

FLUID CONTROL SYSTEMS, DEVICES, AND METHODS FOR REGULATING LIQUID FLOW

Cross Reference to Related Application(s)

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The present disclosure claims the benefit of Singapore Patent Application No. 10202303227U filed on 15 November 2023, which is incorporated in its entirety by reference herein.

10 Technical Field

The present disclosure generally relates to fluid control systems, devices, and methods for regulating liquid flow, such as for use in a reverse osmosis process.

15 Background

Reverse osmosis (RO) is a water purification process that uses semi-permeable membranes to separate water molecules from other substances by applying pressure to overcome osmotic pressure, such as to extract freshwater from seawater. For example, seawater reverse osmosis (SWRO) is used for large-scale desalination around the world. FIG. 1A shows an exemplary SWRO process 100. A high-pressure pump 102 receives seawater 104, such as from a microfiltration unit, and pumps the seawater 104 to RO membranes 106. Freshwater 108 is pumped out from the RO membranes 106 at low pressure and wastewater is pumped out from the RO membranes 106 at high pressure. For example, the wastewater includes brine 110. The brine 110 is sent to an energy recovery device 120 to recover hydraulic energy from the brine 110. Specifically, the energy recovery device 120 receives seawater 104 at low pressure from the microfiltration unit and transfers the hydraulic energy from the high-pressure brine 110 to the low-pressure seawater 104. A booster pump 112 pumps high-pressure seawater 114 from the energy recovery device 120 to the input line for the RO membranes 106. The energy recovery device 120 also releases rejected wastewater at low pressure. For example, the rejected wastewater includes brine 116.

High energy input is required to apply sufficient pressure at the RO membranes 106 overcome the osmotic pressure and extract freshwater 108 from seawater 104. The energy consumption of SWRO remains substantially higher than that for surface water treatment and indirect potable recycling, making SWRO less cost effective than other alternatives for producing potable water. Using energy recovery devices 120 in the SWRO process 100 can recover hydraulic energy from the high-pressure brine 110 and transfer it to the low-pressure seawater 104, thus reducing the amount of energy required for the high-pressure pump 102. In particular, the hydraulic energy contained in the high-pressure brine 110 is typically about 60% of the total energy used to accomplish the SWRO desalination process 100, and over 90% of this hydraulic energy can be recovered.

FIG. 1B shows an exemplary energy recovery device 120 having tubes 122 for communicating seawater 104 and brine 110, as well as pistons 124 for moving the seawater 104 and brine 110 in the tubes 122. The tubes 122 and pistons 124 are housed in a chamber 126 that is cyclically rotatable by a rotor 128. The energy recover device 120 includes a first inlet 130, a first outlet 132, a second inlet 134, and a second outlet 136. The second inlet 134 receives low-pressure seawater 104 into the respective tubes 122 and the rotor 128 rotates the chamber 126. The first inlet 130 receives high-pressure brine 110 from the RO membranes 106 and hydraulic energy from the high-pressure brine 110 pushes the respective pistons 124 through the respective tubes 122, thereby pushing out the seawater 104 in the respective tubes 122. Specifically, the second outlet 136 discharges high-pressure seawater 114 from the respective tubes 122. The brine 110 remaining in the respective tubes 122 is now at low pressure due to the hydraulic energy loss, and the rotor 128 rotates the chamber 126. The second inlet 134 again receives low-pressure seawater 104 into the respective tubes 122 and hydraulic energy from the low-pressure seawater 104 pushes the respective pistons 124 through the respective tubes 122, thereby pushing out the brine 110 remaining in the respective tubes 122. Specifically, the first outlet 132 discharges low-pressure brine 116 from the respective tubes 122. The rotor 128 rotates the chamber 126 so that the high-pressure brine 110 can push out the seawater 104 in the respective tubes 122 as the high-pressure seawater 114.

Accordingly, the rotor 128 cyclically rotates the chamber 126 to deliver high-pressure seawater 114 to the RO membranes 106.

5 The process of recovering the latent hydraulic energy using the device 120 involves cyclical rotation of the chamber 126 or multiple chambers 126. In each cycle, the chambers 126 are brought up to working pressure and/or depressurized rapidly using valves to control liquid flow, such as by switching stream flows into and out of the chambers 126. One problem with the energy recovery device 120 is leakage around the pistons 124, such as due to damaged or improper seals, which can lead to mixing
10 of the brine 110 with seawater 104 in the tubes 122. The seawater 104 may also be contaminated by foreign particles released from the pistons 124 moving against the inner surfaces of the tubes 122. Seawater 104 contaminated by brine 110 and/or foreign particles can increase costs in the SWRO process 100 and maintenance of the equipment used.

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Therefore, in order to address or alleviate at least one of the aforementioned problems and/or disadvantages, there is a need to provide improved fluid control systems, devices, and methods for regulating liquid flow, particularly for reverse osmosis.

20 **Summary**

According to a first aspect of the present disclosure, there is a fluid control device for regulating liquid flow. The fluid control device comprises:

- 25 an outer body comprising at least one first fluidic port for communicating a first liquid into and from the outer body;
- an inner body comprising at least one second fluidic port for communicating a second liquid into and from the inner body, the inner body disposed and fluidically sealed within the outer body such that the first liquid and second liquid are fluidically isolated from each other,
- 30 wherein the inner body is expandable from a contracted state to an expanded state by said communicating of the second liquid into the inner body;
- wherein the inner body is expandable against the first liquid in the outer body to thereby discharge the first liquid from the outer body; and

wherein the inner body is contractable to the contracted state, after the first liquid is discharged from the outer body and the second liquid stops communicating into the inner body, to thereby discharge the second liquid from the inner body.

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According to a second aspect of the present disclosure, there is a fluid control method for regulating liquid flow. The fluid control method comprises:

communicating a first liquid into an outer body of a fluid control device to fill the outer body;

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communicating a second liquid into an inner body of the fluid control device to fill the inner body, the inner body disposed within the outer body and fluidically sealed such that the first liquid and second liquid are fluidically isolated from each other;

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expanding, by said communicating of the second liquid into the inner body, the inner body from a contracted state to an expanded state against the first liquid in the outer body;

discharging, by said expanding of the inner body, the first liquid from the outer body;

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stopping communication of the second liquid into the inner body after discharging the first liquid from the outer body;

contracting the inner body to the contracted state after stopping communication of the second liquid into the inner body; and

discharging, by said contracting of the inner body, the second liquid from the inner body.

