid pressure increasing pump upstream of said liquid inlet.

2. A method of treatment of liquid according to Claim 1, wherein, upon exceeding the liquid pressure threshold at least two of operations (i) to (iv) are performed.

3. A method of treatment of liquid according to Claim 1, wherein, upon exceeding the liquid pressure threshold at least three of operations (i) to (iv) are performed.

4. A method of treatment of liquid according to Claim 1, wherein, upon exceeding the liquid pressure threshold all operations (i) to (iv) are performed.

5. A method of treatment of liquid according to any one of Claims 1 to 4, wherein said membrane comprises a feed side associated with the liquid inlet, a permeate side associated with the permeate outlet and a brine side associated with the brine outlet, and wherein:

- pressurizing feed water supplied to said feed liquid inlet is performed by a pump normally maintaining a fixed output feed water volume notwithstanding variations in water pressure at an outlet thereof, the energy consumption of said pump being a function of the variations in water pressure at said outlet; and
- upon detecting that a predetermined high pressure threshold is reached at said outlet of said pump, changing water supply to said module in order to lower of the water pressure at said outlet of said pump to a pressure below the osmotic pressure at least at the feed side of said membrane, thereby reducing the energy consumption of said pump.

6. A method according to any one of Claims 1 to 5, wherein said liquid feed tank is configured for being filled with feed water and, upon exceeding the threshold pressure, brine directed to the liquid feed tank is configured for replacing the feed water with brine while said feed water is directed to the feed inlet.

7. A method of treatment of liquid according to any one of Claims 1 to 6, wherein said method is operative for treatment of at least one of sea water, brackish water and waste water.

8. A method of treatment of liquid in a treatment facility having at least one water treatment module including at least one membrane and having a feed liquid inlet at a feed side of said at least one membrane, a permeate outlet at a permeate side of said at least one membrane and a brine outlet at a brine side of at least one membrane, said method comprising:

- pressurizing feed water supplied to said feed liquid inlet by a pump normally maintaining a fixed output feed water volume notwithstanding variations in water pressure at an outlet thereof, the energy consumption of said pump being a function of the variations in water pressure at said outlet;
- monitoring the water pressure at said outlet of said pump; and
- upon detecting that a predetermined high pressure threshold is reached at said outlet of said pump, changing water supply to said module in order to

lower of the water pressure at said outlet of said pump to a pressure below the osmotic pressure at least at the feed side of said membrane, thereby reducing the energy consumption of said pump.

9. 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 comprising:

- upon occurrence of an operational threshold representing exceedence of a salinity threshold in said 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 said liquid in said at least one liquid treatment module by at least one of the following:
        - opening a pressure reducing valve downstream of said high pressure pump;
        - increasing the volume output of said 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 said high pressure feed pump to upstream of said high pressure feed pump.

10. A method for treatment of liquid according to Claim 9, wherein said passing liquid from downstream of said high pressure feed pump to upstream of said high pressure feed pump comprises passing said liquid via a flow restrictor arranged in parallel to said high pressure feed pump.

11. A method for treatment of liquid according to Claim 9 or 10, wherein said pressure of said liquid in said 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 said high pressure pump;
- increasing the volume output of said 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 said high pressure feed pump to upstream of said high pressure feed pump.

12. A method for treatment of liquid according to Claim 9, 10 or 11, wherein said pressure of said liquid in said at least one liquid treatment module is reduced at an enhanced speed by all of the following:

- opening a pressure reducing valve downstream of said high pressure pump;
- increasing the volume output of said 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 said high pressure feed pump to upstream of said high pressure feed pump.

13. A method of treatment of liquid according to any one of Claims 9 to 12, wherein said 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.

14. A water treatment system comprising:

- at least one liquid treatment module operative to receive feed water at a liquid inlet thereof and to separate said feed water into permeate and concentrate, said permeate constituting treated water, said at least one liquid treatment module having a brine outlet for release of concentrate whose salinity is such that an operational threshold of said system is exceeded;
- a liquid pressure reducing valve at said 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 said at least one liquid treatment module;
- a feed water flow rate sensor located upstream of said high pressure pump and providing a feed water flow rate output;
- a pump controller receiving said feed water flow rate output and controlling the operation of said high pressure pump;
- a liquid pressure sensor for providing an output indication of liquid pressure at at least one of an inlet to said at least one liquid treatment module, an outlet from said at least one liquid treatment module and within said at least one liquid treatment module;
- a circulation pump which removes brine from said at least one liquid treatment module and supplies liquid to said liquid inlet;

- a liquid feed tank;
- a system controller receiving at least said output indication of liquid pressure within said at least one liquid treatment module, said system controller being operative, upon exceedance of a liquid pressure threshold in said at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, to reduce said liquid pressure in said at least one liquid treatment module by performing at least one of the following functions:
  i. reducing said liquid pressure at said brine outlet to a level above atmospheric pressure which exceeds osmotic pressure of said liquid in said at least one liquid treatment module;
  ii. increasing liquid inlet at the liquid inlet using a designated liquid volume at times other than upon and immediately following said exceedance;
  iii. equilibrating liquid pressures between a liquid pressure inside said at least one liquid treatment module and inside a liquid feed tank; and
  iv. providing a pressure reducing backflow liquid path from said liquid inlet of said at least one liquid treatment module to bypasses a liquid pressure increasing pump upstream of said liquid inlet.

15. A water treatment system according to Claim 14, wherein said system controller is operative, upon exceedance of a liquid pressure threshold in said at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, to reduce said liquid pressure in said at least one liquid treatment module by performing any combination of operations (i) to (iv).

16. A system according to Claim 14 or 15, wherein said system further comprises a bypass for the high pressure feed pump, configured for allowing feed liquid to bypass the pump from an upstream side thereof to a downstream side thereof in order to reduce inlet pressure.

17. A system according to Claim 14, 15 or 16, wherein said liquid feed tank has an inlet associated with the circulation pump and an outlet associated with the liquid feed inlet of the treatment module.

18. A system according to any one of Claims 14 to 17, wherein said system is operative for treatment of at least one of sea water, brackish water and waste water

19. A water treatment system comprising:

- at least one water treatment module including at least one membrane and having a feed liquid inlet at a feed side of said at least one membrane, a permeate outlet at a permeate side of said 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 said output indication of liquid pressure within said at least one liquid treatment module, said system controller being operative, upon exceedance of a liquid pressure threshold in said at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, to reduce said liquid pressure in said at least one liquid treatment module by performing at least one of the following functions:
  - **i)** pressurizing feed water supplied to said feed liquid inlet by employing said high pressure pump, the energy consumption of said high pressure pump being a function of the variations in water pressure at said outlet;
  - **ii)** monitoring the water pressure at said outlet of said high pressure pump; and
  - **iii)** when a predetermined high pressure threshold is reached at said outlet of said high pressure pump, immediately making changes in the water supply to said at least one liquid treatment module, thereby to cause immediate lowering of the water pressure at said outlet of said high pressure pump, to a pressure below the osmotic pressure at the feed side of part but not all of said at least one liquid treatment module, thereby immediately reducing the energy consumption of said high pressure pump, thereby provide an overall energy cost savings per unit of water treated.

20. A water treatment system comprising:

- at least one water treatment module including at least one membrane and having a feed liquid inlet at a feed side of said at least one membrane, a permeate outlet at a permeate side of said 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 said high pressure feed pump;
- a circulation pump;
- a system controller receiving at least said output indication of liquid pressure within said at least one liquid treatment module, said system controller being operative, upon exceedance of a liquid pressure threshold in said at least one liquid treatment module, representing exceedence of a salinity threshold in the liquid therein, to reduce said liquid pressure in said at least one liquid treatment module by performing at least one of the following functions:

i) upon occurrence of an operational threshold representing exceedence of a salinity threshold in said at least one liquid treatment module, effecting the following:

ii) removing brine from the at least one liquid treatment module; and

iii) reducing, at an enhanced speed, pressure of said liquid in said at least one liquid treatment module by at least one of the following:

(a) opening said pressure reducing valve downstream of said high pressure feed pump;

(b) increasing the volume output of said 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

(c) passing liquid from downstream of said high pressure feed pump to upstream of said high pressure feed pump.

21. A water treatment system according to claim 21 and also comprising a flow restrictor arranged in parallel to said high pressure feed pump and wherein said passing liquid from downstream of said high pressure feed pump to upstream of said high pressure feed pump comprises passing said liquid via said flow restrictor.

22. A water treatment system according to claim 21 and wherein said pressure of said liquid in said at least one liquid treatment module is reduced at an enhanced speed by performing any combination of operations (a) to (c).

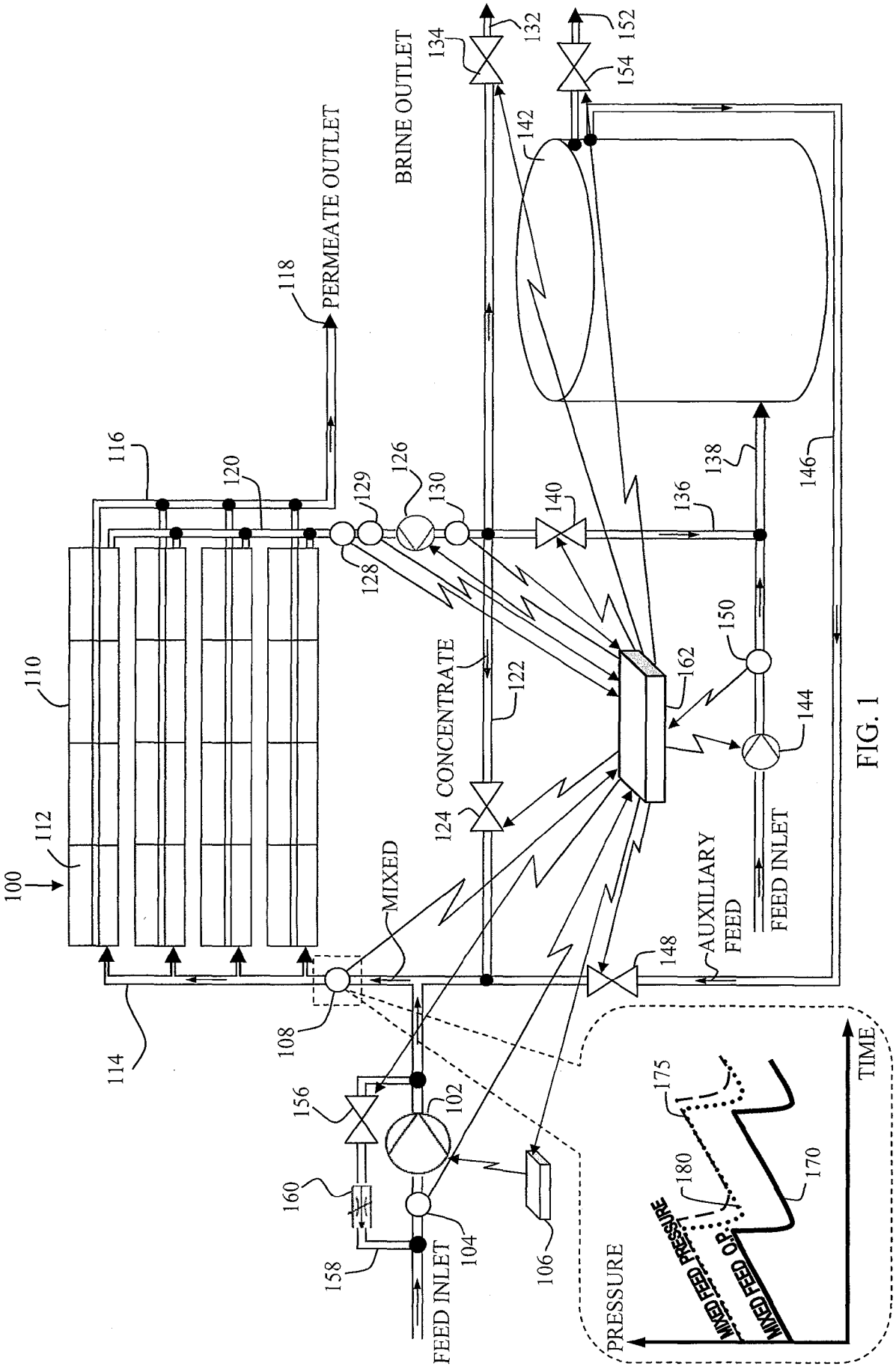

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110
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PERMEATE OUTLET
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CONCENTRATE
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154
156
158
160
162
102
104
106
108
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP.
170
175
180

FIG. 1

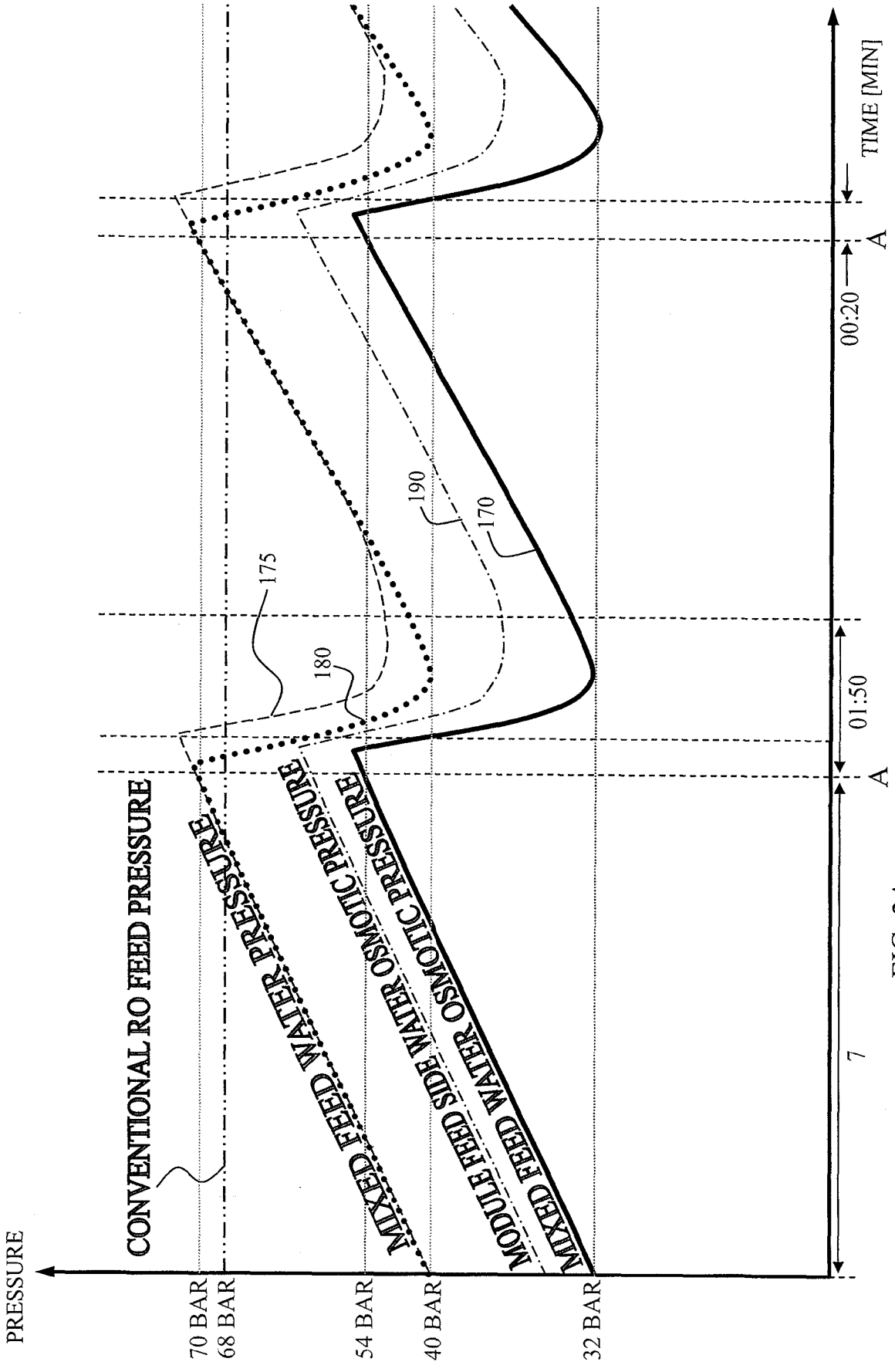

PRESSURE
70 BAR
68 BAR
54 BAR
40 BAR
32 BAR
CONVENTIONAL RO FEED PRESSURE
MIXED FEED WATER PRESSURE
MIXED FEED WATER OSMOTIC PRESSURE
MODULE FEED SIDE WATER OSMOTIC PRESSURE
MIXED FEED WATER
175
180
190
170
TIME [MIN]
A
00:20
A
01:50
7

FIG. 2A

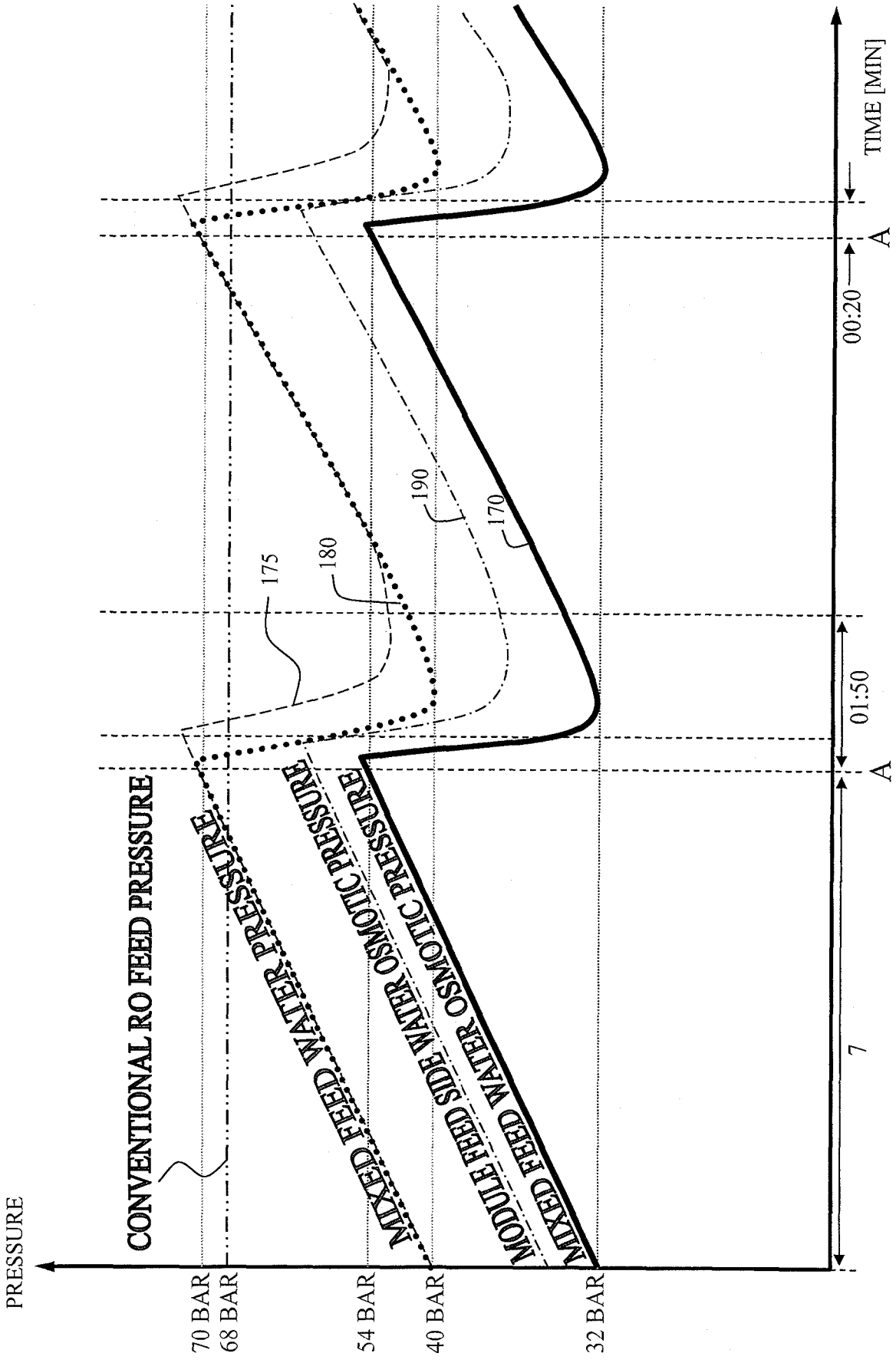

PRESSURE
70 BAR
68 BAR
54 BAR
40 BAR
32 BAR
CONVENTIONAL RO FEED PRESSURE
MIXED FEED WATER PRESSURE
MIXED FEED SIDE WATER OSMOTIC PRESSURE
MODULE FEED WATER OSMOTIC PRESSURE
175
180
190
170
A
A
01:50
00:20
7
TIME [MIN]

