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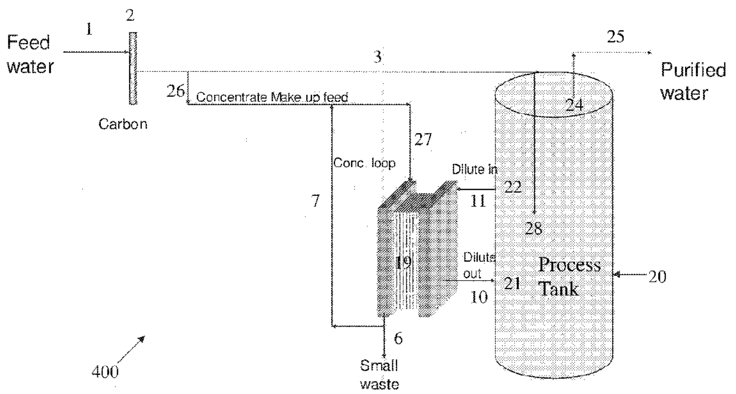

FIG. 1

(57) Abstract: The methods and systems disclosed here relate to treating water using a hybrid softener system. In certain embodiments, a method of treating water comprises passing a portion of a water stream to be treated through an electrochemical water treatment device to produce a first treated water stream and passing a first portion of the first treated water stream through an ion exchange device to produce a second treated water stream. In certain embodiments, the hybrid softener system produces water of less than 1 gpg in hardness. The methods and systems disclosed here also relate to a portable version of the hybrid softener.

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HYBRID SOFTENER

FIELD OF THE INVENTION

[0001] The methods and systems disclosed here generally relate to a method and apparatus for treating water by combining non-salt based electrochemical water treatment technology with a traditional salt-based softener.

SUMMARY

[0002] Aspects and embodiments of the present disclosure are directed to a method for treating water comprising passing a portion of a water stream to be treated through an electrochemical water treatment device to produce a first treated water stream, and passing a first portion of the first treated water stream through an ion exchange device to produce a second treated water stream.

[0003] In another aspect, the method further comprises recirculating a concentrate stream through the electrochemical water treatment device. In yet another aspect, the method further comprises passing a second portion of the first treated water stream through the ion exchange device to produce make-up water in fluid communication with the recirculating concentrate stream. In certain aspects, the method further comprises discharging a portion of the recirculating concentrate stream. In at least one aspect, the method further comprises monitoring a feed volume of the water stream to be treated. In another aspect, the method further comprises discharging less than 30 percent of the feed volume of the water stream to be treated. In certain aspects, the method further comprises measuring at least one property of the ion exchange device. In at least one aspect, the method further comprises controlling removal of ion exchange media based on the at least one measured property of the ion exchange device.

[0004] Aspects and embodiments of the present disclosure are directed to a water treatment system comprising an electrochemical water treatment device having an inlet and an outlet, a first water stream in fluid communication with the inlet of the electrochemical water treatment device, a second water stream in fluid communication with the outlet of the electrochemical water treatment device, and an ion exchange device having an inlet and an outlet, and positioned downstream and in fluid communication with the second water stream.

[0005] In certain aspects, the system further comprises a first product stream in fluid communication with the outlet of the ion exchange device. In another aspect, the system further comprises a recirculating concentrate stream in fluid communication with the inlet and the outlet of the electrochemical water treatment device. In yet another aspect, the system further comprises a second product stream in fluid communication with the outlet of the electrochemical water treatment device. In another aspect, the system further comprises a waste stream in fluid communication with the recirculating concentrate stream. In at least one aspect, the ion exchange device comprises a removable cartridge.

[0006] These and other objects, along with advantages and features of the systems and methods described here herein disclosed, will become apparent through reference to the following description and the accompanying drawings. Furthermore, it is to be understood that the features of the various embodiments described herein are not mutually exclusive and can exist in various combinations and permutations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Non-limiting embodiments of the systems and methods described herein will be conveyed by way of example, and optionally, with reference to the accompanying drawings. In the following description, various embodiments of the systems and methods recited here are described with reference to the following drawings, in which:

[0008] FIG. 1 is a process flow diagram of a treatment system comprising an electrochemical water treatment device;

[0009] FIG. 2A is a process flow diagram of a treatment system in accordance with one or more embodiments of the methods and systems disclosed herein; and

[0010] FIG. 2B is the process flow diagram depicted in FIG. 2A, where the ion exchange device is a portable ion exchange device.

DETAILED DESCRIPTION

[0011] Water that contains hardness species such as calcium and magnesium may be undesirable for some uses, for example, in industrial, commercial, residential or household applications. Hard water requires more soap and synthetic detergents for home laundry and washing, and contributes to scaling in boilers and industrial equipment. Hardness is caused by compounds of calcium and magnesium, as well as a variety of other metals, and is primarily a function of the geology of the area where the surface water is located. Water is an excellent solvent and readily dissolves minerals it comes in contact with. As water moves through soil and rock, it dissolves very small amounts of minerals and holds them in solution. Calcium and magnesium dissolved in water are the two most common minerals that make water “hard,” although iron, strontium, and manganese are also known to contribute. The hardness of water is referred to by three types of measurements: grains per gallon (gpg), milligrams per liter (mg/L), or parts per million (ppm). Hardness is usually reported as an equivalent quantity of calcium carbonate ($CaCO_3$). One grain of hardness equals 17.1 mg/L or 17.1 ppm of hardness. The typical guidelines for a classification of water hardness are: zero to 60 mg/L of calcium carbonate is classified as soft; 61 mg/L to 120 mg/L as moderately hard; 121 mg/L to 180 mg/L as hard; and more than 180 mg/L as very hard.