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According to a third aspect of the present disclosure, there is a fluid control system for regulating liquid flow. The fluid control system comprises:

a first fluid control device and a second fluid control device fluidically connected to each other for regulating liquid flow, each fluid control device comprising:

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an outer body comprising at least one first fluidic port for communicating a first liquid into and from the outer body

- an inner body comprising at least one second fluidic port for communicating a second liquid into and from the inner body, the inner body disposed and fluidically sealed within the outer body such that the first liquid and second liquid are fluidically isolated from each other,
- 5 wherein each inner body is expandable from a contracted state to an expanded state by said communicating of the second liquid into the respective inner body;
- wherein the respective inner body is expandable against the first liquid in the respective outer body to thereby discharge the first liquid from the
- 10 respective outer body; and
- wherein the fluid control devices are configured to alternate between:
- communicating the first liquid into the outer body of the first fluid control device and communicating the second liquid into the inner body of the first fluid control device to thereby discharge the first liquid from
- 15 the outer body of the first fluid control device; and
- communicating the first liquid into the outer body of the second fluid control device and communicating the second liquid into the inner body of the second fluid control device to thereby discharge the first liquid from the outer body of the second fluid control device; and
- 20 wherein each inner body is contractable towards the contracted state, after the first liquid is discharged from the respective outer body and the second liquid stops communicating into the respective inner body, to thereby discharge the second liquid from the respective inner body.
- 25 According to a fourth aspect of the present disclosure, there is a fluid control method for regulating liquid flow using a plurality of fluid control devices. The fluid control method comprises:
- alternatingly communicating a first liquid into an outer body of the fluid control devices to fill the respective outer body;
- 30 alternatingly communicating a second liquid into an inner body of the fluid control devices to fill the respective inner body, the respective inner body disposed within the respective outer body and fluidically sealed such that the first liquid and second liquid are fluidically isolated from each other;

expanding, by said communicating of the second liquid into the respective inner body, the respective inner body from a contracted state to an expanded state against the first liquid in the respective outer body;

5 discharging, by said expanding of the respective inner body, the first liquid from the respective outer body;

 stopping communication of the second liquid into the respective inner body after discharging the first liquid from the respective outer body;

 contracting the respective inner body to the contracted state after stopping communication of the second liquid into the respective inner body; and

10 discharging, by said contracting of the respective inner body, the second liquid from the respective inner body; and

 alternating said discharging of the first liquid and second liquid from the respective fluid control devices by alternating communication of the first liquid and second liquid into the respective fluid control devices.

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Fluid control systems, devices, and methods for regulating liquid flow according to the present disclosure are thus disclosed herein. Various features and advantages of the present disclosure will become more apparent from the following detailed description of the embodiments of the present disclosure, by way of non-limiting examples only, along with the accompanying drawings.

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Brief Description of the Drawings

FIG. 1A and FIG. 1B are illustrations of a seawater reverse osmosis process.

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FIG. 2A to FIG. 2F are illustrations of a fluid control device for regulating liquid flow, according to embodiments of the present disclosure.

FIG. 3 is a flowchart illustration of a fluid control method for regulating liquid flow, according to embodiments of the present disclosure.

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FIG. 4A and FIG. 4B are illustrations of a fluid control system for regulating liquid flow, according to embodiments of the present disclosure.

FIG. 5A and FIG. 5B are illustrations of another fluid control system for regulating liquid flow, according to embodiments of the present disclosure.

- 5 FIG. 6 is an illustration of another fluid control system for regulating liquid flow, according to embodiments of the present disclosure.

FIG. 7 is a flowchart illustration of another fluid control method for regulating liquid flow, according to embodiments of the present disclosure.

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Detailed Description

For purposes of brevity and clarity, descriptions of embodiments of the present disclosure are directed to fluid control systems, devices, and methods for regulating liquid flow, in accordance with the drawings. While parts of the present disclosure will be described in conjunction with the embodiments provided herein, it will be understood that they are not intended to limit the present disclosure to these embodiments. On the contrary, the present disclosure is intended to cover alternatives, modifications and equivalents to the embodiments described herein, which are included within the scope of the present disclosure as defined by the appended claims. Furthermore, in the following detailed description, specific details are set forth in order to provide a thorough understanding of the present disclosure. However, it will be recognized by an individual having ordinary skill in the art, i.e. a skilled person, that the present disclosure may be practiced without specific details, and/or with multiple details arising from combinations of features of particular embodiments. In a number of instances, well-known systems, methods, procedures, and components have not been described in detail so as to not unnecessarily obscure features of the embodiments of the present disclosure.

- 30 In embodiments of the present disclosure, depiction of a given element or consideration or use of a particular element number in a particular figure or a reference thereto in corresponding descriptive material can encompass the same, an equivalent,

or an analogous element or element number identified in another figure or descriptive material associated therewith.

References to “an embodiment / example”, “another embodiment / example”, “some
5 embodiments / examples”, “some other embodiments / examples”, and so on, indicate
that the embodiment(s) / example(s) so described may include a particular feature,
structure, characteristic, property, element, or limitation, but that not every
embodiment / example necessarily includes that particular feature, structure,
characteristic, property, element or limitation. Furthermore, repeated use of the phrase
10 “in an embodiment / example” or “in another embodiment / example” does not
necessarily refer to the same embodiment / example.

The terms “comprising”, “including”, “having”, and the like do not exclude the presence
of other features / elements / steps than those listed in an embodiment. Recitation of
15 certain features / elements / steps in mutually different embodiments does not indicate
that a combination of these features / elements / steps cannot be used in an
embodiment.

As used herein, the terms “a” and “an” are defined as one or more than one. The use
20 of “/” in a figure or associated text is understood to mean “and/or” unless otherwise
indicated. The term “set” is defined as a non-empty finite organization of elements that
mathematically exhibits a cardinality of at least one (e.g. a set as defined herein can
correspond to a unit, singlet, or single-element set, or a multiple-element set), in
accordance with known mathematical definitions. The recitation of a particular
25 numerical value or value range herein is understood to include or be a recitation of an
approximate numerical value or value range.