FIG. 2B

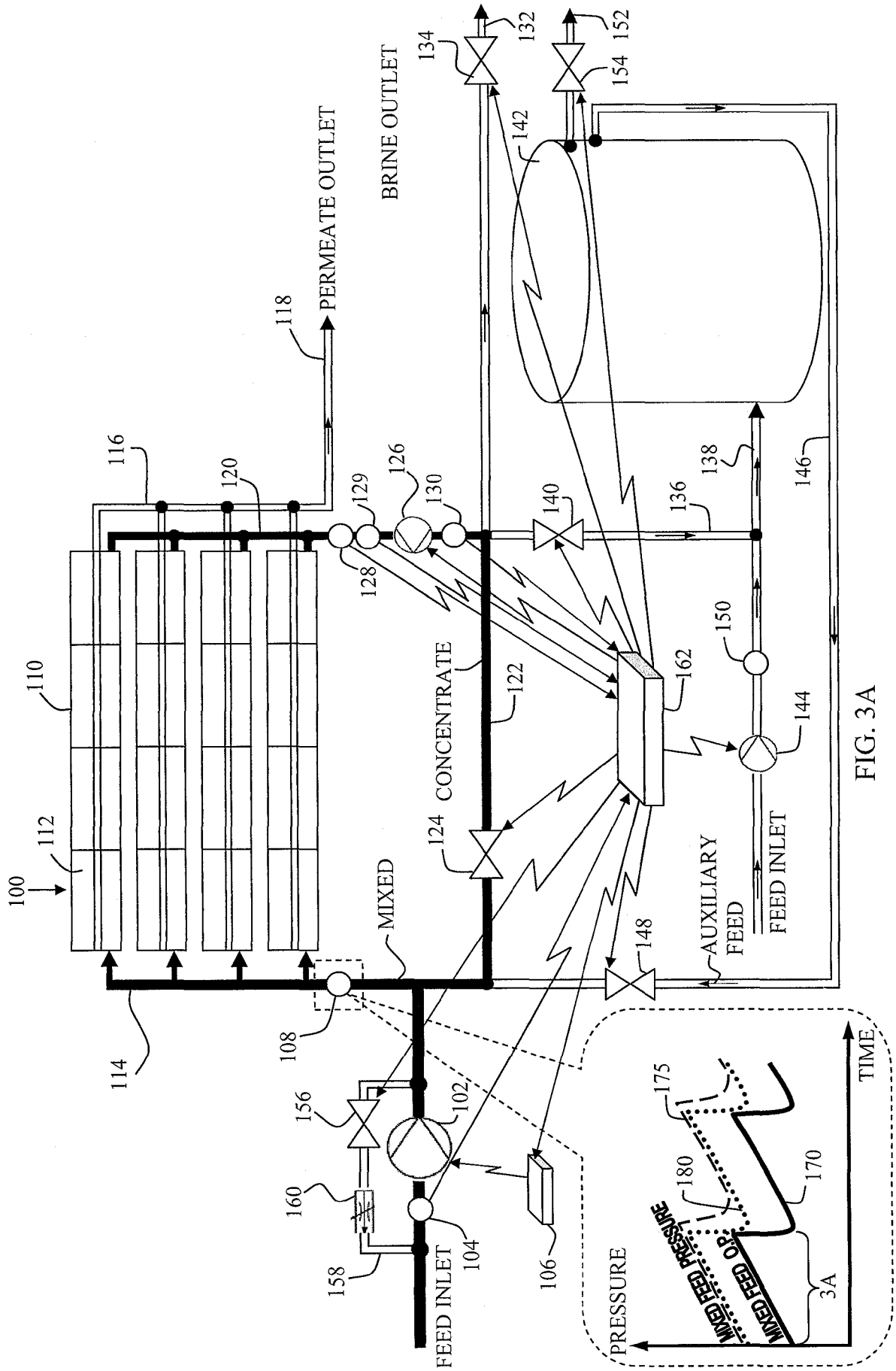

100
110
112
114
116
118
PERMEATE OUTLET
120
BRINE OUTLET
122
CONCENTRATE
124
126
128
129
130
132
134
136
138
140
142
144
146
148
150
152
154
156
158
160
162
102
104
106
108
MIXED
FEED INLET
AUXILIARY FEED
FEED INLET
PRESSURE
TIME
175
180
170
MIXED FEED PRESSURE
MIXED FEED OP
3A

FIG. 3A

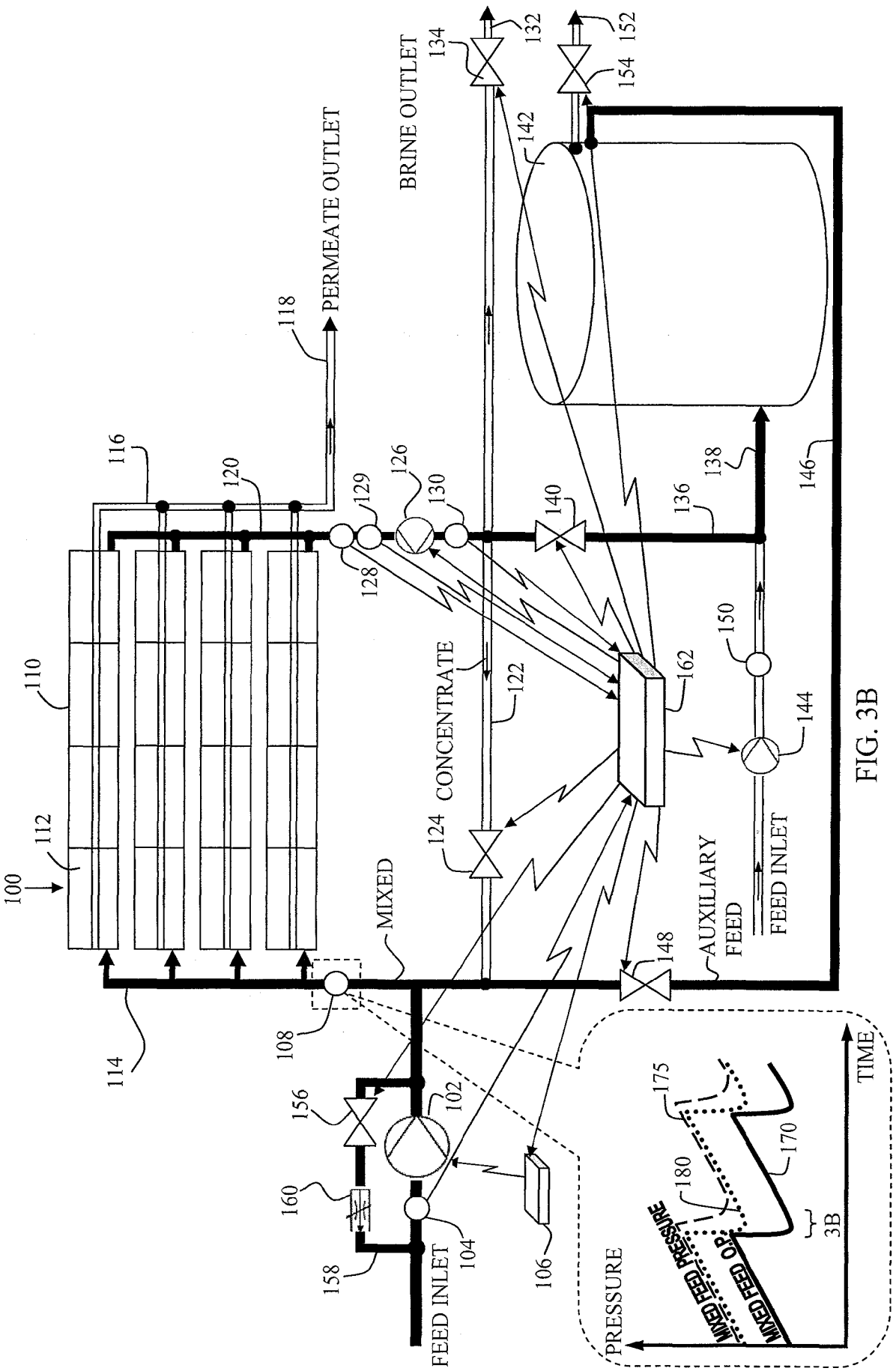

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
3B
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
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148
150
152
154
156
158
160
162
170
175
180

FIG. 3B

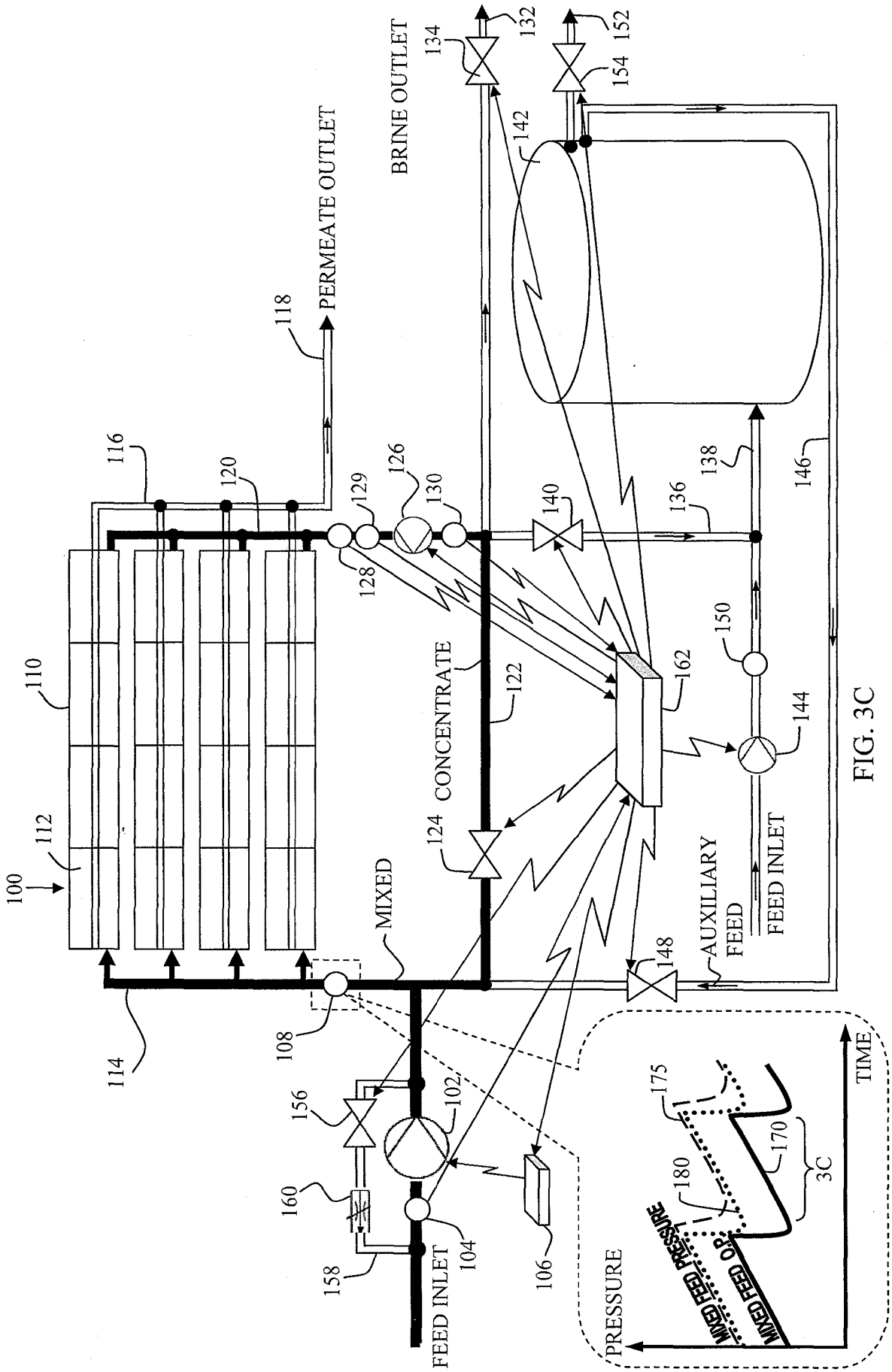

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP
3C
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
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158
160
162
170
175
180

FIG. 3C

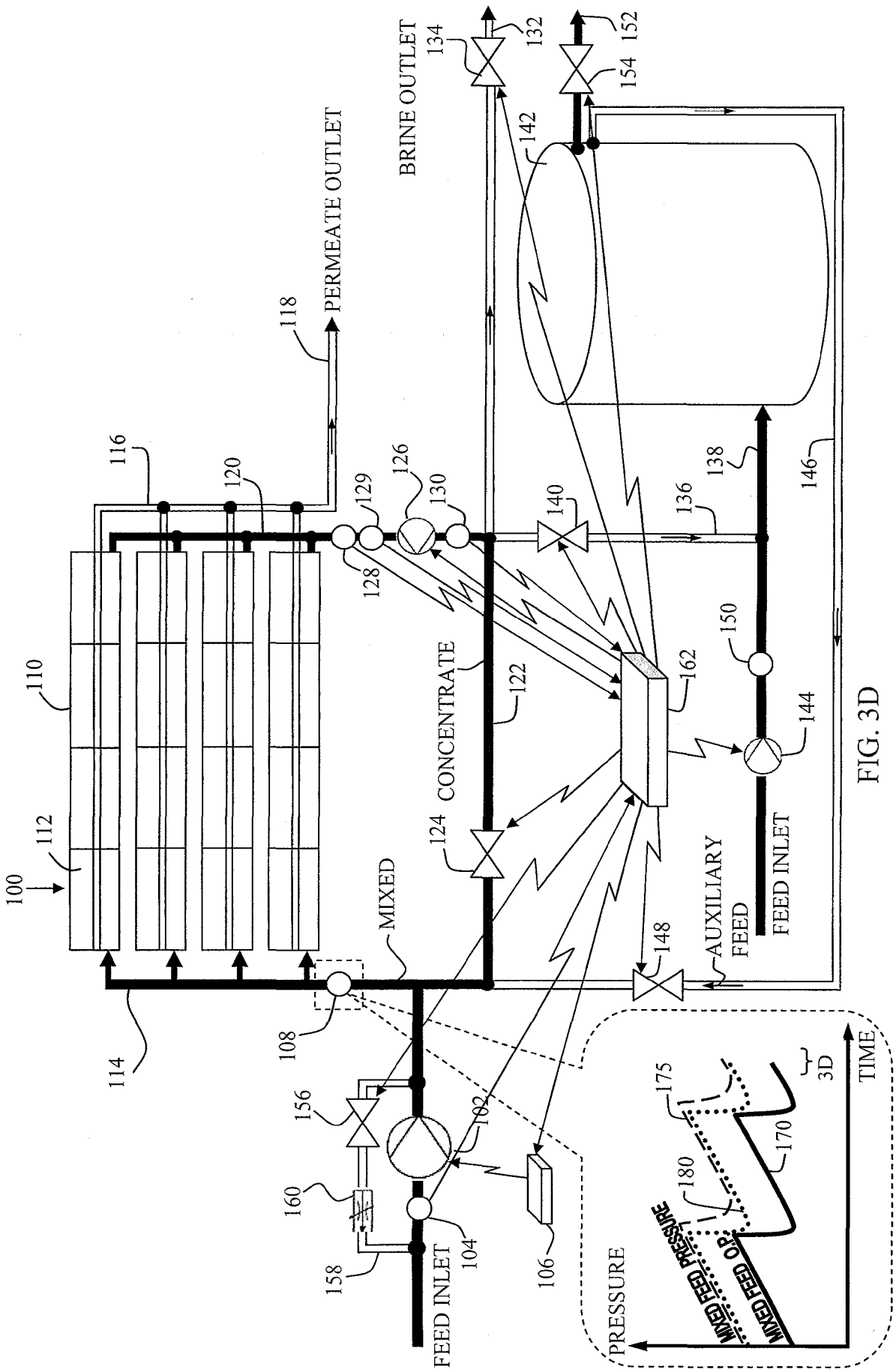

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP.
3D
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
146
148
150
152
154
156
158
160
162
170
175
180

FIG. 3D

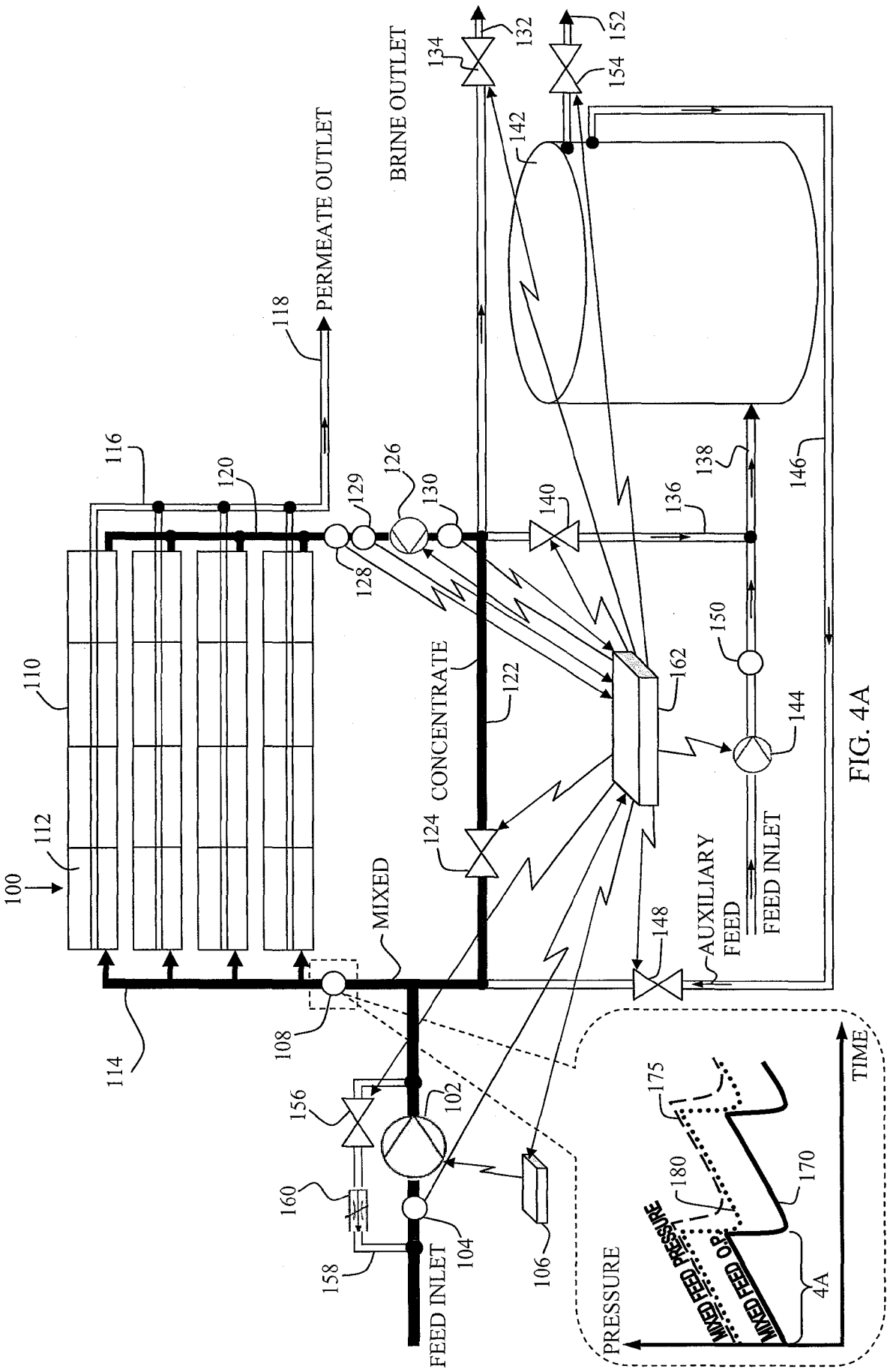

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP
4A
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
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148
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152
154
156
158
160
162
170
175
180