Embodiments of the present disclosure describe a fluid control device 200 for
regulating liquid flow, such as shown in FIG. 2A to FIG. 2D. Particularly, the fluid
30 control device 200 can be used in various applications, for example in a reverse
osmosis process such as the SWRO process 100 wherein the fluid control device 200
may be used as an energy recovery device.

The fluid control device 200 includes an outer body 210 and an inner body 220. The outer body 210 includes at least one first fluidic port for communicating a first liquid into and from the outer body 210. In some embodiments as shown in FIG. 2A to FIG. 2C, the at least one first fluidic port includes a sole first fluidic port 212 selectably configurable to function as an inlet or an outlet. The first fluidic port 212 is selectably configured to function as an inlet for communicating the first liquid into the outer body 210 to fill the outer body 210. The first fluidic port 212 is selectably configured to function as an outlet for discharging the first liquid from the outer body 210. For example, the fluid control device 200 includes a fluidic component, such as a directional control valve, for selectably configuring the first fluidic port 212 of the outer body 210 to function as an inlet or an outlet.

Alternatively in some embodiments as shown in FIG. 2E, the at least one first fluidic port of the outer body 210 includes a first inlet 214 and a first outlet 216, the first inlet 214 for communicating the first liquid into the outer body 210 to fill the outer body 210, and the first outlet 216 for discharging the first liquid from the outer body 210. The fluid control device 200 may include respective fluidic components, such as non-return valves, for configuring one-way fluid flow through the first inlet 214 and first outlet 216, respectively.

The inner body 220 includes at least one second fluidic port communicating a second liquid into and from the inner body 220. In some embodiments as shown in FIG. 2A to FIG. 2E, the at least one second fluidic port includes a sole second fluidic port 222 selectably configurable to function as an inlet or an outlet. The second fluidic port 222 is selectably configured to function as an inlet for communicating the second liquid into the inner body 220 to fill the inner body 220. The second fluidic port 222 is selectably configured to function as an outlet for discharging the second liquid from the inner body 220. For example, the fluid control device 200 includes a fluidic component, such as a directional control valve, for selectably configuring the second fluidic port 222 of the inner body 220 to function as an inlet or an outlet. Alternatively, the at least one second fluidic port includes an inlet and an outlet for communicating the second liquid into and out from the inner body 220, respectively, and the fluid control device 200

may further include respective fluidic components, such as non-return valves, for configuring one-way fluid flow through the inlet and outlet, respectively.

In many embodiments, the fluid control device 200 is used in the SWRO process 100, wherein the first liquid includes seawater and the second liquid includes brine. Particularly, the first liquid enters the first fluidic port 212 or the first inlet 214 of the outer body 210 at low pressure and may be referred to as low-pressure first liquid 230, such as low-pressure seawater. The second liquid enters the second fluidic port 222, when configured or used as an inlet, of the inner body 220 at high pressure and may be referred to as high-pressure second liquid 240, such as high-pressure brine.

Further, the inner body 220 is disposed and fluidically sealed within the outer body 210 such that the first liquid and second liquid are fluidically isolated from each other. The first liquid contained in the outer body 210 and the second liquid contained in the inner body are immiscible with each other. The inner body 220 is changeable between a contracted state and an expanded state. For example, FIG. 2B shows the inner body 220 in the contracted state and FIG. 2C shows the inner body 220 in the expanded state.

The inner body 220 is expandable from the contracted state to the expanded state by said communicating of the second liquid into the inner body 220. Particularly, the high-pressure second liquid 240 entering the second fluidic port 222 of the inner body 220 when configured or used as an inlet fills the inner body 220 and expands the inner body 220. The inner body 220 is expandable against the first liquid in the outer body 210, i.e. the low-pressure first liquid 230 filling the outer body 210, to thereby discharge the first liquid from the outer body 210. Specifically, the expansion of the inner body 220 pushes the first liquid in the outer body 210 out through the first fluidic port 212 or the first outlet 216. The first liquid exits the first outlet 216 of the outer body 210 at high pressure and may be referred to as high-pressure first liquid 232, such as high-pressure seawater.

The expandable inner body 220 is thus able to transfer the hydraulic pressure from the high-pressure second liquid 240 inside the inner body 220 to the low-pressure first

liquid 230 outside the inner body 220, thereby enabling the first liquid to be discharged from the outer body 210 as the high-pressure first liquid 232. The outer body 210 is made of a structurally rigid material to pressurize the low-pressure first liquid 230 and support the high-pressure liquid flows therein. When used as an energy recovery
5 device in the SWRO process 100, the fluid control device 200 can reduce the power rating of the high-pressure pump 102 and the overall power consumption of the SWRO process 100.

After the first liquid is discharged from the outer body 210 and the second liquid stops
10 communicating into the inner body 220, the inner body 220 is contractable to the contracted state to thereby discharge the second liquid from the inner body 220. Specifically, when there is no inflow of the high-pressure second liquid 240, the inner body 220 contracts and returns to the contracted state, and the contraction of the inner body 220 pushes the remaining second liquid in the inner body 220 out through the
15 second fluidic port 222 when configured or used as an outlet. The second liquid exits the second fluidic port 222 at low pressure and may be referred to as low-pressure second liquid 242, such as low-pressure brine.

In some embodiments, the inner body 220 is contractable to the contracted state by
20 the first liquid communicating into the outer body 210. Specifically, inflow of the low-pressure first liquid 230 into the outer body 210 pushes against the inner body 220, thereby contracting the inner body 220 and discharging the second liquid therein from the inner body 220. Alternatively or additionally, the inner body 220 is biased towards the contracted state. For example, the inner body 220 includes elastomeric
25 materials or spring-like components configured to bias the inner body 220 towards the contracted state.

In some embodiments as shown in FIG. 2A to FIG. 2D, the inner body 220 includes a
30 bellow structure 250 that is expandable in response to a force exerted thereon by the high-pressure second liquid 240 entering and filling the internal volume of the bellow structure 250, thereby extending the bellow structure 250 and expanding the inner body 220 to the expanded state. When there is no inflow of the high-pressure second liquid 240 into the inner body 220, inflow of the low-pressure first liquid 230 into the

outer body 210 pushes against the extended bellow structure 250 and contracts it, thereby contracting and returning the inner body 220 to the contracted state. FIG. 2C and FIG. 2D show the inner body 220 with bellow structure 260 in the contracted state and expanded state, respectively. For example, the bellow structure 260 is made of a
5 metallic material such as stainless steel (e.g. grade 304, 316, or 321), nickel, titanium, or other metallic alloys such as Hastelloy. The material should also be non-corrosive and/or food-grade to reduce health risks.

In some embodiments as shown in FIG. 2E and FIG. 2F, the inner body 220 includes
10 an elastic diaphragm 260 that is stretchable in response to a force exerted thereon by the high-pressure second liquid 240 entering and filling the internal volume of the inner body 220, thereby expanding the inner body 220 to the expanded state. The elastic diaphragm 250 is biased to contract, so when there is no inflow of the high-pressure second liquid 240 into the inner body 220, the elastic diaphragm 260 contracts and
15 returns the inner body 220 to the contracted state. For example, the elastic diaphragm 260 is made of a polymer material, such as polyvinylchloride-based polymer, fluorocarbon-based polymer, or fluorosilicone-based polymer. The material should also be non-corrosive and/or food-grade to reduce health risks.

20 Preferably, an outer surface of the inner body 220 is physically separated from an inner surface of the outer body 210. For example as shown in FIG. 2D, the edges 252 of the bellow structure 250 are the outer surface of the inner body 220 that is physically separated from the inner surface of the outer body 210. For example as shown in FIG. 2F, the edges 262 of the elastic diaphragm 260 are within the outer surface of the
25 inner body 220, so that the edges 262 are physically separated from the inner surface of the outer body 210. This physical separation, such as the gap 270 shown in FIG. 2D, between the outer surface of the inner body 220 and the inner surface of the outer body 210 prevents the inner body 220 from moving against the inner surface of the outer body 210 during contraction and expansion of the inner body 220. This would
30 prevent foreign particles getting dislodged or released from the inner surface of the outer body 210, thereby avoiding contamination of the first liquid (e.g. seawater) in the outer body 210. Another advantage of the fluid control device 200 is that the first liquid and second liquid are filled in fluidically isolated chambers that prevent them from

mixing with each other. The physical separation also reduces wearing of the surfaces of the outer body 210 and inner body 220 since there is no physical contact between them, thereby reducing risk of leakages and mixing of the liquids. Further, the inner surfaces of the outer body 210 and inner body 220 are preferably smooth to minimize frictional resistance during expansion and contraction of the inner body 220. The inner surfaces are preferably hydrophobic to reduce risk of biofouling which can pose health risks.

With reference to FIG. 3, embodiments of the present disclosure describe a fluid control method 300 for regulating liquid flow, such as by using the fluid control device 200. The method 300 includes a step 302 of communicating a first liquid (e.g. the low-pressure first liquid 230) into an outer body 210 of the fluid control device 200 to fill the outer body 210. The method 300 includes a step 304 of communicating a second liquid (e.g. the high-pressure second liquid 240) into an inner body 220 of the fluid control device 200 to fill the inner body 220, the inner body 220 disposed and fluidically sealed within the outer body 210 such that the first liquid and second liquid are fluidically isolated from each other. The method 300 includes a step 306 of expanding, by said communicating of the second liquid into the inner body 220, the inner body 220 from a contracted state to an expanded state against the first liquid in the outer body 210. The method 300 includes a step 308 of discharging, by said expanding of the inner body 220, the first liquid (e.g. the high-pressure first liquid 232) from the outer body 210. The method 300 includes a step 310 of stopping communication of the second liquid into the inner body 220 after discharging the first liquid from the outer body 210. The method 300 includes a step 312 of contracting the inner body 220 to the contracted state after stopping communication of the second liquid into the inner body 220. The method 300 includes a step 314 of discharging, by said contracting of the inner body 220, the second liquid (e.g. the low-pressure second liquid 242) from the inner body 220.

In many embodiments, the fluid control method 300 can be used in various applications, for example in a reverse osmosis process such as the SWRO process 100. The first liquid enters the outer body 210, such as via the first fluidic port 212 or the first inlet 214, at a lower pressure (i.e. the low-pressure first liquid 230 such as low-

pressure seawater), and the first liquid exits the outer body 210, such as via the first fluidic port 212 or the first outlet 216, at a higher pressure (i.e. the high-pressure first liquid 232 such as high-pressure seawater). The second liquid enters the inner body 220, such as via the second fluidic port 222 at a higher pressure (i.e. the high-pressure second liquid 240 such as high-pressure brine), and the second liquid exits the inner body 220, such as via the second fluidic port 222, at a lower pressure (i.e. the low-pressure second liquid 242 such as low-pressure brine).

Embodiments of the present disclosure describe a fluid control system for regulating liquid flow. Particularly, the fluid control system includes a plurality of the fluid control devices 200 fluidically connected to each other for regulating liquid flow. More specifically, the fluid control system includes a first fluid control device 200A and a second fluid control device 200B fluidically connected to each other for regulating liquid flow. Each of the fluid control devices 200A, 200B is identical to the fluid control device 200 described above with reference to FIG. 2A to FIG. 2D. It will be appreciated that the above description for the fluid control device 200 apply equally to each of the fluid control devices 200A, 200B.

Further, the fluid control devices 200A, 200B are configured to alternate between a first configuration and a second configuration. In the first configuration, the fluid control devices 200A, 200B are configured for communicating the first liquid into the outer body 210 of the first fluid control device 200A and communicating the second liquid into the inner body 220 of the first fluid control device 200A to thereby discharge the first liquid from the outer body 210 of the first fluid control device 200A. In the second configuration, the fluid control devices 200A, 200B are configured for communicating the first liquid into the outer body 210 of the second fluid control device 200B and communicating the second liquid into the inner body 220 of the second fluid control device 200B to thereby discharge the first liquid from the outer body 210 of the second fluid control device 200B. Accordingly, the first liquid is alternately discharged from the first fluid control device 200A and second fluid control device 200B.