FIG. 4A

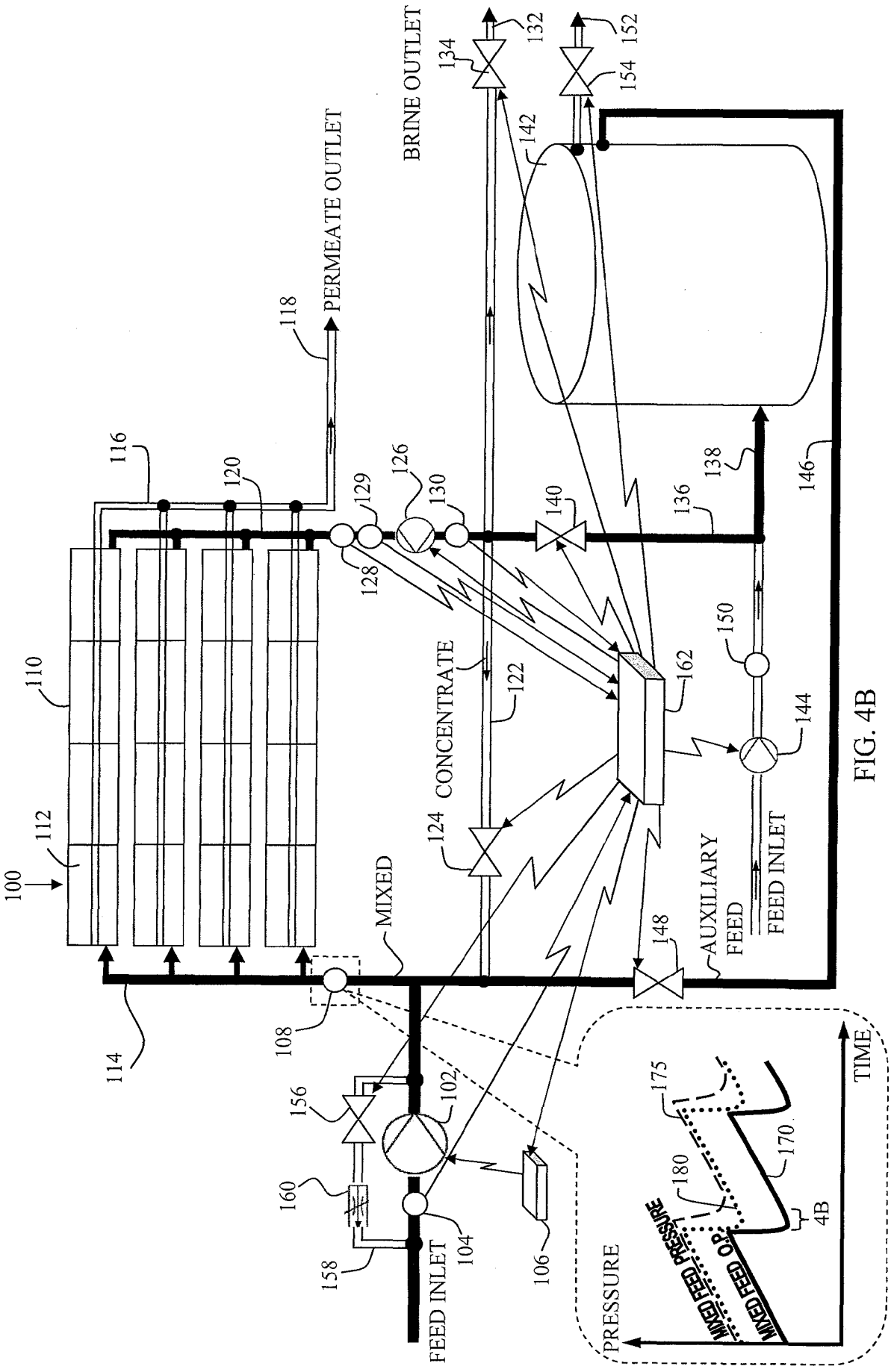

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
4B
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
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148
150
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154
156
158
160
162
170
175
180

FIG. 4B

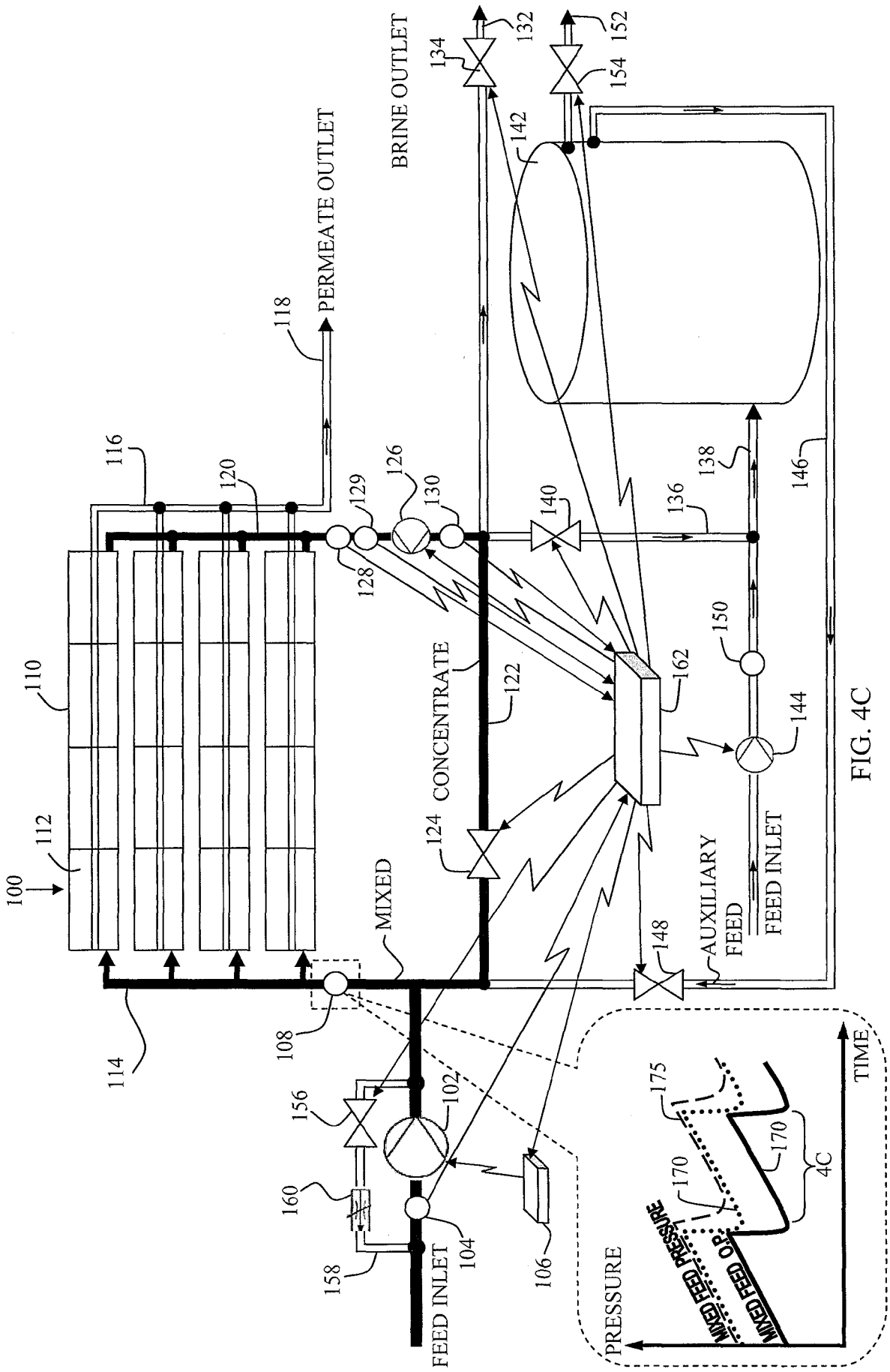

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP
4C
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
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148
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152
154
156
158
160
162
170
175

FIG. 4C

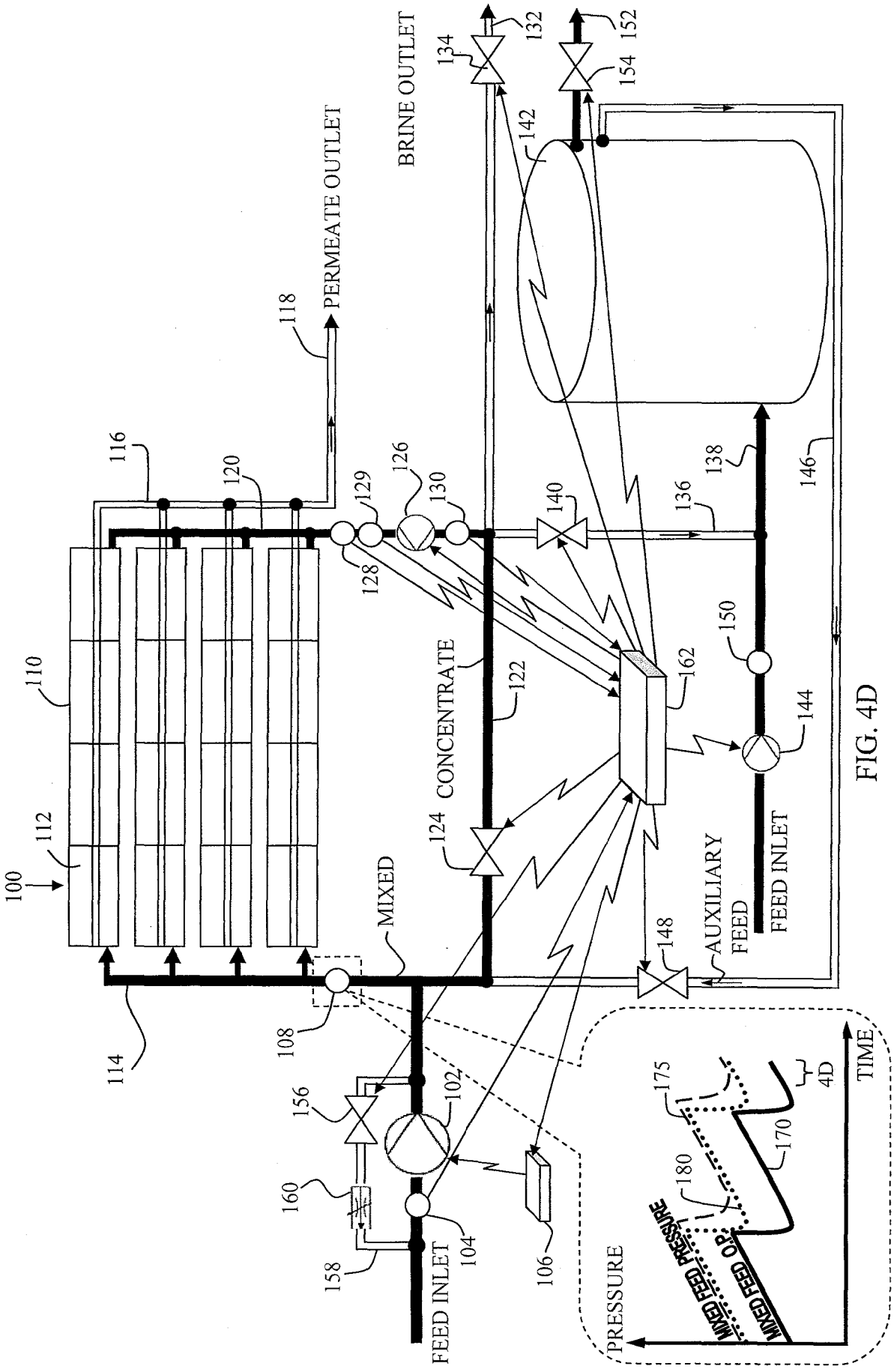

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
4D
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
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142
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154
156
158
160
162
170
175
180

FIG. 4D

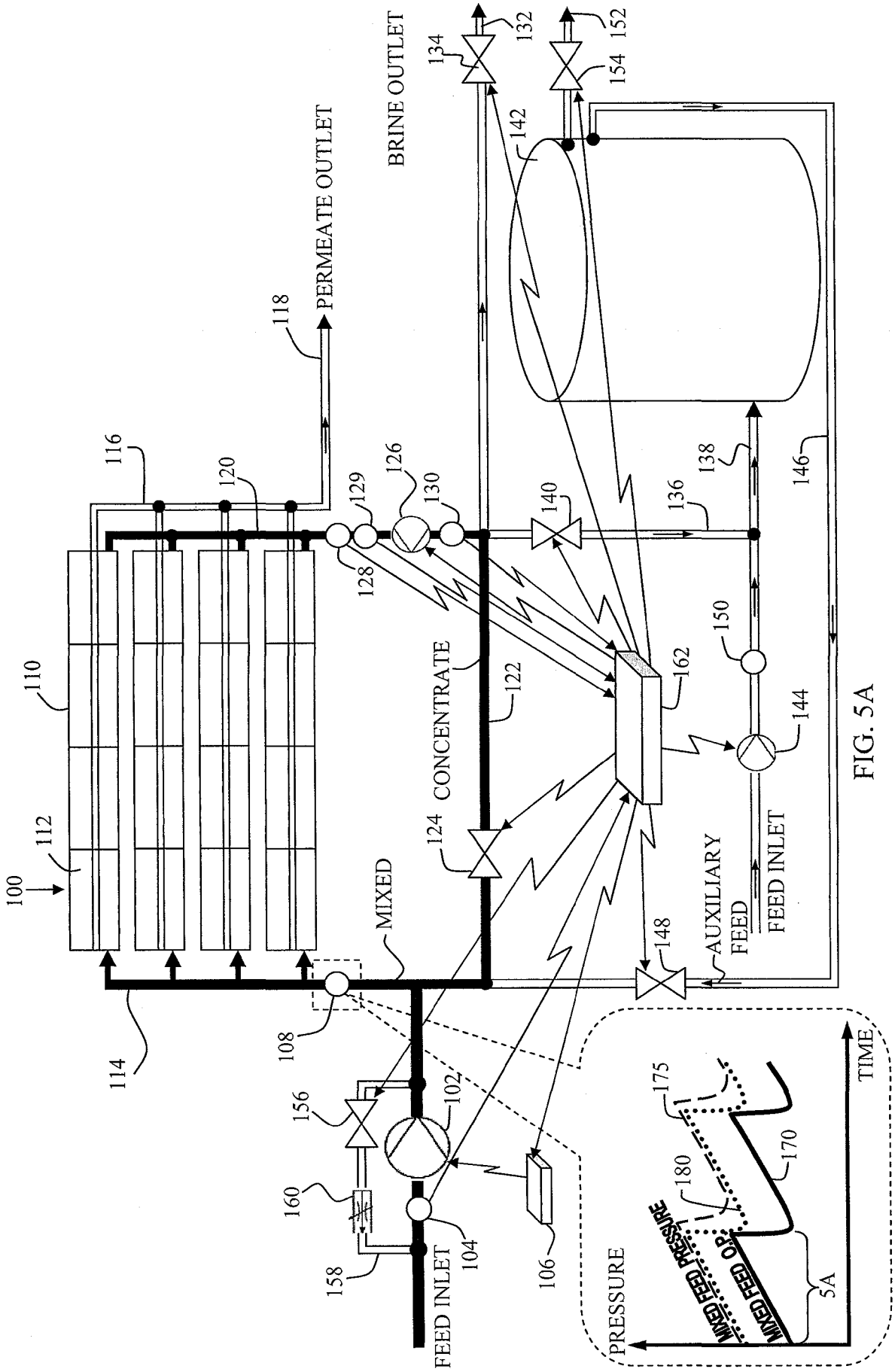

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP
5A
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
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148
150
152
154
156
158
160
162
170
175
180

FIG. 5A

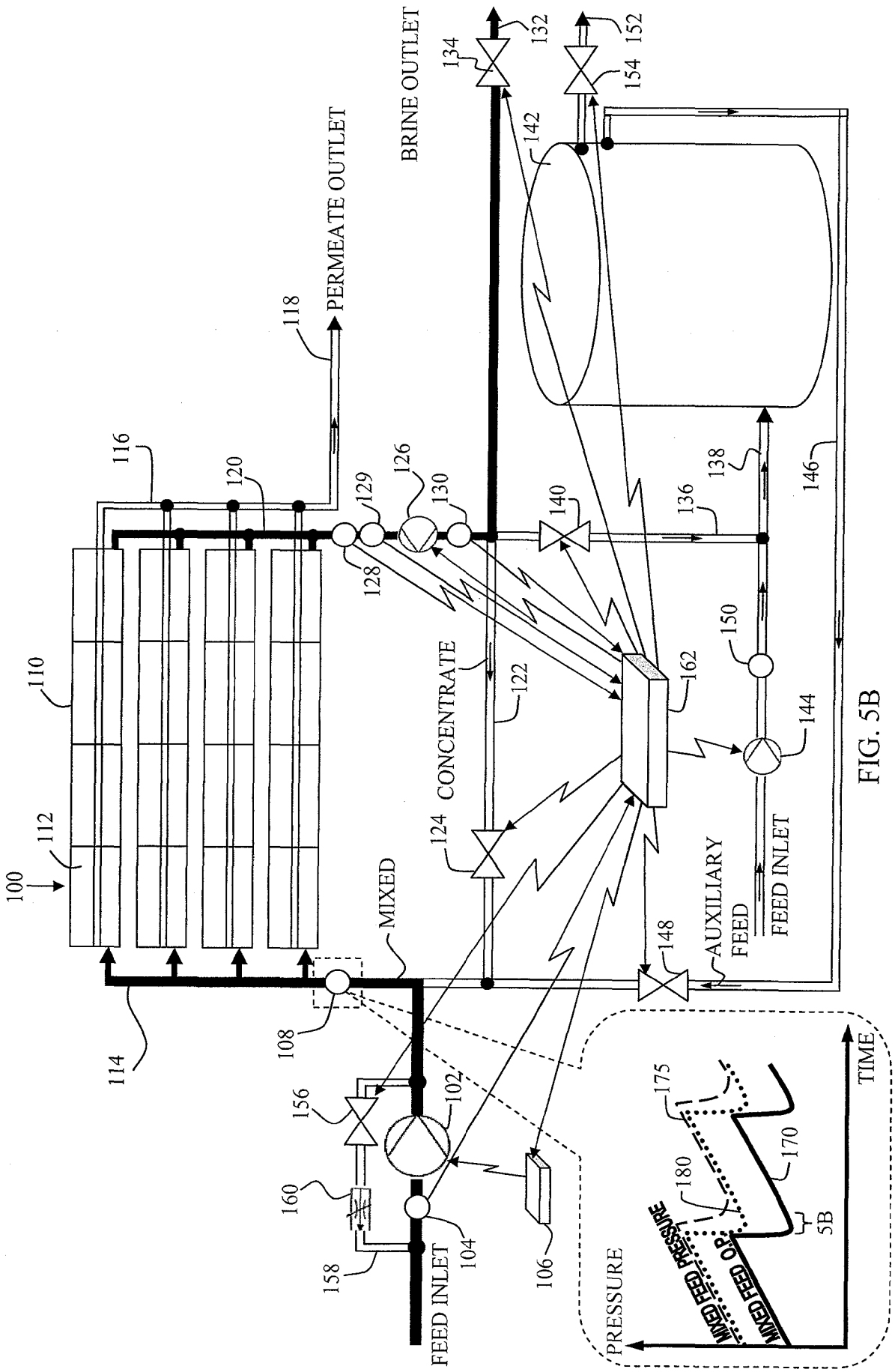

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
5B
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
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150
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154
156
158
160
162
170
175
180