FIG. 4A and FIG. 4B show an exemplary fluid control system 400 comprising the first fluid control device 200A and the second fluid control device 200B fluidically connected

to each other for regulating liquid flow, such as in the SWRO process 100. For example, the fluid control devices 200A, 200B are the fluid control devices 200 as shown in FIG. 2A to FIG. 2D. The fluid control system 400 further includes a plurality of fluidic components for controlling liquid flow to and from the fluid control devices 200A, 200B.

5 For example, the fluidic components include valves such as directional control valves and non-return valves.

In a first configuration of the fluid control system 400 as shown in FIG. 4A, the first liquid (seawater) flows into the second fluid control device 200B and the second liquid

10 (brine) flows into the first fluid control device 200A. Specifically, low-pressure seawater 430 enters the fluid control system 400 and flows through the non-return valve 416 into the outer body 210 of the second fluidic device 200B. The low-pressure seawater 430 fills the outer body 210 of the second fluidic device 200B and contracts the inner body 220 of the second fluidic device 200B. The contracting inner body 220 of the

15 second fluidic device 200B causes brine inside the inner body 220 to be discharged as low-pressure brine 442 from the inner body 220. The low-pressure brine 442 flows through the non-return valve 414 and exits the fluid control system 400.

High-pressure brine 440 enters the fluid control system 400 and flows through the

20 directional control valve 420 into the inner body 220 of the first fluidic device 200A. The non-return valve 410 is closed to prevent the high-pressure brine 440 from mixing with the low-pressure brine 442 exiting the second fluidic device 200B. The high-pressure brine 440 fills the inner body 220 of the first fluidic device 200A and expands the inner body 220 of the first fluidic device 200A. The expanding inner body 220 of

25 the first fluidic device 200A causes seawater inside the outer body 210 of the first fluidic device 200A to be discharged as high-pressure seawater 432 from the outer body 210. The high-pressure seawater 432 flows through the directional control valve 422 and exits the fluid control system 400. The non-return valve 412 is closed to prevent the high-pressure seawater 432 from mixing with the low-pressure seawater

30 430 entering the second fluidic device 200B.

In a second configuration of the fluid control system 400 as shown in FIG. 4B, the first liquid (seawater) flows into the first fluid control device 200A and the second liquid

(brine) flows into the second fluid control device 200B. Specifically, low-pressure seawater 430 enters the fluid control system 400 and flows through the non-return valve 412 into the outer body 210 of the first fluidic device 200A. The low-pressure seawater 430 fills the outer body 210 of the first fluidic device 200A and contracts the inner body 220 of the first fluidic device 200A. The contracting inner body 220 of the first fluidic device 200A causes brine inside the inner body 220 to be discharged as low-pressure brine 442 from the inner body 220. The low-pressure brine 442 flows through the non-return valve 410 and exits the fluid control system 400.

High-pressure brine 440 enters the fluid control system 400 and flows through the directional control valve 420 into the inner body 220 of the second fluidic device 200B. The non-return valve 414 is closed to prevent the high-pressure brine 440 from mixing with the low-pressure brine 442 exiting the first fluidic device 200A. The high-pressure brine 440 fills the inner body 220 of the second fluidic device 200B and expands the inner body 220 of the second fluidic device 200B. The expanding inner body 220 of the second fluidic device 200B causes seawater inside the outer body 210 of the second fluidic device 200B to be discharged as high-pressure seawater 432 from the outer body 210. The high-pressure seawater 432 flows through the directional control valve 422 and exits the fluid control system 400. The non-return valve 416 is closed to prevent the high-pressure seawater 432 from mixing with the low-pressure seawater 430 entering the first fluidic device 200A.

The non-return valves 410,412,414,416 are configured for allowing liquid to flow through it in only one direction. The directional control valves 420,422 are configured for selectably controlling the direction of liquid flow. For example in the first configuration as shown in FIG. 4A, the directional control valve 420 enables liquid flow towards the first fluid control device 200A (port AB to port A) but not towards the second fluid control device 200B, and the directional control valve 422 enables liquid flow from the first fluid control device 200A (port B to port AB) but not from the second fluid control device 200B. For example in the second configuration as shown in FIG. 4B, the directional control valve 420 enables liquid flow towards the second fluid control device 200B (port AB to port B) but not towards the first fluid control device

200A, and the directional control valve 422 enables liquid flow from the second fluid control device 200B (port A to port AB) but not from the first fluid control device 200A.

5 The fluid control system 400 is configured to alternate between the first and second configurations such that high-pressure seawater 432 and low-pressure brine 442 are discharged alternately from the first and second fluid control devices 200A,200B. Using two (or more) fluid control devices 200 in the fluid control system 400 allows for more efficient energy recovery from the inflow of high-pressure brine 440 and for more continuous outflow of high-pressure seawater 432 to be used in the SWRO process
10 100. Although the fluid control system 400 is described as having the first and second fluid control devices 200A,200B, it will be appreciated that the fluid control system 400 can have three or more fluid control devices 200 working cooperatively with each other to regulate liquid flow in the fluid control system 400.

15 FIG. 5A and FIG. 5B show an exemplary fluid control system 500 comprising the first fluid control device 200A and the second fluid control device 200B fluidically connected to each other for regulating liquid flow, such as in the SWRO process 100. For example, the fluid control devices 200A,200B are the fluid control devices 200 as shown in FIG. 2A to FIG. 2D. The fluid control system 500 further includes a plurality of fluidic
20 components for controlling liquid flow to and from the fluid control devices 200A,200B. For example, the fluidic components include valves such as directional control valves.

In a first configuration of the fluid control system 500 as shown in FIG. 5A, the first liquid (seawater) flows into the second fluid control device 200B and the second liquid
25 (brine) flows into the first fluid control device 200A. Specifically, low-pressure seawater 530 enters the fluid control system 500 and flows through the directional control valve 522 into the outer body 210 of the second fluidic device 200B. The low-pressure seawater 530 fills the outer body 210 of the second fluidic device 200B and contracts the inner body 220 of the second fluidic device 200B. The contracting inner body 220
30 of the second fluidic device 200B causes brine inside the inner body 220 to be discharged as low-pressure brine 542 from the inner body 220. The low-pressure brine 542 flows through the directional control valve 520 and exits the fluid control system 500.

High-pressure brine 540 enters the fluid control system 500 and flows through the directional control valve 520 into the inner body 220 of the first fluidic device 200A. The high-pressure brine 540 fills the inner body 220 of the first fluidic device 200A and expands the inner body 220 of the first fluidic device 200A. The expanding inner body 220 of the first fluidic device 200A causes seawater inside the outer body 210 of the first fluidic device 200A to be discharged as high-pressure seawater 532 from the outer body 210. The high-pressure seawater 532 flows through the directional control valve 522 and exits the fluid control system 500.

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In a second configuration of the fluid control system 500 as shown in FIG. 5B, the first liquid (seawater) flows into the first fluid control device 200A and the second liquid (brine) flows into the second fluid control device 200B. Specifically, low-pressure seawater 530 enters the fluid control system 500 and flows through the directional control valve 522 into the outer body 210 of the first fluidic device 200A. The low-pressure seawater 530 fills the outer body 210 of the first fluidic device 200A and contracts the inner body 220 of the first fluidic device 200A. The contracting inner body 220 of the first fluidic device 200A causes brine inside the inner body 220 to be discharged as low-pressure brine 542 from the inner body 220. The low-pressure brine 542 flows through the directional control valve 520 and exits the fluid control system 500.

High-pressure brine 540 enters the fluid control system 500 and flows through the directional control valve 520 into the inner body 220 of the second fluidic device 200B. The high-pressure brine 540 fills the inner body 220 of the second fluidic device 200B and expands the inner body 220 of the second fluidic device 200B. The expanding inner body 220 of the second fluidic device 200B causes seawater inside the outer body 210 of the second fluidic device 200B to be discharged as high-pressure seawater 532 from the outer body 210. The high-pressure seawater 532 flows through the directional control valve 522 and exits the fluid control system 500.

The directional control valves 520,522 are configured for selectably controlling the direction of liquid flow. For example in the first configuration as shown in FIG. 5A, the

directional control valve 520 enables liquid inflow into the first fluid control device 200A (port A to port P) and liquid outflow from the second fluid control device 200B (port T to port B), and the directional control valve 522 enables liquid inflow into the second fluid control device 200B (port A to port P) and liquid outflow from the first fluid control device 200A (port T to port B). For example in the second configuration as shown in FIG. 5B, the directional control valve 520 enables liquid inflow into the second fluid control device 200B (port A to port T) and liquid outflow from the first fluid control device 200A (port P to port B), and the directional control valve 522 enables liquid inflow into the first fluid control device 200A (port T to port A) and liquid outflow from the second fluid control device 200B (port B to port P).

The fluid control system 500 is configured to alternate between the first and second configurations such that high-pressure seawater 532 and low-pressure brine 542 are discharged alternately from the first and second fluid control devices 200A, 200B. Using two (or more) fluid control devices 200 in the fluid control system 500 allows for more efficient energy recovery from the inflow of high-pressure brine 540 and for more continuous outflow of high-pressure seawater 532 to be used in the SWRO process 100. Although the fluid control system 500 is described as having the first and second fluid control devices 200A, 200B, it will be appreciated that the fluid control system 500 can have three or more fluid control devices 200 working cooperatively with each other to regulate liquid flow in the fluid control system 500.

FIG. 6 shows an exemplary fluid control system 600 comprising the first fluid control device 200A and the second fluid control device 200B fluidically connected to each other for regulating liquid flow, such as in the SWRO process 100. For example, the fluid control devices 200A, 200B are the fluid control devices 200 as shown in FIG. 2E and FIG. 2F. The fluid control system 600 further includes a plurality of fluidic components for controlling liquid flow to and from the fluid control devices 200A, 200B. For example, the fluidic components include valves such as directional control valves.

In a first configuration of the fluid control system 600 as shown in FIG. 6, the first liquid (seawater) flows into the second fluid control device 200B and the second liquid (brine) flows into the first fluid control device 200A. Specifically, low-pressure seawater 630

enters the fluid control system 600 and flows through the non-return valve 616 into the outer body 210 of the second fluidic device 200B. The low-pressure seawater 630 fills the outer body 210 of the second fluidic device 200B and contracts the inner body 220 of the second fluidic device 200B. The contracting inner body 220 of the second fluidic device 200B causes brine inside the inner body 220 to be discharged as low-pressure brine 642 from the inner body 220. The low-pressure brine 642 flows through the directional control valve 624 and exits the fluid control system 600.

High-pressure brine 640 enters the fluid control system 600 and flows through the directional control valve 620 into the inner body 220 of the first fluidic device 200A. The high-pressure brine 640 fills the inner body 220 of the first fluidic device 200A and expands the inner body 220 of the first fluidic device 200A. The expanding inner body 220 of the first fluidic device 200A causes seawater inside the outer body 210 of the first fluidic device 200A to be discharged as high-pressure seawater 632 from the outer body 210. The high-pressure seawater 632 flows through the non-return valve 610 and directional control valve 626 and exits the fluid control system 500.

In a second configuration of the fluid control system 600, the first liquid (seawater) flows into the first fluid control device 200A and the second liquid (brine) flows into the second fluid control device 200B. Specifically, low-pressure seawater 630 enters the fluid control system 600 and flows through the non-return valve 612 into the outer body 210 of the first fluidic device 200A. The low-pressure seawater 630 fills the outer body 210 of the first fluidic device 200A and contracts the inner body 220 of the first fluidic device 200A. The contracting inner body 220 of the first fluidic device 200A causes brine inside the inner body 220 to be discharged as low-pressure brine 642 from the inner body 220. The low-pressure brine 642 flows through the directional control valve 620 and exits the fluid control system 500.

High-pressure brine 640 enters the fluid control system 500 and flows through the directional control valve 624 into the inner body 220 of the second fluidic device 200B. The high-pressure brine 640 fills the inner body 220 of the second fluidic device 200B and expands the inner body 220 of the second fluidic device 200B. The expanding inner body 220 of the second fluidic device 200B causes seawater inside the outer

body 210 of the second fluidic device 200B to be discharged as high-pressure seawater 632 from the outer body 210. The high-pressure seawater 632 flows through the non-return valve 614 and directional control valve 626 and exits the fluid control system 600.