FIG. 5B

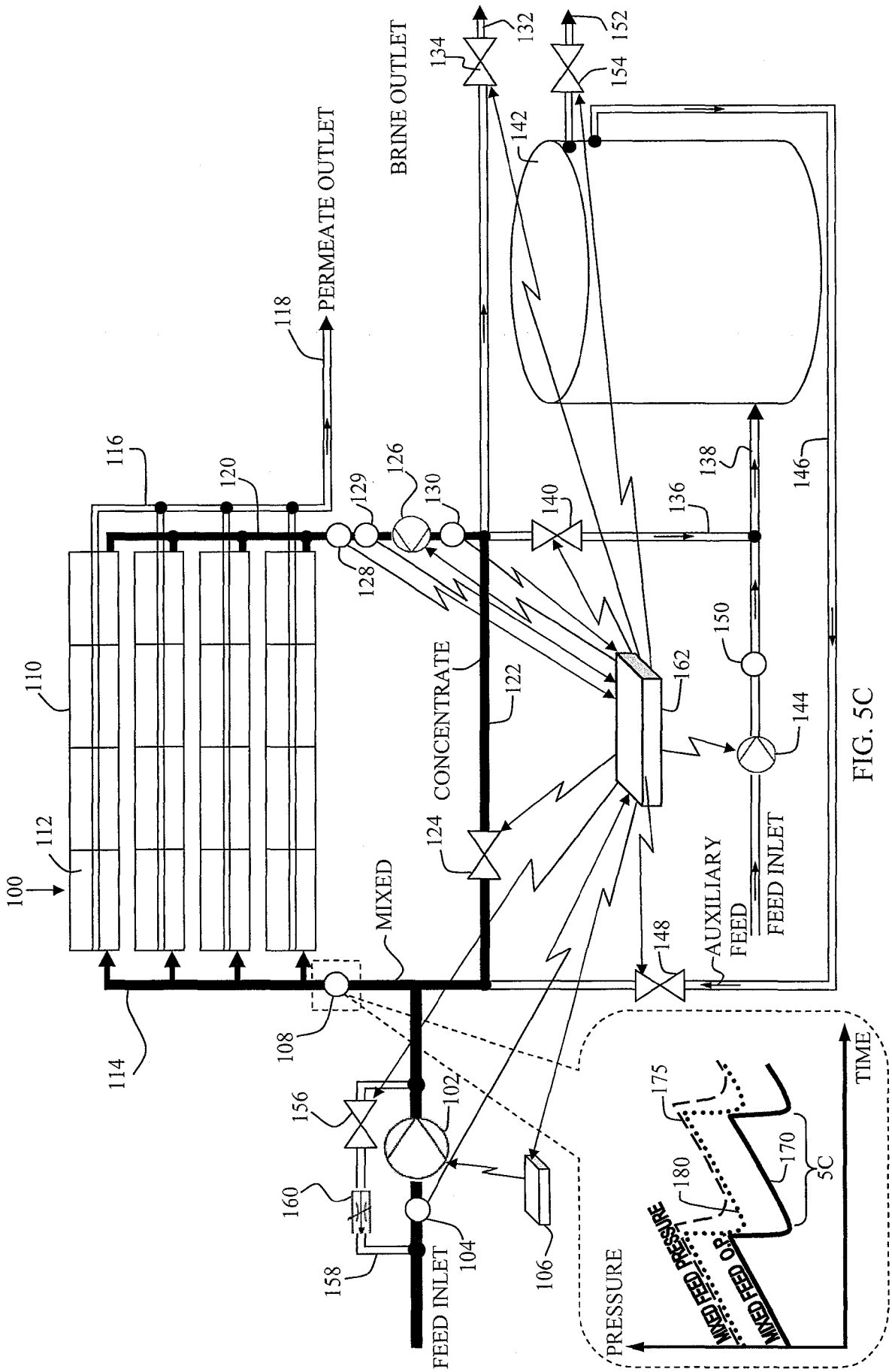

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED OP. PRESSURE
MIXED FEED OP.
5C
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
146
148
150
152
154
156
158
160
162
170
175
180

FIG. 5C

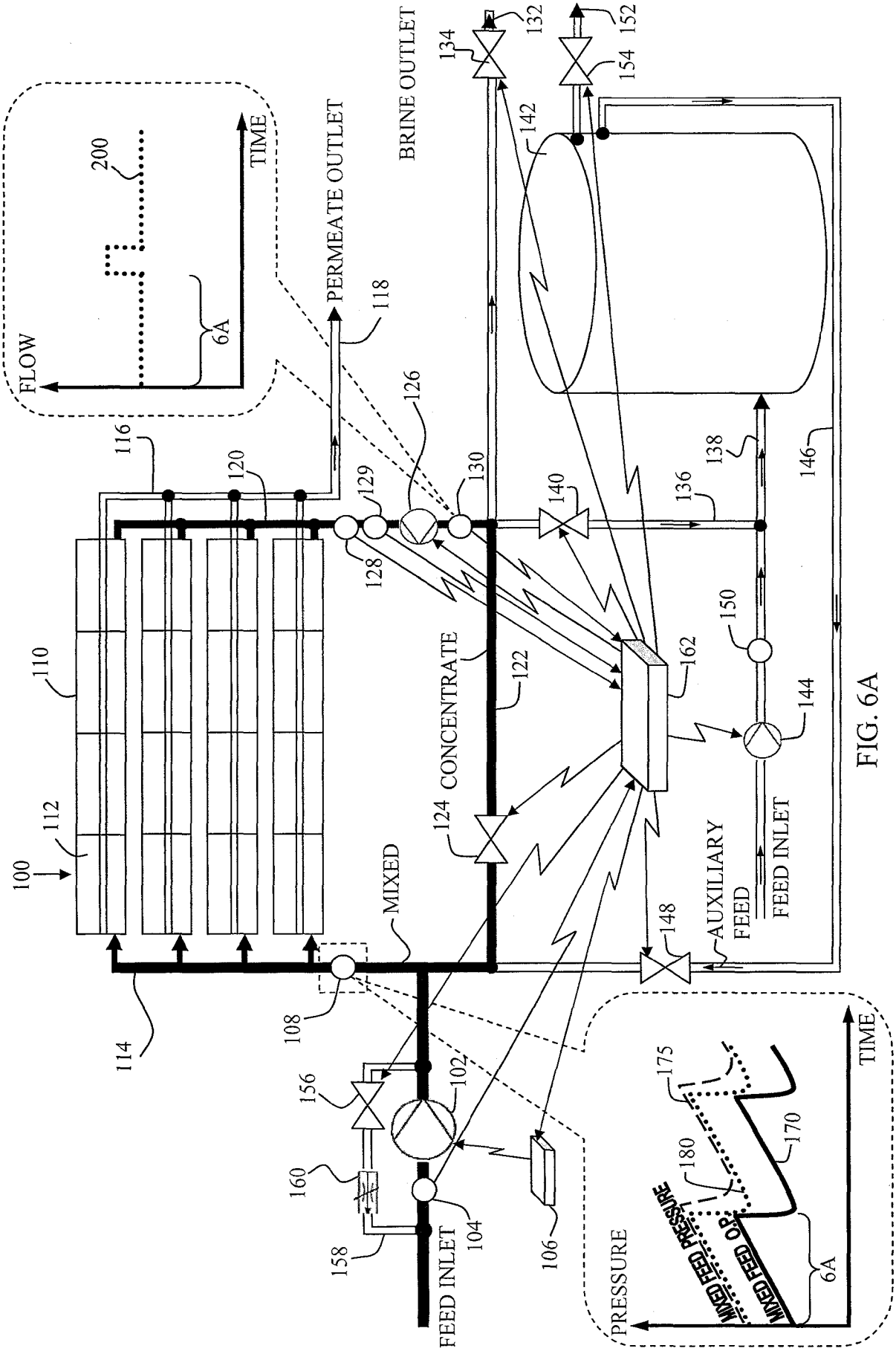

FLOW
TIME
200
6A
PERMEATE OUTLET
BRINE OUTLET
118
116
120
126
129
130
132
134
142
152
154
138
136
140
146
128
110
112
100
CONCENTRATE
122
162
150
144
124
MIXED
AUXILIARY FEED
FEED INLET
148
114
108
156
102
160
158
104
106
FEED INLET
PRESSURE
TIME
175
180
170
MIXED FEED PRESSURE
MIXED FEED O.P.
6A

FIG. 6A

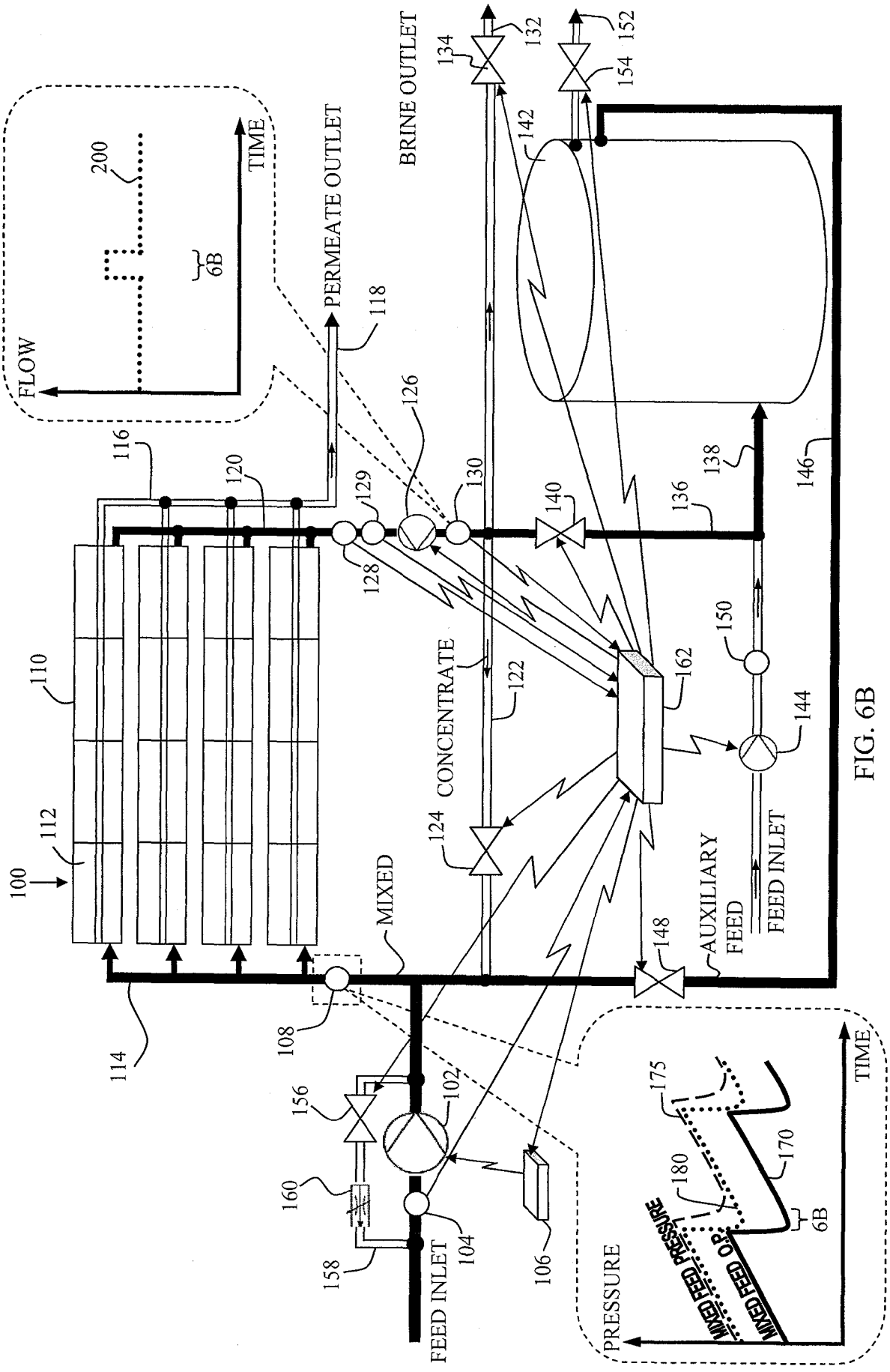

FLOW
TIME
200
6B
PERMEATE OUTLET
118
BRINE OUTLET
134
132
152
154
142
126
116
120
129
130
140
136
138
146
128
110
CONCENTRATE
122
162
150
144
112
124
100
MIXED
148
AUXILIARY FEED
FEED INLET
114
108
156
102
160
158
104
106
FEED INLET
PRESSURE
TIME
175
180
170
6B
MIXED FEED PRESSURE
MIXED FEED O.P.

FIG. 6B

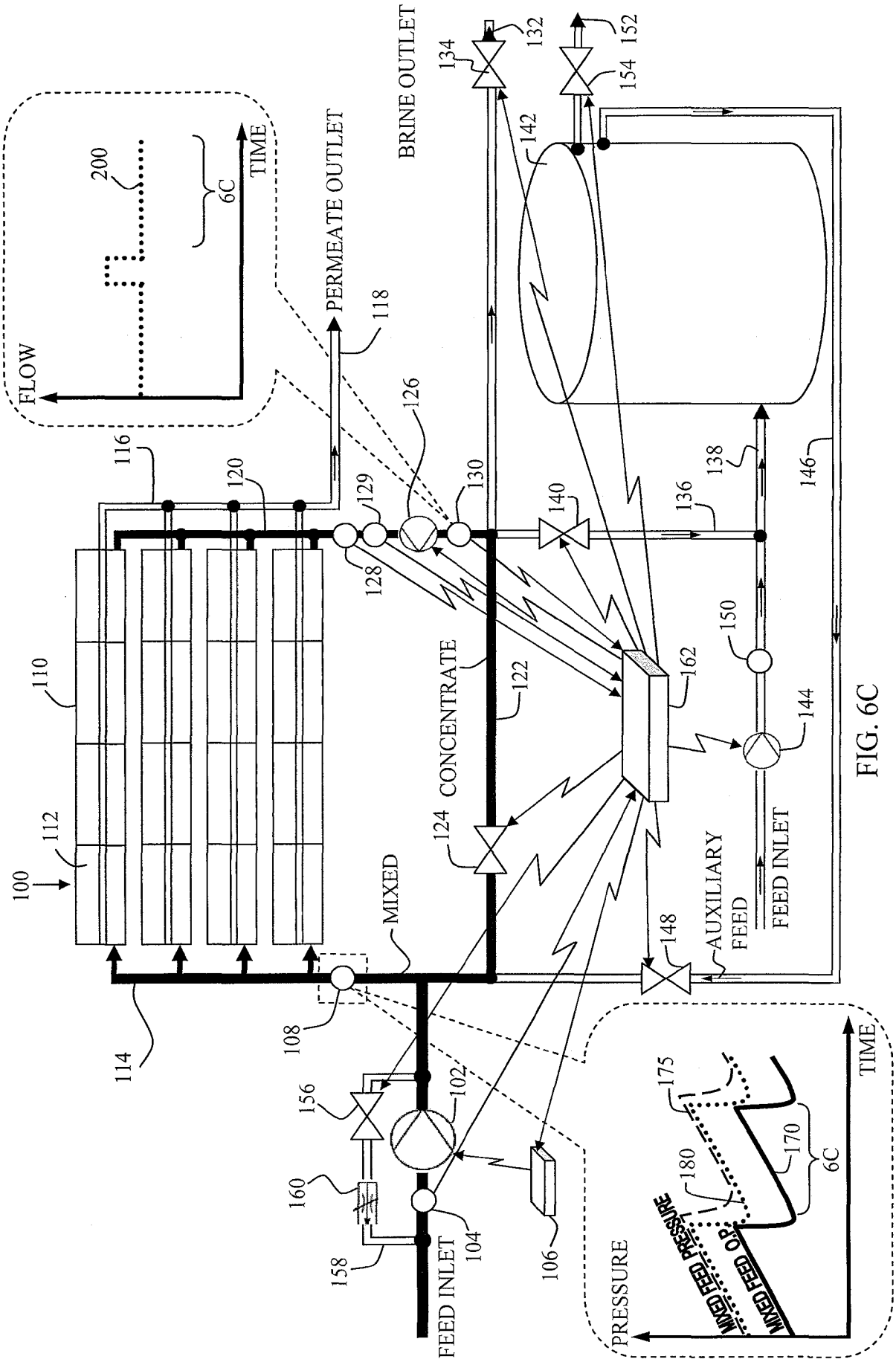

BRINE OUTLET
PERMEATE OUTLET
FLOW
TIME
6C
200
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
146
148
150
152
154
156
158
160
162
170
175
180

FIG. 6C

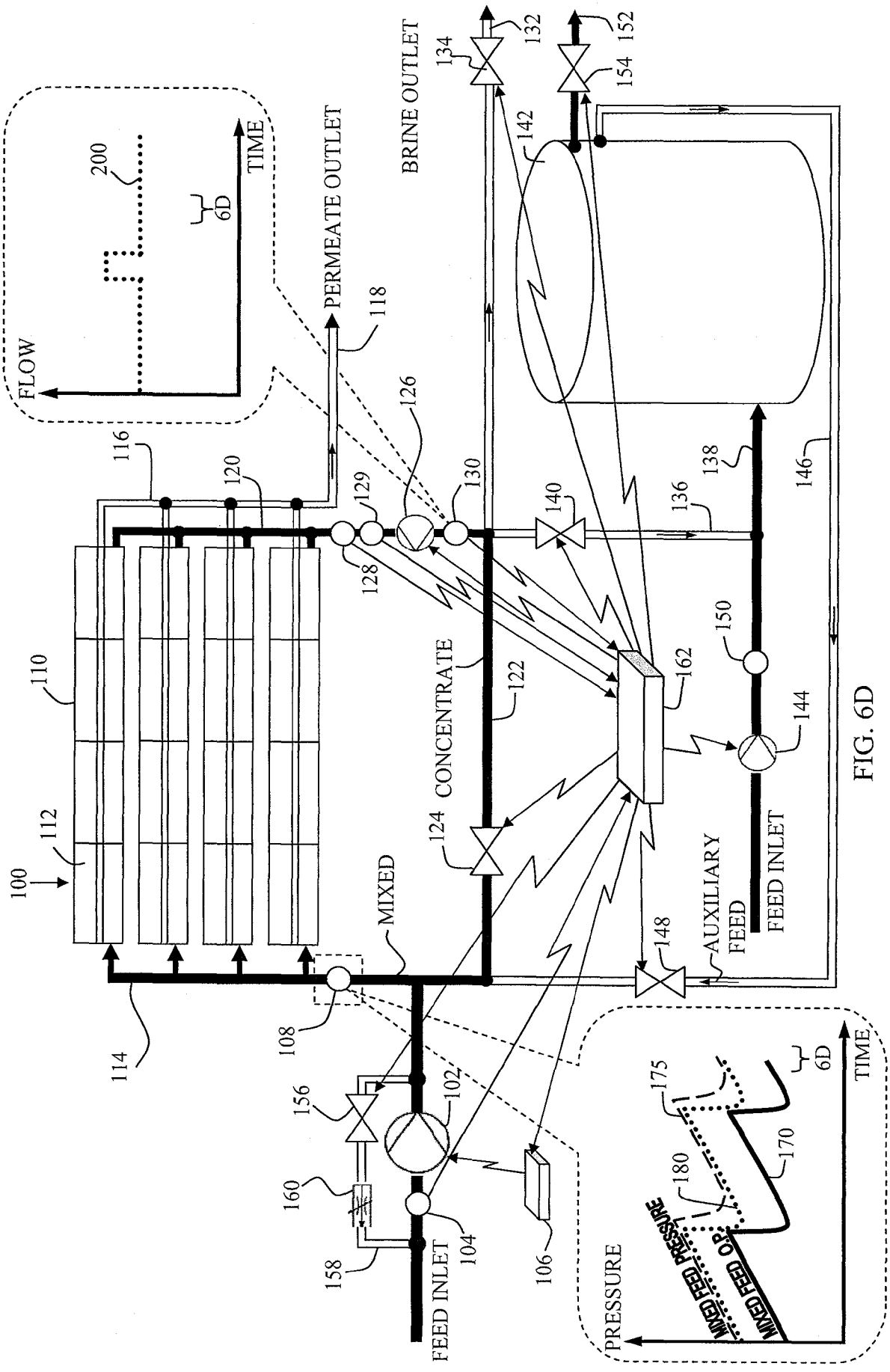

FLOW
TIME
6D
200
PERMEATE OUTLET
118
BRINE OUTLET
132
134
152
154
142
126
116
120
129
130
140
136
138
146
128
110
CONCENTRATE
122
162
150
144
112
100
124
MIXED
AUXILIARY FEED
FEED INLET
148
114
108
102
156
160
158
104
106
PRESSURE
TIME
6D
175
180
170
MIXED FEED PRESSURE
MIXED FEED OP