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The non-return valves 610,612,614,616 are configured for allowing liquid to flow through it in only one direction. The directional control valves 620,622,624,626 are configured for selectably controlling the direction of liquid flow. For example in the first configuration as shown in FIG. 6, the directional control valve 620 enables liquid flow
10 towards the first fluid control device 200A, the directional control valve 624 enables liquid flow from the second fluid control device 200B, and the directional control valve 626 enables liquid flow from the first fluid control device 200A. The directional control valve 622 may be configured to control flow of the high-pressure brine 640 to the first fluid control device 200A or second fluid control device 200B.

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The fluid control system 600 is configured to alternate between the first and second configurations such that high-pressure seawater 632 and low-pressure brine 642 are discharged alternately from the first and second fluid control devices 200A,200B. Using two (or more) fluid control devices 200 in the fluid control system 600 allows for
20 more efficient energy recovery from the inflow of high-pressure brine 640 and for more continuous outflow of high-pressure seawater 632 to be used in the SWRO process 100. Although the fluid control system 600 is described as having the first and second fluid control devices 200A,200B, it will be appreciated that the fluid control system 600 can have three or more fluid control devices 200 working cooperatively with each other
25 to regulate liquid flow in the fluid control system 600.

As described in various embodiments above, the fluid control devices 200 and the fluid control systems 400,500,600 include fluidic components for controlling liquid flow to and from the fluid control devices 200. For example, the fluidic components include
30 valves such as directional control valves and non-return valves. The fluidic components are selectably controlled to achieve controlled cyclic flow of through the fluid control devices 200, such as to alternate between the first and second configurations. Additionally or alternatively, a computer control module such as a

programmable logic controller (PLC) may be used to control the fluidic components. For example, the PLC is configured for sequence control of the various valves to improve efficiency of the valve switching and cycling between the first and second configurations. Using the PLC would consequently improve the overall efficiency and
5 reduce the energy footprint of the SWRO process 100.

With reference to FIG. 7, embodiments of the present disclosure describe a fluid control method 700 for regulating liquid flow using a plurality of fluid control devices 200, such as using the fluid control system 400,500,600. The method 700 includes a
10 step 702 of alternately communicating a first liquid into an outer body 210 of the fluid control devices 200 to fill the respective outer body 210. The method 300 includes a step 704 of alternately communicating a second liquid into an inner body 220 of the fluid control devices 200 to fill the respective inner body 220, the respective inner body 220 disposed and fluidically sealed within the respective outer body 210 such that the
15 first liquid and second liquid are fluidically isolated from each other. The method 700 includes a step 706 of expanding, by said communicating of the second liquid into the respective inner body 220, the respective inner body 220 from a contracted state to an expanded state against the first liquid in the respective outer body 210. The method 700 includes a step 708 of discharging, by said expanding of the respective inner body
20 220, the first liquid from the respective outer body 210. The method 700 includes a step 710 of stopping communication of the second liquid into the respective inner body 220 after discharging the first liquid from the respective outer body 210. The method 700 includes a step 712 of contracting the respective inner body 220 to the contracted state after stopping communication of the second liquid into the respective inner body
25 220. The method 700 includes a step 714 of discharging, by said contracting of the respective inner body 220, the second liquid from the respective inner body 220. The method 700 includes a step 716 of alternating said discharging of the first liquid and second liquid from the respective fluid control devices 200 by alternating communication of the first liquid and second liquid into the respective fluid control
30 devices 200.

In many embodiments, the fluid control method 700 can be used in various applications, for example in a reverse osmosis process such as the SWRO process

100. The first liquid enters the respective outer body 210 at a lower pressure (e.g. the low-pressure seawater 430,530,630), and the first liquid exits the respective outer body 210 at a higher pressure (e.g. the high-pressure seawater 432,532,632). The second liquid enters the respective inner body 220 at a higher pressure (e.g. the high-pressure brine 440,540,640), and the second liquid exits the respective inner body 220 at a lower pressure (e.g. the low-pressure brine 442,542,642).

The fluid control devices 200, fluid control systems 400,500,600, and fluid control methods 300,700 described in various embodiments herein can be used in many applications including the SWRO process 100. Particularly, one or more fluid control devices 200 can be used as energy recovery devices in the SWRO process 100, such as shown in the fluid control systems 400,500,600, to reduce the power rating of the high-pressure pump 102 and the overall power consumption of the SWRO process 100. In an exemplary SWRO process 100 used in a desalination system, the permeate flowrate may be about 20 m³ per day and the power consumption may be about 1320 kWh per day without using energy recovery devices. When energy recovery devices such as the fluid control devices 200 are used, the power savings from the fluid control devices 200 are about 380 kWh per day, which is about 28.7% reduction in overall power consumption. The reduced power consumption can lead to significant operational cost savings over the operating life of the desalination system.

In the foregoing detailed description, embodiments of the present disclosure in relation to fluid control systems, devices, and methods for regulating liquid flow are described with reference to the provided figures. The description of the various embodiments herein is not intended to call out or be limited only to specific or particular representations of the present disclosure, but merely to illustrate non-limiting examples of the present disclosure. The present disclosure serves to address at least one of the mentioned problems and issues associated with the prior art. Although only some embodiments of the present disclosure are disclosed herein, it will be apparent to a person having ordinary skill in the art in view of this disclosure that a variety of changes and/or modifications can be made to the disclosed embodiments without departing from the scope of the present disclosure. Therefore, the scope of the

disclosure as well as the scope of the following claims is not limited to embodiments described herein.

Claims

1. A fluid control device for regulating liquid flow, the fluid control device comprising:
- 5 an outer body comprising at least one first fluidic port for communicating a first liquid into and from the outer body;
- an inner body comprising at least one second fluidic port for communicating a second liquid into and from the inner body, the inner body disposed and fluidically sealed within the outer body such that the first liquid
- 10 and second liquid are fluidically isolated from each other,
- wherein the inner body is expandable from a contracted state to an expanded state by said communicating of the second liquid into the inner body;
- wherein the inner body is expandable against the first liquid in the outer body to thereby discharge the first liquid from the outer body; and
- 15 wherein the inner body is contractable to the contracted state, after the first liquid is discharged from the outer body and the second liquid stops communicating into the inner body, to thereby discharge the second liquid from the inner body.
- 20 2. The fluid control device according to claim 1, wherein the inner body is contractable to the contracted state by the first liquid communicating into the outer body.
3. The fluid control device according to claim 1 or 2, wherein the inner body is
- 25 biased towards to the contracted state.
4. The fluid control device according to any one of claims 1 to 3, wherein the inner body comprises an expandable bellow structure that optionally comprises a metallic material.
- 30 5. The fluid control device according to any one of claims 1 to 3, wherein the inner body comprises an elastomeric material that optionally comprises a polymer material.

6. The fluid control device according to any one of claims 1 to 5, wherein an outer surface of the inner body is physically separated from an inner surface of the outer body.
- 5 7. A fluid control method for regulating liquid flow, the fluid control method comprising:
- communicating a first liquid into an outer body of a fluid control device to fill the outer body;
- communicating a second liquid into an inner body of the fluid control
10 device to fill the inner body, the inner body disposed within the outer body and fluidically sealed such that the first liquid and second liquid are fluidically isolated from each other;
- expanding, by said communicating of the second liquid into the inner body, the inner body from a contracted state to an expanded state against the
15 first liquid in the outer body;
- discharging, by said expanding of the inner body, the first liquid from the outer body;
- stopping communication of the second liquid into the inner body after discharging the first liquid from the outer body;
- 20 contracting the inner body to the contracted state after stopping communication of the second liquid into the inner body; and
- discharging, by said contracting of the inner body, the second liquid from the inner body.
- 25 8. The fluid control method according to claim 7, comprising contracting the inner body to the contracted state by communicating the first liquid into the outer body.
9. The fluid control method according to claim 7 or 8, comprising biasing the inner body towards to the contracted state.
- 30 10. The fluid control method according to any one of claims 7 to 9, wherein the first liquid enters the outer body at a lower pressure, and the first liquid exits the outer body at a higher pressure.

11. The fluid control method according to any one of claims 7 to 10, wherein the second liquid enters the inner body at a higher pressure, and the second liquid exits the inner body at a lower pressure.
- 5 12. The fluid control method according to any one of claims 7 to 11, in use in a reverse osmosis process, wherein the first liquid comprises seawater and the second liquid comprises brine.
- 10 13. A fluid control system for regulating liquid flow, the fluid control system comprising:
- a first fluid control device and a second fluid control device fluidically connected to each other for regulating liquid flow, each fluid control device comprising:
 - 15 an outer body comprising at least one first fluidic port for communicating a first liquid into and from the outer body
 - an inner body comprising at least one second fluidic port for communicating a second liquid into and from the inner body, the inner body disposed and fluidically sealed within the outer body such that the
 - 20 first liquid and second liquid are fluidically isolated from each other,
 - wherein each inner body is expandable from a contracted state to an expanded state by said communicating of the second liquid into the respective inner body;
 - wherein the respective inner body is expandable against the first liquid
 - 25 in the respective outer body to thereby discharge the first liquid from the respective outer body; and
 - wherein the fluid control devices are configured to alternate between:
 - communicating the first liquid into the outer body of the first fluid control device and communicating the second liquid into the inner body
 - 30 of the first fluid control device to thereby discharge the first liquid from the outer body of the first fluid control device; and
 - communicating the first liquid into the outer body of the second fluid control device and communicating the second liquid into the inner

body of the second fluid control device to thereby discharge the first liquid from the outer body of the second fluid control device; and wherein each inner body is contractable towards the contracted state, after the first liquid is discharged from the respective outer body and the second liquid stops communicating into the respective inner body, to thereby discharge the second liquid from the respective inner body.

14. The fluid control system according to claim 13, wherein each inner body is contractable to the contracted state by the first liquid communicating into the respective outer body.

15. The fluid control system according to claim 13 or 14, wherein each inner body is biased towards to the contracted state.

16. The fluid control system according to any one of claims 13 to 15, wherein each inner body comprises an expandable bellow structure that optionally comprises a metallic material.

17. The fluid control system according to any one of claims 13 to 15, wherein each inner body comprises an elastomeric material that optionally comprises a polymer material.

18. The fluid control system according to any one of claims 13 to 17, wherein an outer surface of the respective inner body is physically separated from an inner surface of the respective outer body.

19. A fluid control method for regulating liquid flow using a plurality of fluid control devices, the fluid control method comprising:
alternatingly communicating a first liquid into an outer body of the fluid control devices to fill the respective outer body;
alternatingly communicating a second liquid into an inner body of the fluid control devices to fill the respective inner body, the respective inner body

disposed within the respective outer body and fluidically sealed such that the first liquid and second liquid are fluidically isolated from each other;

expanding, by said communicating of the second liquid into the respective inner body, the respective inner body from a contracted state to an expanded state against the first liquid in the respective outer body;

discharging, by said expanding of the respective inner body, the first liquid from the respective outer body;

stopping communication of the second liquid into the respective inner body after discharging the first liquid from the respective outer body;

contracting the respective inner body to the contracted state after stopping communication of the second liquid into the respective inner body; and

discharging, by said contracting of the respective inner body, the second liquid from the respective inner body; and

alternating said discharging of the first liquid and second liquid from the respective fluid control devices by alternating communication of the first liquid and second liquid into the respective fluid control devices.

20. The fluid control method according to claim 19, comprising contracting the respective inner body to the contracted state by communicating the first liquid into the respective outer body.

21. The fluid control method according to claim 19 or 20, comprising biasing the respective inner body towards to the contracted state.

22. The fluid control method according to any one of claims 19 to 21, wherein the first liquid enters the respective outer body at a lower pressure, and the first liquid exits the respective outer body at a higher pressure.

23. The fluid control method according to any one of claims 19 to 22, wherein the second liquid enters the respective inner body at a higher pressure, and the second liquid exits the respective inner body at a lower pressure.

24. The fluid control method according to any one of claims 19 to 23, in use in a reverse osmosis process, wherein the first liquid comprises seawater and the second liquid comprises brine.