FIG. 6D

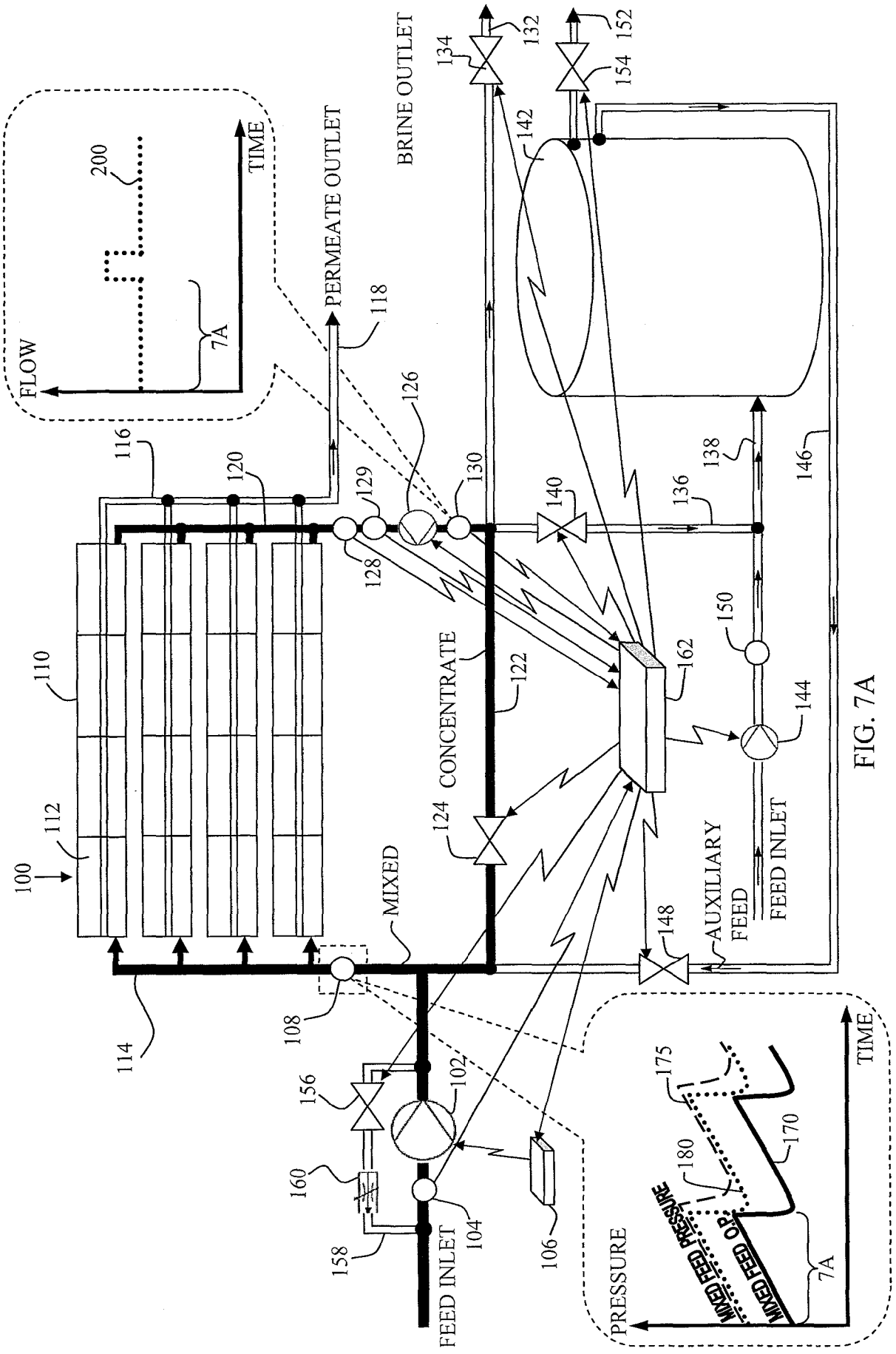

FLOW
TIME
200
7A
PERMEATE OUTLET
BRINE OUTLET
118
134
132
152
154
142
116
120
129
126
130
140
136
138
146
128
110
CONCENTRATE
122
162
150
144
112
100
124
MIXED
AUXILIARY
FEED
FEED INLET
148
114
108
156
102
160
158
104
106
FEED INLET
PRESSURE
TIME
175
180
170
MIXED FEED PRESSURE
MIXED FEED O.P.
7A

FIG. 7A

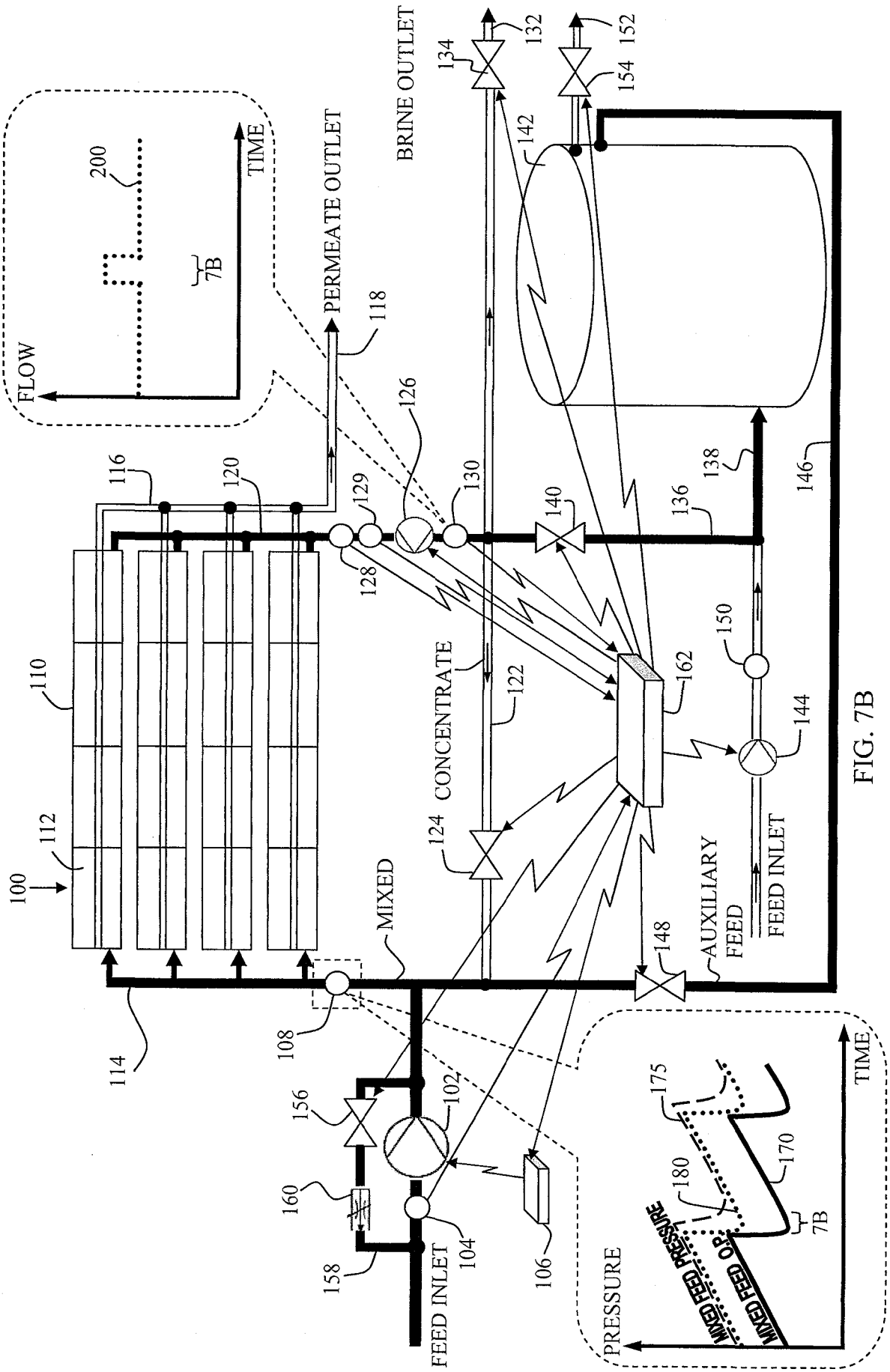

FLOW
TIME
200
7B
PERMEATE OUTLET
BRINE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
7B
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
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132
134
136
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142
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158
160
162
170
175
180

FIG. 7B

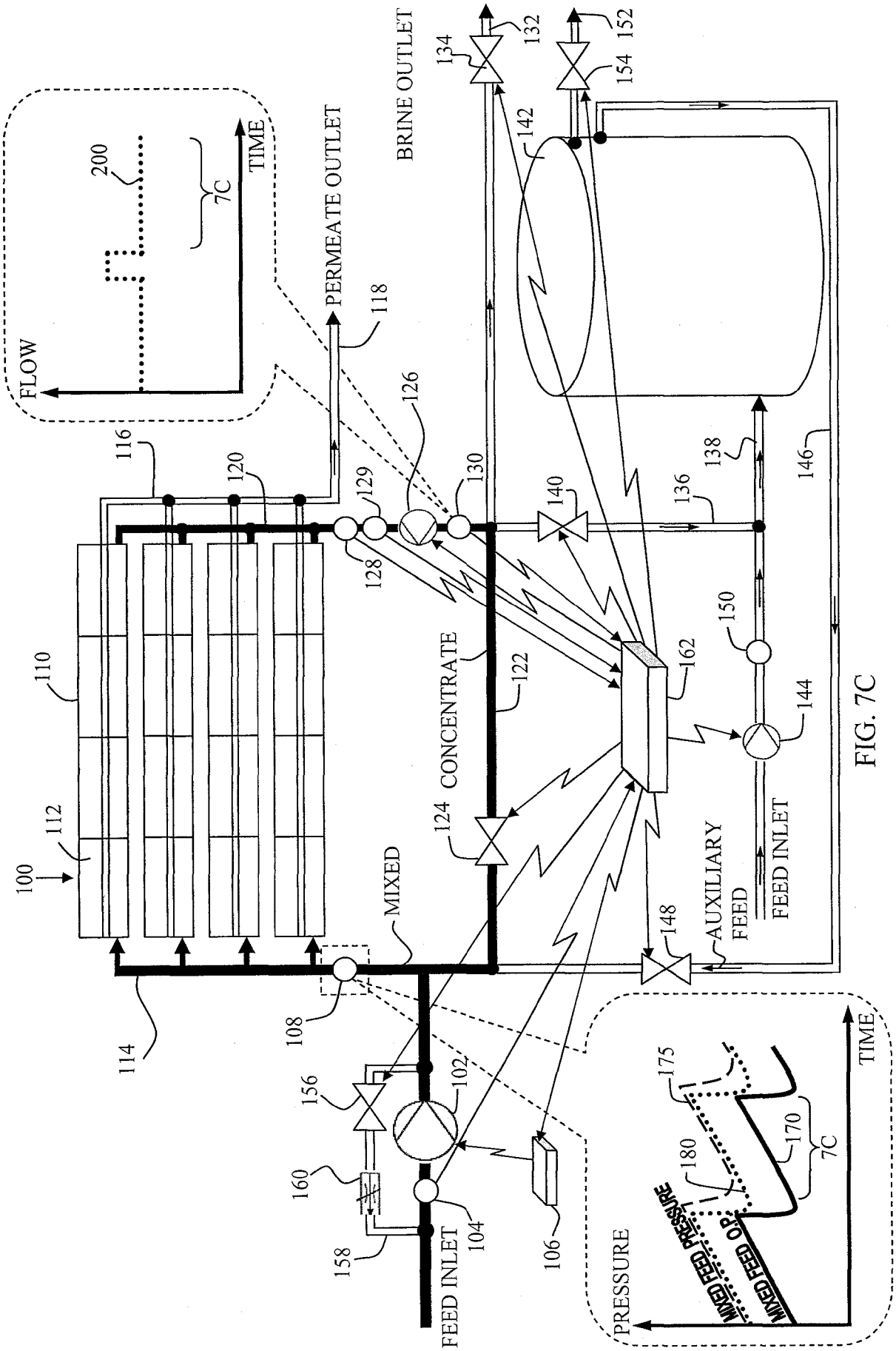

FLOW
TIME
200
7C
PERMEATE OUTLET
118
BRINE OUTLET
134
132
152
154
142
116
120
129
126
130
140
136
138
146
128
110
CONCENTRATE
122
162
150
144
112
100
MIXED
124
AUXILIARY
FEED
FEED INLET
148
114
108
156
102
160
158
104
106
FEED INLET
PRESSURE
TIME
175
180
170
7C
MIXED FEED PRESSURE
MIXED FEED O.P.

FIG. 7C

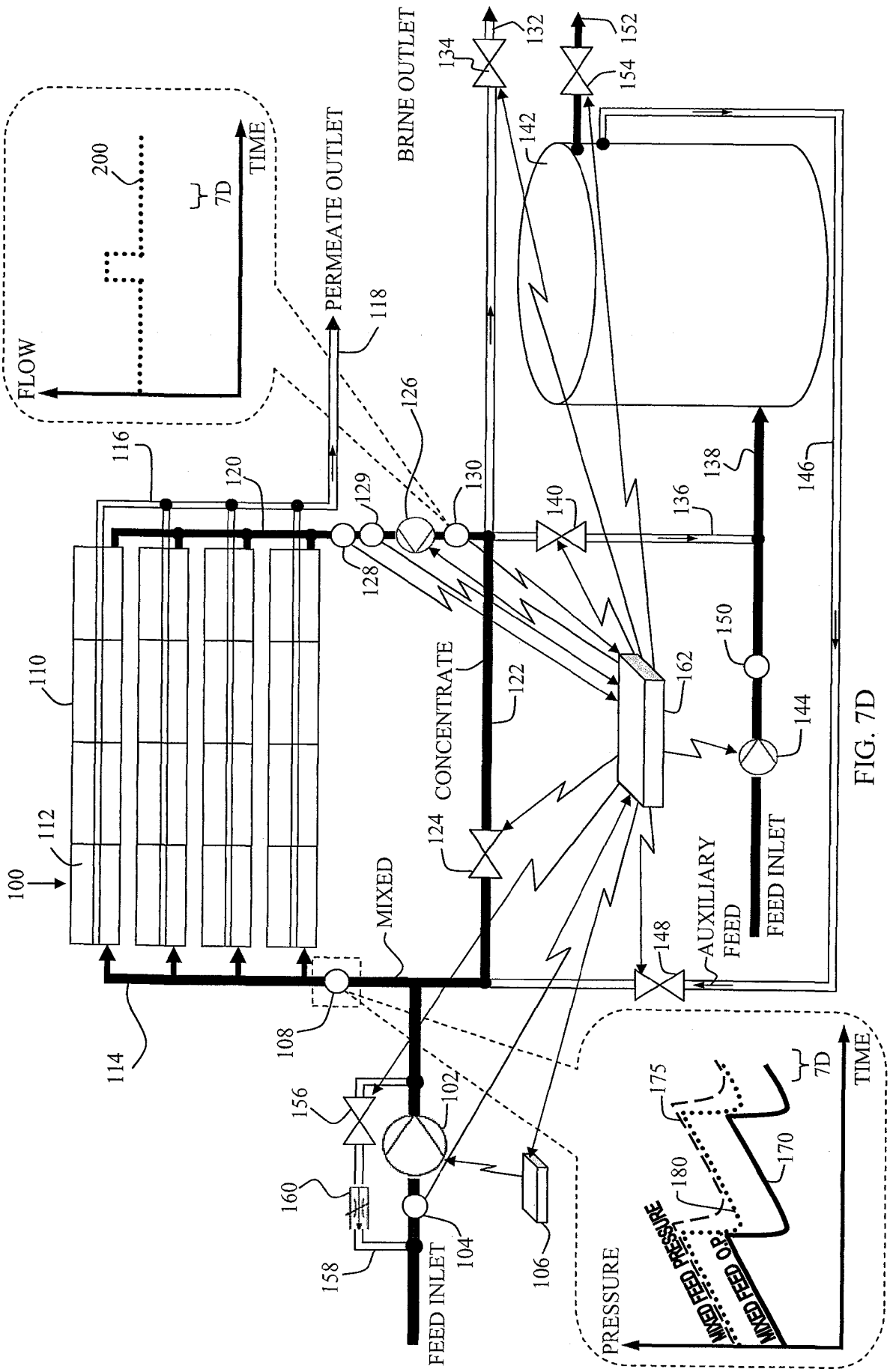

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
FLOW
TIME
7D
200
PRESSURE
TIME
7D
MIXED FEED PRESSURE
MIXED FEED O.P.
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
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158
160
162
170
175
180

FIG. 7D

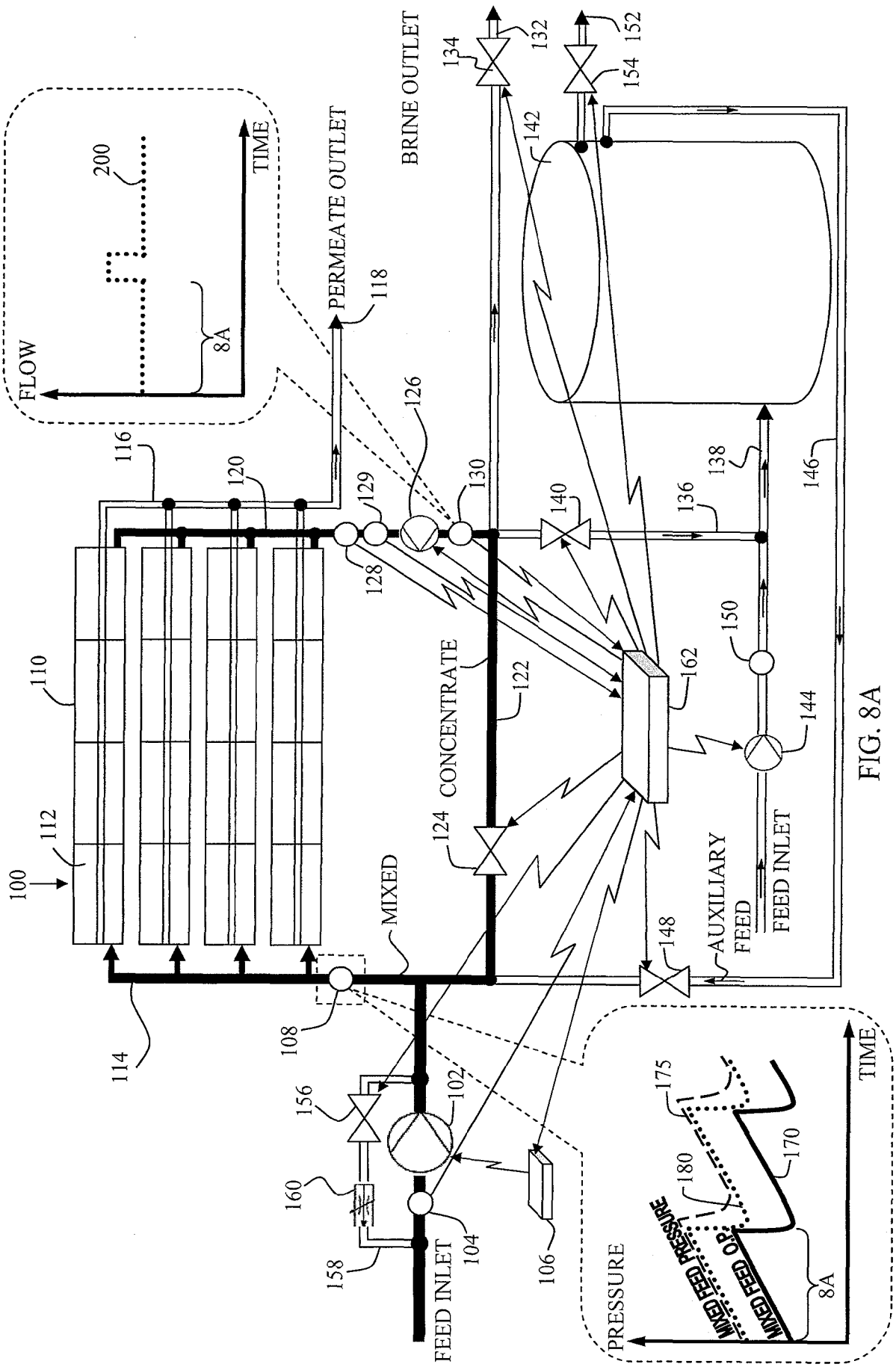

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
FLOW
TIME
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
8A
8A
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
142
144
146
148
150
152
154
156
158
160
162
170
175
180
200

FIG. 8A

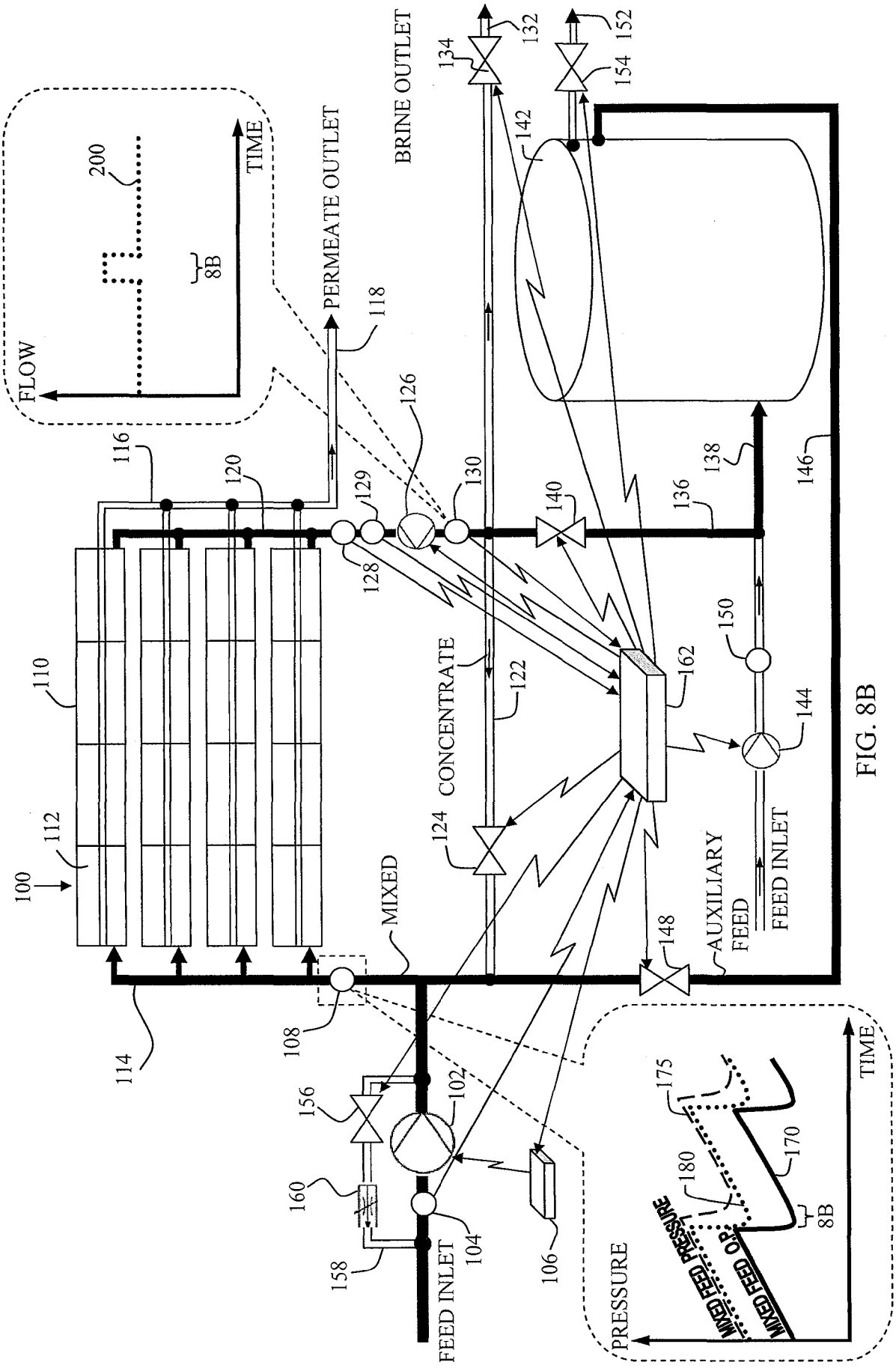

BRINE OUTLET
PERMEATE OUTLET
TIME
FLOW
200
8B
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP
175
180
170
8B
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
129
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132
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136
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150
152
154
156
158
160
162

FIG. 8B

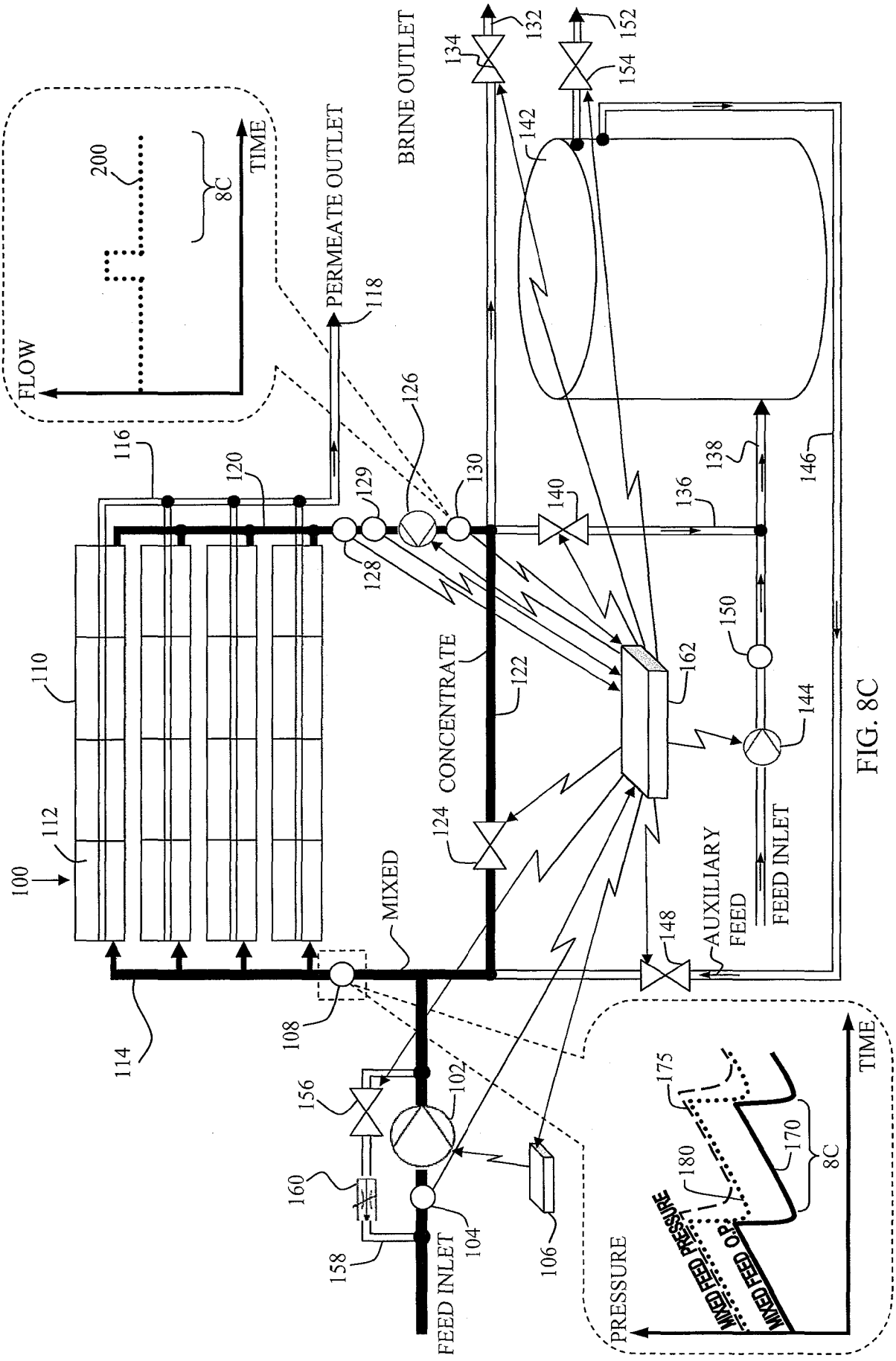

FLOW
TIME
200
8C
PERMEATE OUTLET
118
BRINE OUTLET
134
132
152
154
142
116
120
129
126
130
140
136
138
146
128
110
112
100
CONCENTRATE
122
162
150
144
124
MIXED
AUXILIARY FEED
FEED INLET
148
114
108
156
102
160
158
104
106
FEED INLET
PRESSURE
TIME
175
180
170
8C
MIXED FEED PRESSURE
MIXED FEED O.P.

FIG. 8C

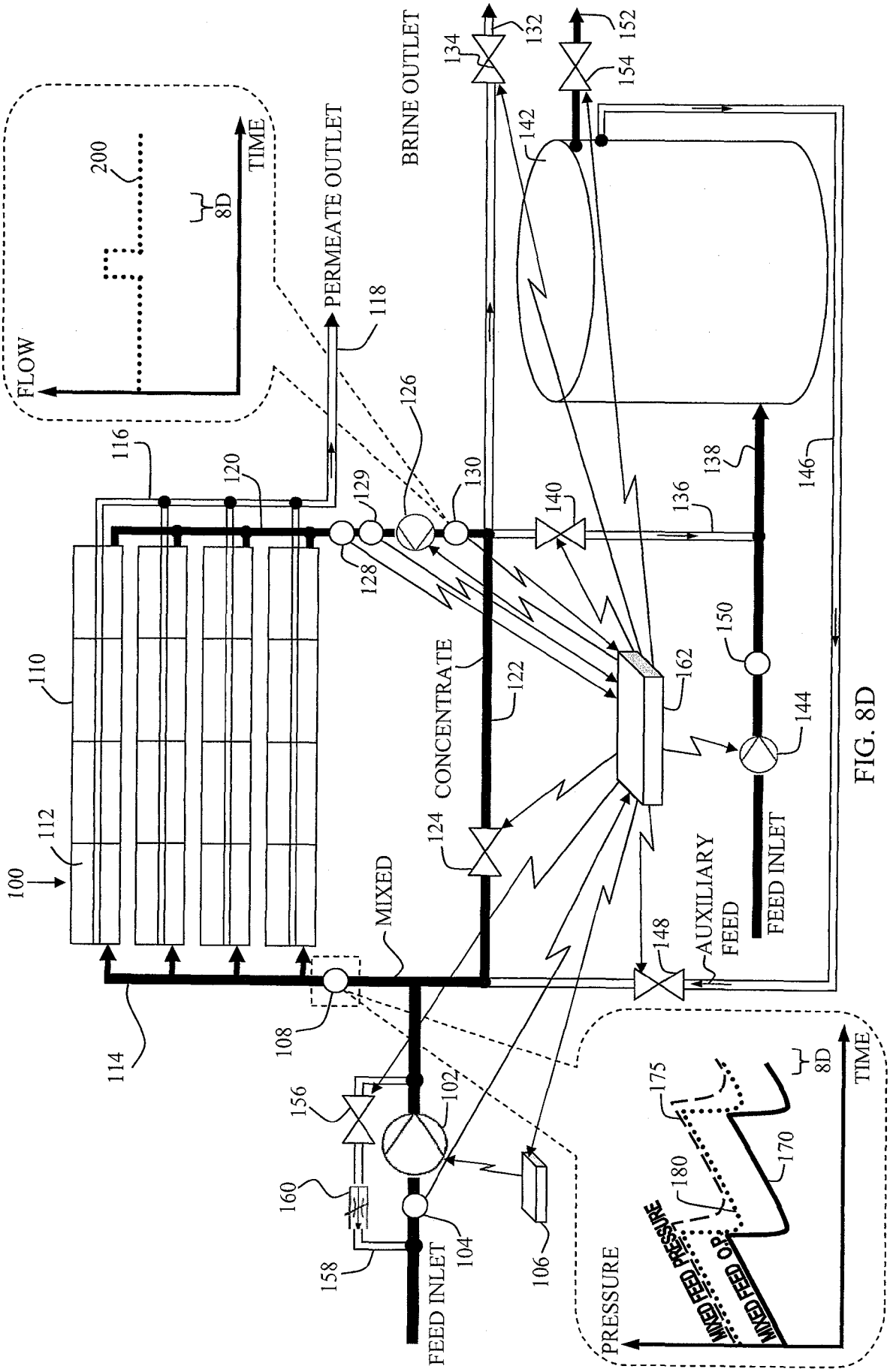

FLOW
TIME
8D
200
PERMEATE OUTLET
BRINE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
8D
MIXED FEED PRESSURE
MIXED FEED O.P.
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
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175
180

FIG. 8D

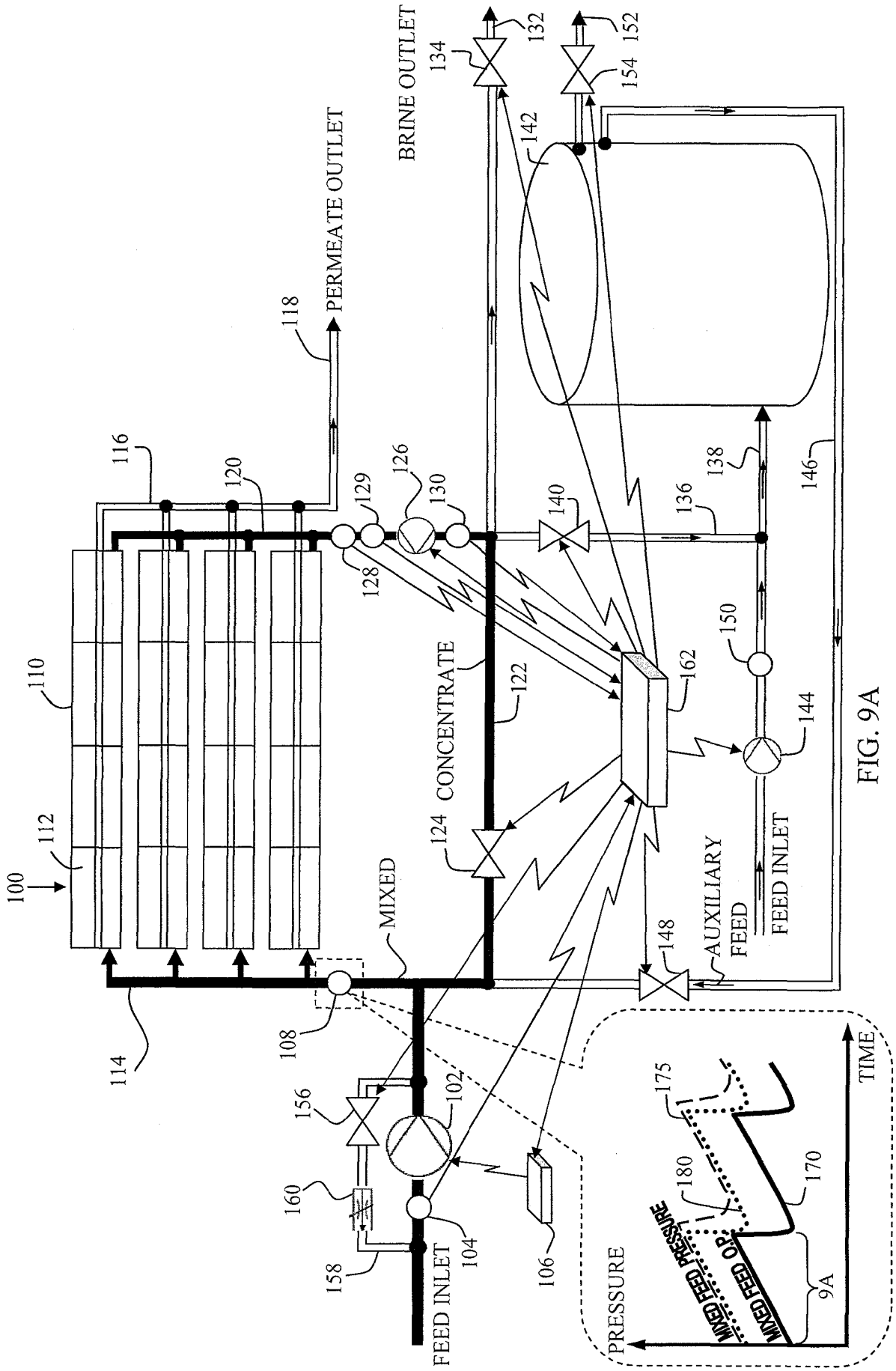

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
MIXED
AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED OP
9A
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FIG. 9A

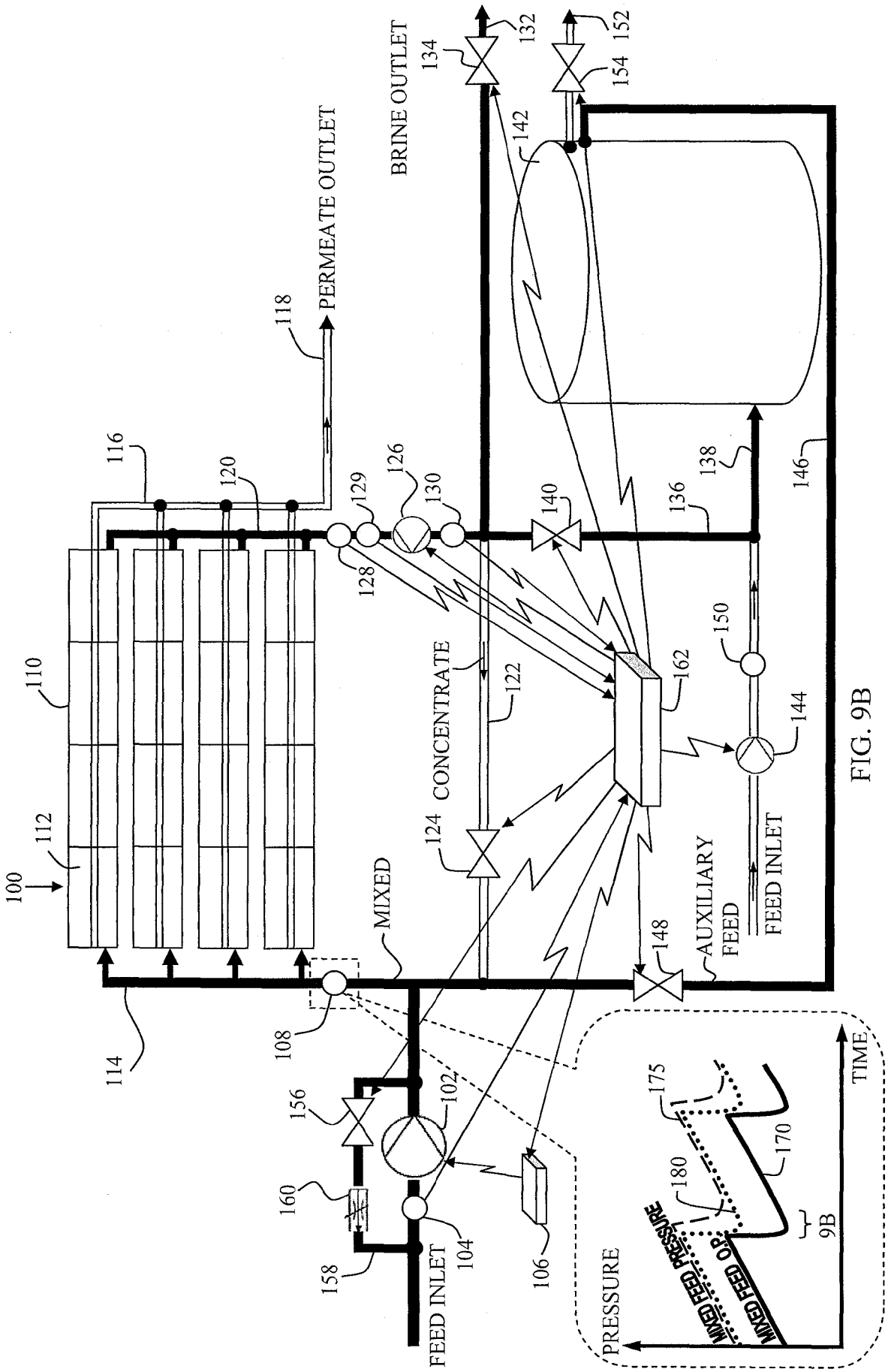

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CONCENTRATE
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AUXILIARY FEED
FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
9B
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FIG. 9B

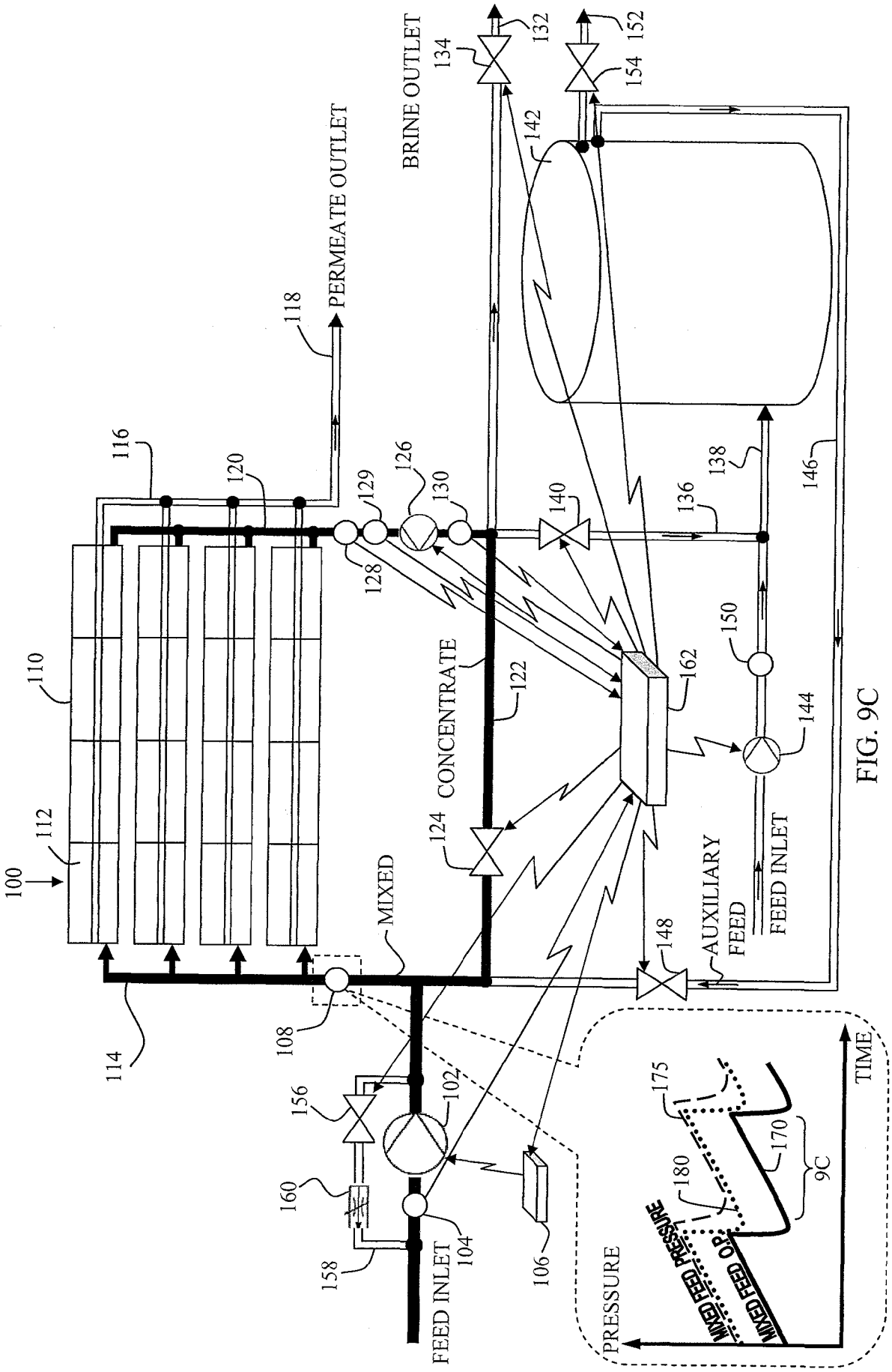

BRINE OUTLET
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FEED INLET
FEED INLET
PRESSURE
TIME
MIXED FEED PRESSURE
MIXED FEED O.P.
9C
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FIG. 9C

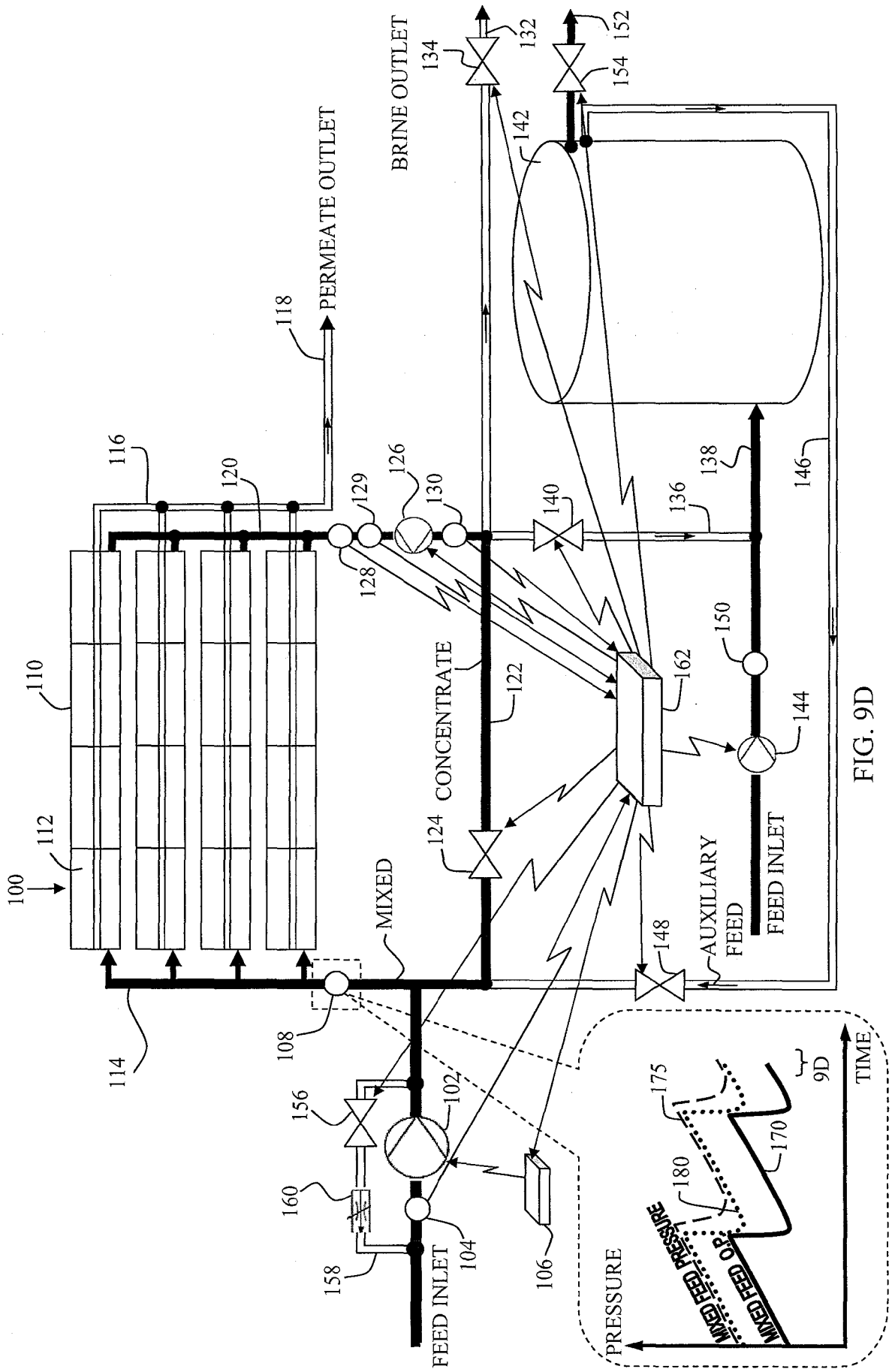

BRINE OUTLET
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FEED INLET
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MIXED FEED PRESSURE
MIXED FEED OP.
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FIG. 9D

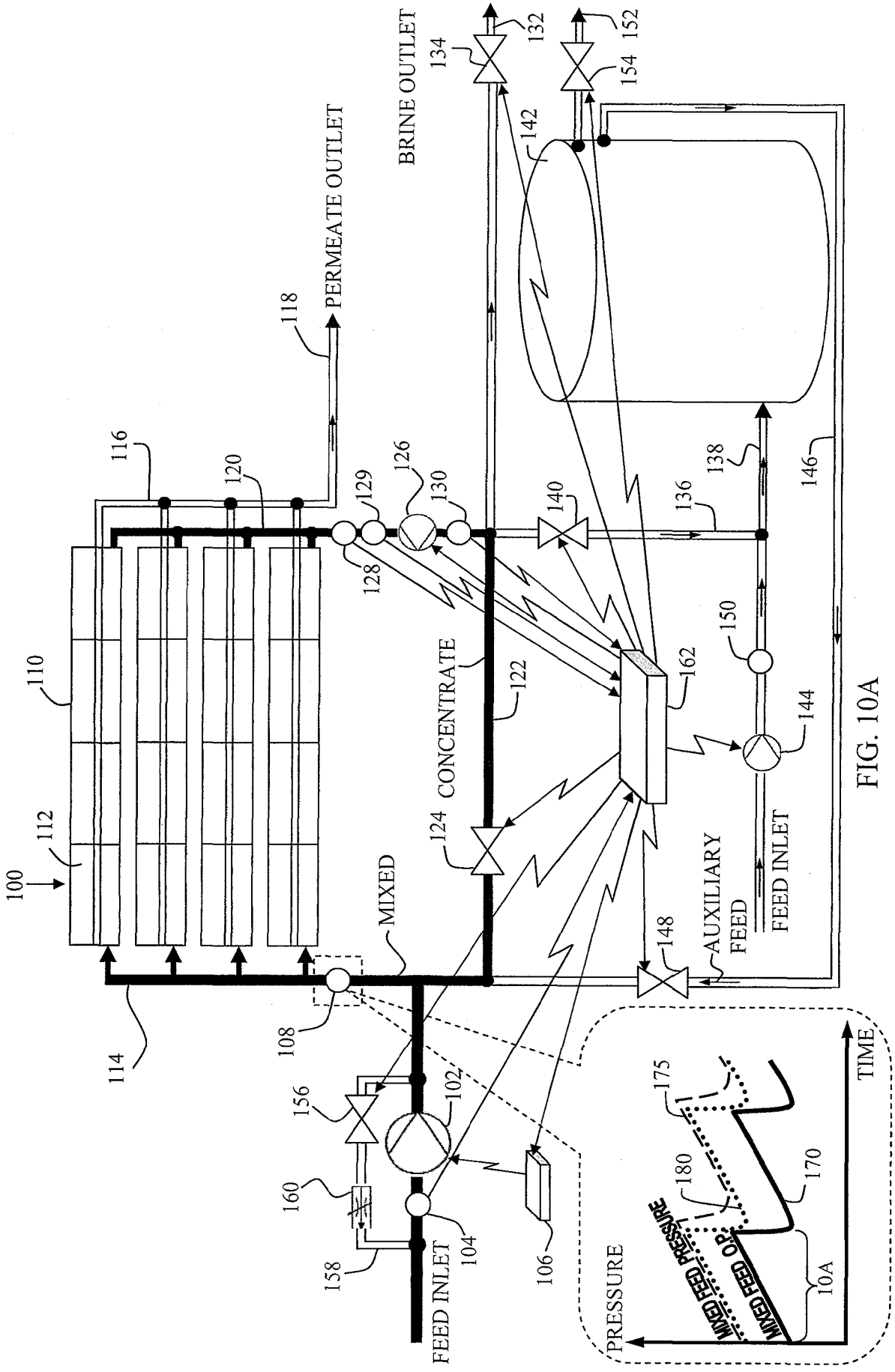

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FEED INLET
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MIXED FEED PRESSURE
MIXED FEED O.P.
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FIG. 10A

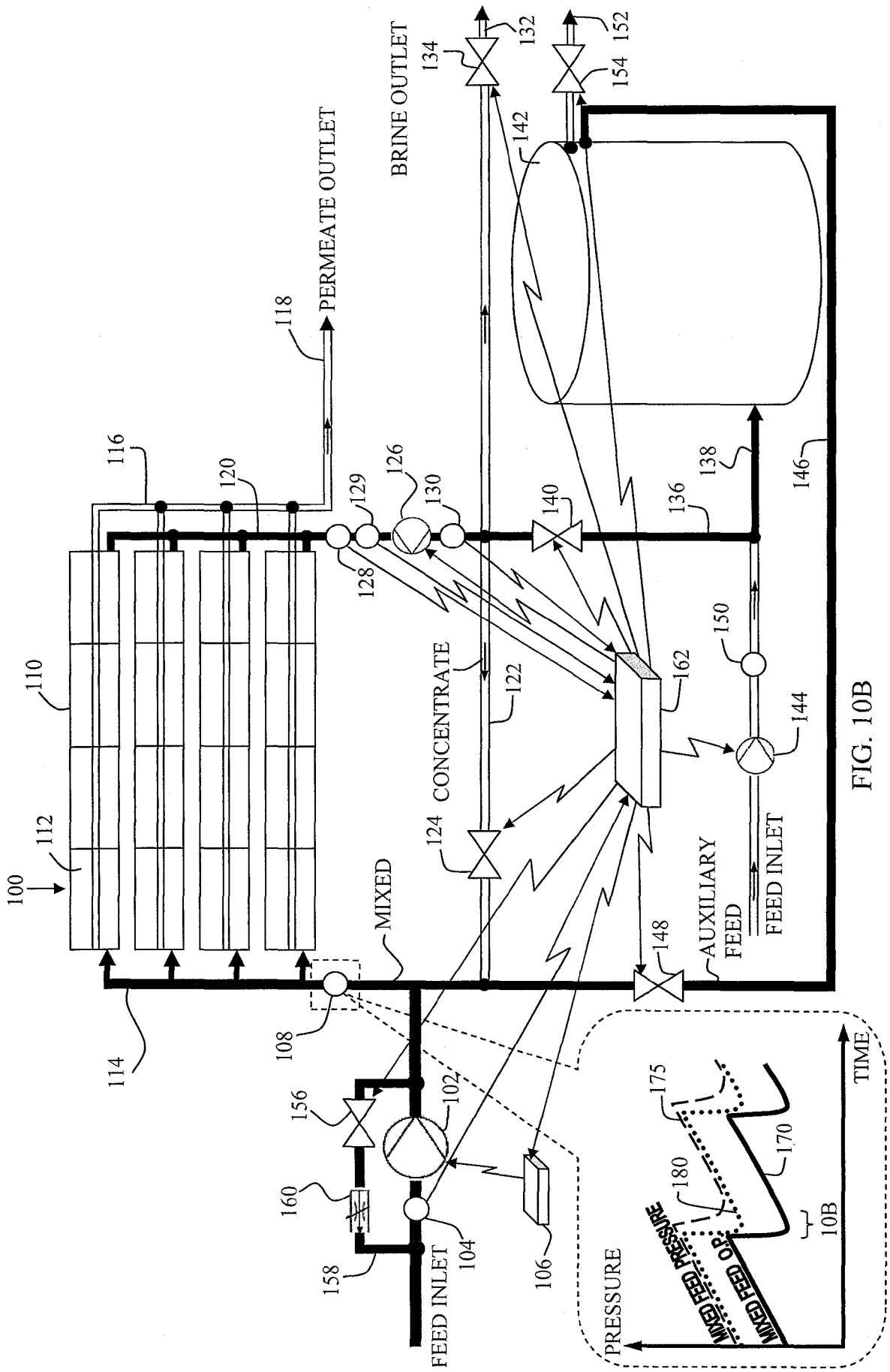

BRINE OUTLET
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PRESSURE
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MIXED FEED PRESSURE
MIXED FEED OP
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FIG. 10B

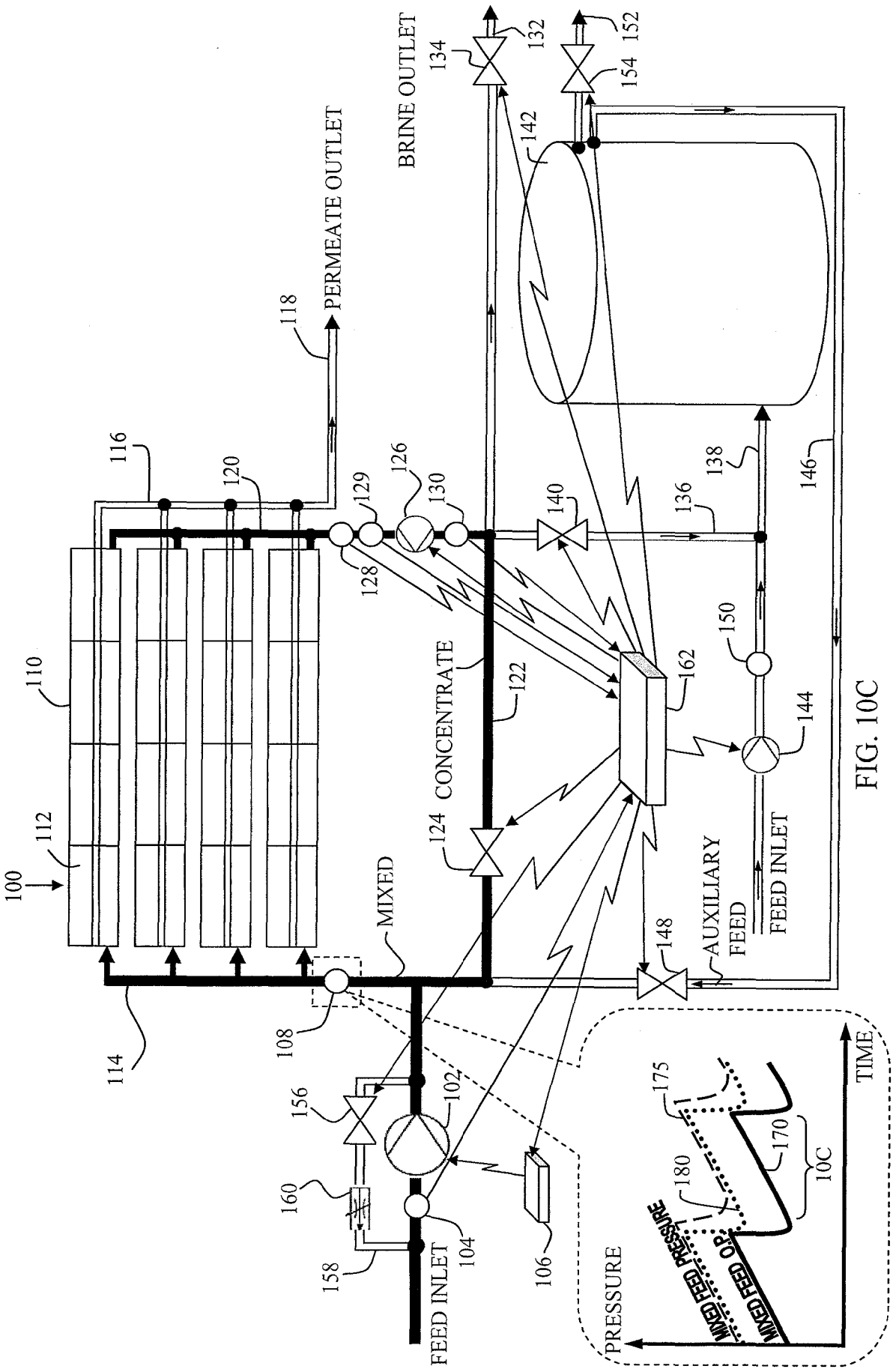

BRINE OUTLET
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FEED INLET
PRESSURE
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MIXED FEED PRESSURE
MIXED FEED O.P.
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FIG. 10C

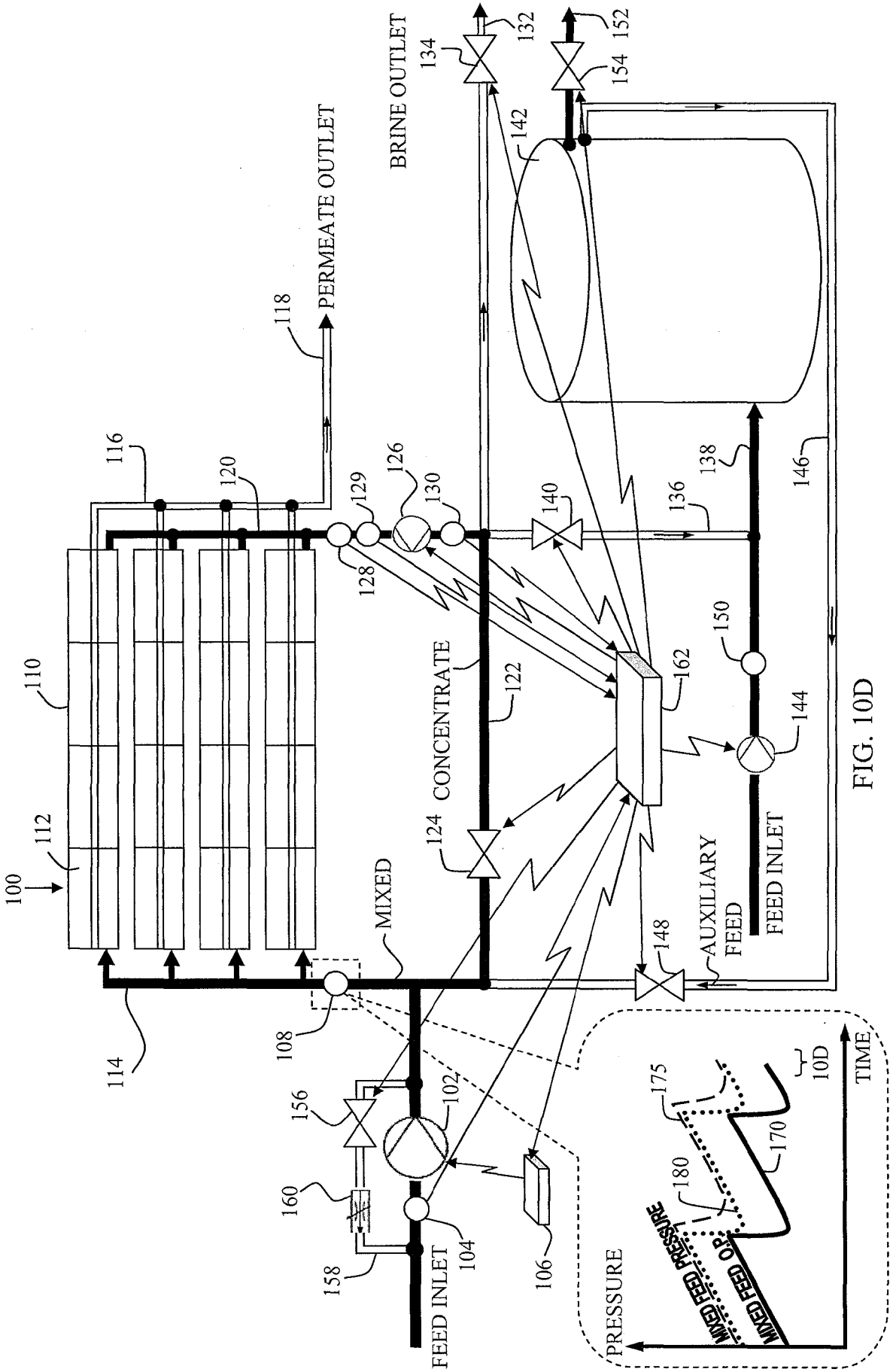

BRINE OUTLET
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PRESSURE
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MIXED FEED PRESSURE
MIXED FEED O.P.

FIG. 10D

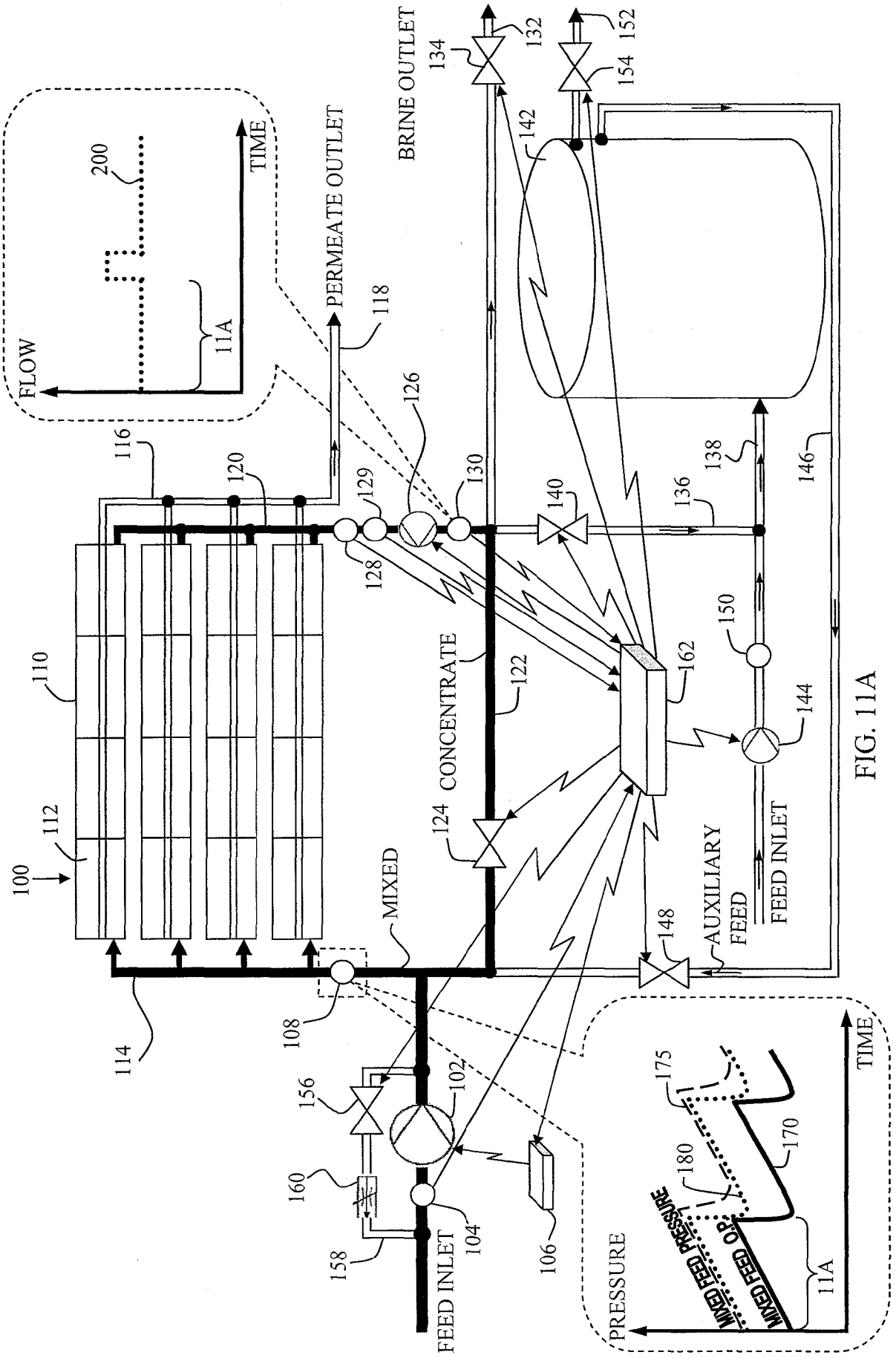

FLOW
TIME
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PERMEATE OUTLET
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CONCENTRATE
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MIXED
AUXILIARY FEED
FEED INLET
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FEED INLET
PRESSURE
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MIXED FEED PRESSURE
MIXED FEED O.P.
11A

FIG. 11A

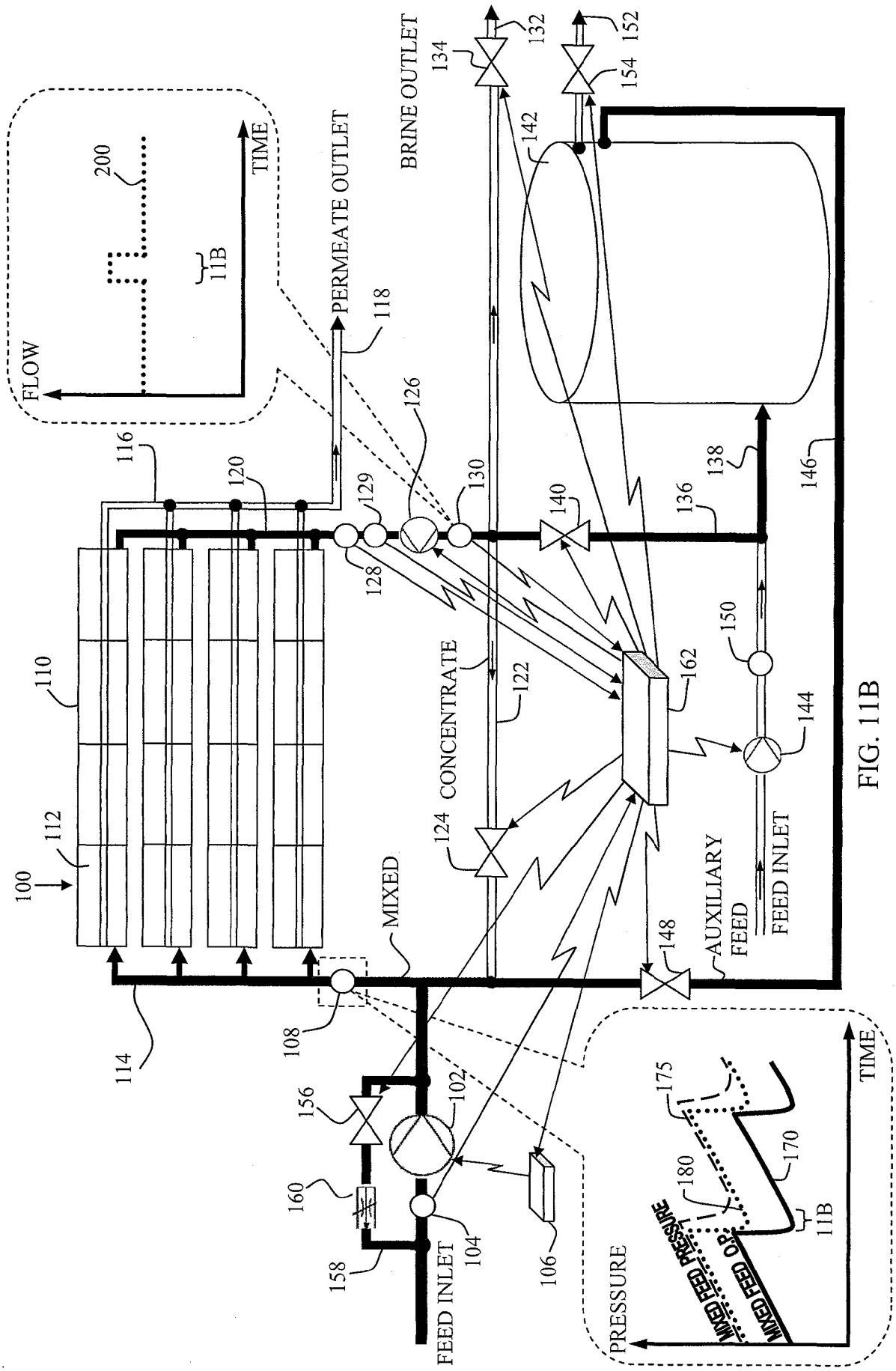

FLOW
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MIXED FEED OP

FIG. 11B

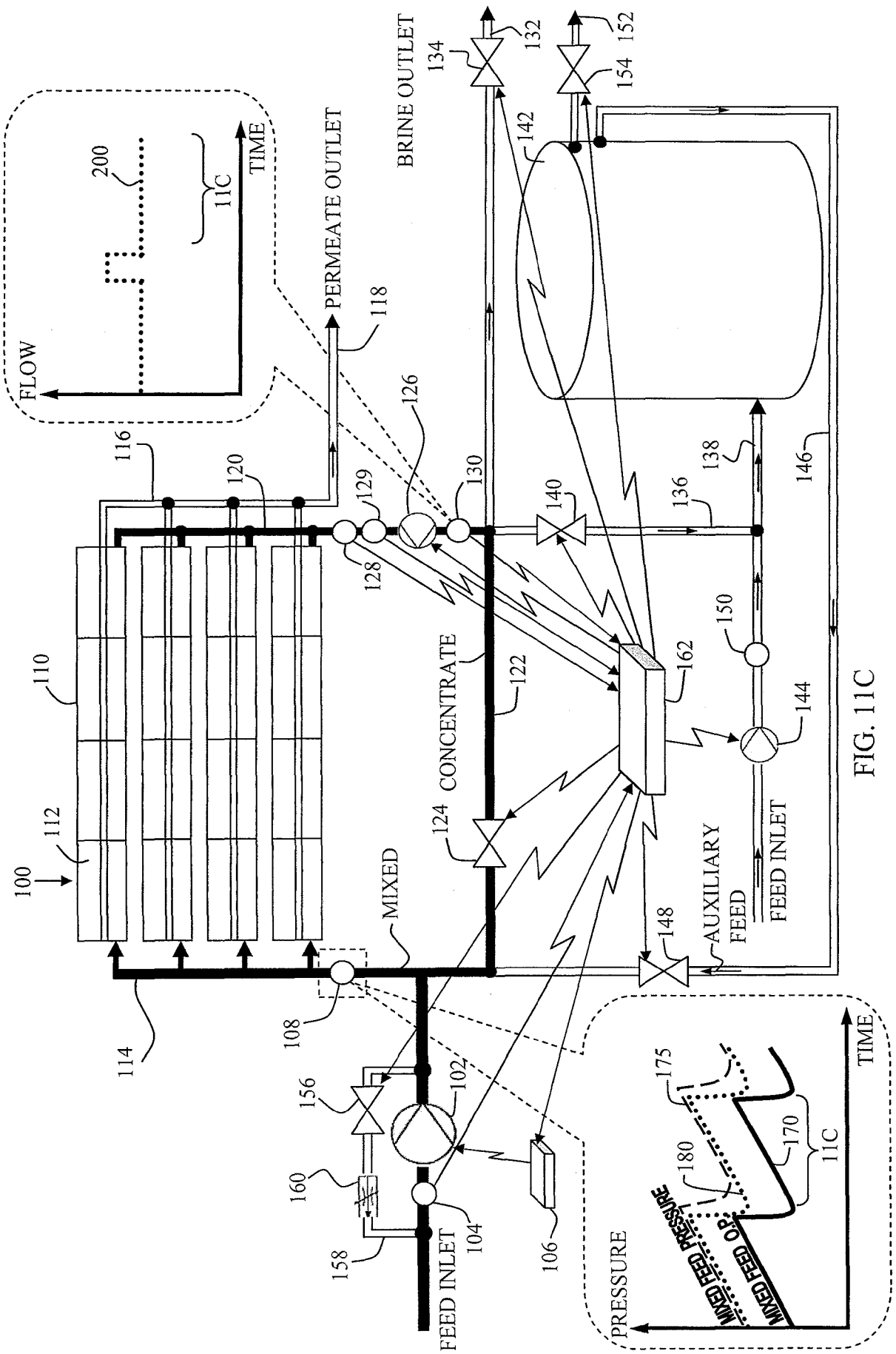

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MIXED FEED OP

FIG. 11C

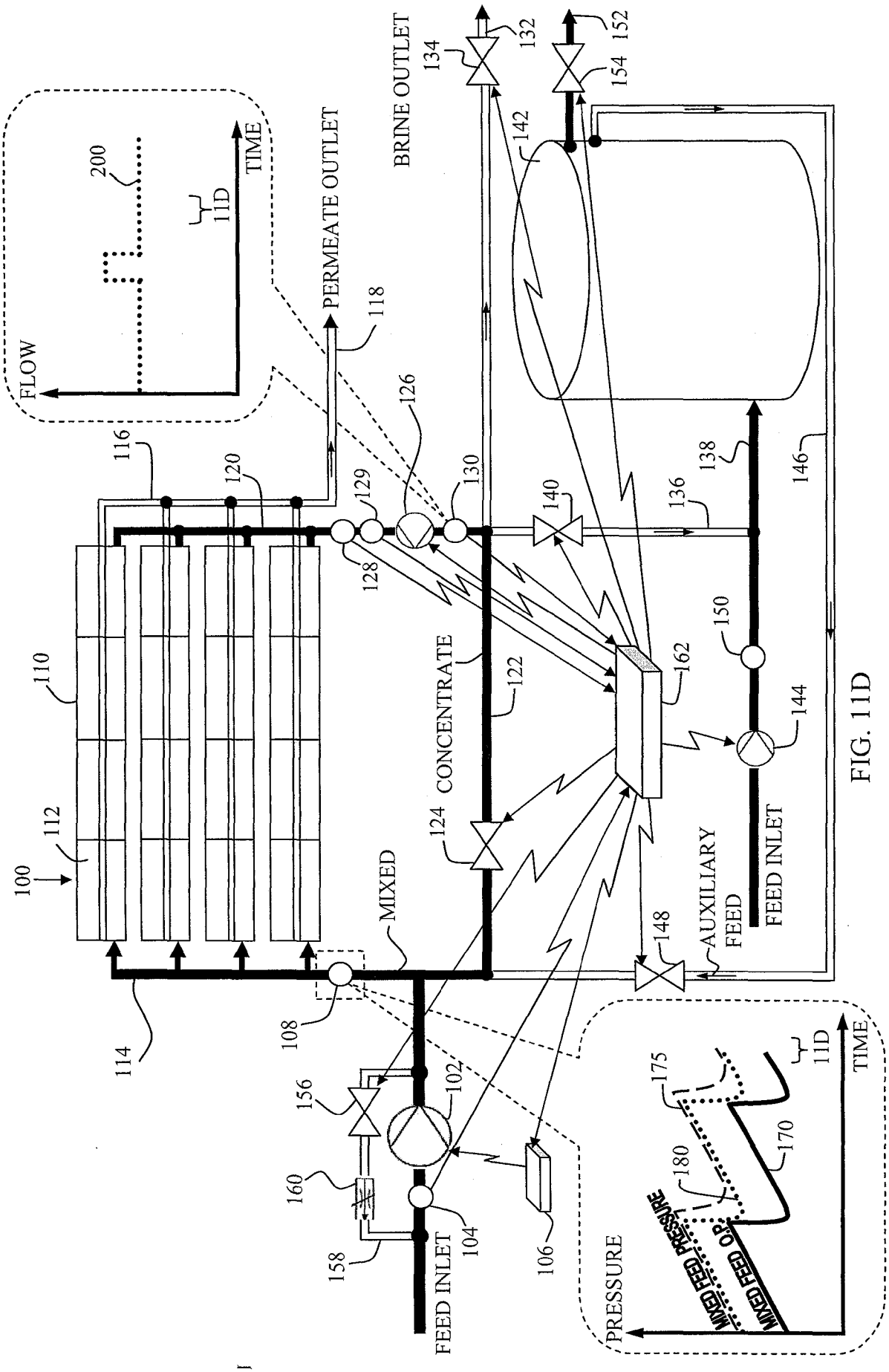

BRINE OUTLET
PERMEATE OUTLET
CONCENTRATE
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FEED INLET
FEED INLET
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MIXED FEED PRESSURE
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FIG. 11D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2016/050248

A. CLASSIFICATION OF SUBJECT MATTER

IPC (2016.01) B01D 65/02, B01D 61/02, B01D 61/14, B01D 61/12, B01D 61/22, C02F 1/44

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC (2016.01) B01D 65/02, B01D 61/02, B01D 61/14, B01D 61/12, B01D 61/22, C02F 1/44

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See extra sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014061129 A1 (HOZ BENAYA, ; ISRAEL AEROSPACE INDUSTRIES LTD) 06 Mar 2014 (2014/03/06) Figures: 1A, 2A, 2B ; Abstract; Paragraphs: 0065, 0070-0074, 0081-0086	1-3,5,7,8,10,17,19
A		4,9,11-16,18,20-22
X	US 2009120873 A1 (BECKER NATHANIEL T, ; BRAUN RYSZARD, ; CHRISTENSEN, JR. ROBERT I, ; EKBOM STEFAN, ; FONG ROBIN, ; SCHULER ALEXANDRA, ; DANISCO US INC) 14 May 2009 (2009/05/14) Figures: 2, 14, 15A, 15D, 15E,15H, 15I, 16A-E, 32-35, 44; Paragraphs: 0108,0124,0128,0137,0142,0160-0174, 0222-0227, 0251-0256.	1-3,5-11,13-22
A		4,12
A	US 4629568 A (KINETICO, INC) 16 Dec 1986 (1986/12/16)	1-22

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 Jul 2016	14 Jul 2016
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616	Authorized officer Aamidor Josh Telephone No. 972-2-5651722

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2016/050248

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4784771 A (ENVIRONMENTAL WATER TECHNOLOGY, INC) 15 Nov 1988 (1988/11/15)	1-22

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2016/050248

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
US 2014061129 A1	06 Mar 2014	US 2014061129 A1	06 Mar 2014
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		EP 2641652 A3	08 Jan 2014
		ES 2437850 T3	14 Jan 2014
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		JP 2010538823 A	16 Dec 2010
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		RU 2460576 C2	10 Sep 2012
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		US 9375683 B2	28 Jun 2016
		WO 2009035700 A2	19 Mar 2009

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2016/050248

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
		WO 2009035700 A3	30 Apr 2009
US 4629568 A	16 Dec 1986	US 4629568 A	16 Dec 1986
		US 4650586 A	17 Mar 1987
US 4784771 A	15 Nov 1988	US 4784771 A	15 Nov 1988
		CA 1313625 C	16 Feb 1993

B. FIELDS SEARCHED:

* Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Databases consulted: Google Patents, PatBase

Search terms used: foul, clog, scale, flush, rinse, osmotic, pressure, filter, membrane, threshold, limit, maximum, flow, rate, speed, volume, brine, concentrare, permeate, feed, salinity. CPC classification: B01D2321/02, B01D2321/04, B01D2321/06, B01D2321/10, B01D2321/14, B01D2321/20, C02F2209/03, C02F2209/40, C02F2209/44, C02F2209/44.