[0012] Ion exchange is the reversible interchange of ions between a solid (the ion exchange resin) and a liquid. Since they act as "chemical sponges," ion exchange resins are ideally suited for effective removal of contaminants from water and other liquids. This technology offers a number of advantages in industrial water demineralization and softening, wastewater recycling, and other water treatment processes, including increased water recovery, decreases in waste, and improved operational flexibility. Ion exchange resins are also used in a variety of specialized applications such as chemical processing, pharmaceuticals, mining, and food and beverage processing.

[0013] Hard water contains greater than about 60 ppm calcium carbonate and is often treated prior to use by a water softener. Typically, the water softener is of the rechargeable ion exchange type and is charged with cation resin in the sodium form and anion resin in the chloride form. As water passes through the resin bed, major contributors to hardness, such as calcium and magnesium species, are exchanged for sodium. In this manner, the water can be softened by a water softening system as the concentration of divalent cations and, in particular, calcium and magnesium ions, decreases.

[0014] In water softening systems, the hardness ions become ionically bound to oppositely-charged ionic species that are mixed on the surface of the ion exchange resin. The ion exchange resin eventually becomes saturated with ionically bound hardness ion species and must be regenerated. Regeneration involves replacing the bound hardness species with more soluble ionic species, such as sodium chloride. The hardness species bound on the ion exchange resin are replaced by the sodium ions and the ion exchange resins are ready again for a subsequent water-softening step. Currently, the predominant technology for water softening is a cation exchange resin bed that captures hardness ions such as calcium and magnesium and exchanges them for sodium ions. The cation exchange resin bed is regenerated periodically by passing brine solution through the bed. Typically, the specification for soft water produced from the salt regenerated softener is 1 gpg or less in quality. The use of salt-based softeners is restricted in many regions because the dispensing of excess salt from these softeners into the ground raises ground water salinity levels to much higher levels, which may create problems for municipalities or wells that draw water from the ground for use. Salt from softener discharge also causes the destruction of useful bacteria at waste treatment plants. More recently, in certain geographic regions, discharge of brine to a domestic septic system or to the environment is regulated or prohibited.

[0015] Other methods of softening water include the use of reverse osmosis devices that can supply high purity water, but generally do so at a slow rate and require the use of a high-pressure pump. Furthermore, many reverse osmosis membranes can be fouled by the presence of dissolved materials, such as silica, which may often be found in well water.

[0016] Quality drinking water is often associated with highly purified water. However, as long as the water is free of microbial contamination, the best drinking water may not necessarily be the most chemically pure. For example, water that has been purified to a high resistivity, for example, greater than about 1 megaOhm, may be so devoid of ionic content that it becomes "hungry" and corrosive to material such as copper, which may be used in water piping systems. Taste may also be affected by, for example, the removal of bicarbonate species. Furthermore, beneficial or desirable chemicals that have been added to the water, for example, fluoride and chlorine species, may be removed along with undesirable species, resulting in water that may need to be re-fortified. In some regions, minimum levels of calcium may be necessary in order to comply with health and safety regulations. Thus, a high purity system that removes greater than, for example, 90% or 99% of the calcium from the water supply may be inappropriate in these locations. In addition, many consumers accustomed to water treated by a traditional water softener may prefer water that exhibits the aesthetic qualities associated with this type of treatment process.

[0017] The performance of electrochemical water treatment devices, especially in hard water applications, is limited by precipitation formed from hard ions such as calcium and magnesium. When water exceeds the solubility limit, hard ions, such as calcium and magnesium, drop out as crystals. One of the methods for determining the solubility limits is the Langelier Saturation Index (LSI). LSI is a calculated number used to predict the calcium carbonate stability of water. LSI may be calculated according to a standard method, for example, ASTM D 3739. The resulting value indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate.

[0018] The Langelier saturation level approaches the concept of saturation using pH as a main variable. LSI is expressed as the difference between the actual system pH and the saturation pH, and can be interpreted as the pH change required to bring water to equilibrium. Water with an LSI of 1.0 is one pH unit above saturation. Reducing the pH by 1 unit will bring the water into equilibrium. This occurs because the portion of total alkalinity present as CO_3^{-2} decreases as the pH decreases. For LSI > 0, water is super saturated and tends to precipitate a scale layer of $CaCO_3$. For LSI = 0 or LSI close to 0, water is saturated (in equilibrium) with $CaCO_3$. A scale layer of $CaCO_3$ is neither precipitated nor dissolved. Water quality, changes in temperature, or evaporation could change the index. For LSI < 0, water is under saturated and tends to dissolve solid $CaCO_3$.

[0019] If the actual pH of the water is below the saturation pH, the LSI is negative and the water has a very limited scaling potential. If the actual pH exceeds the saturation pH, then LSI is positive, and being supersaturated with $CaCO_3$, the water has a tendency to form scale. At increasing positive index values, the scaling potential increases.

[0020] LSI values are also dependent on temperature, with LSI becoming more positive as the water temperature increases. This has particular implications in situations where well water is used. The temperature of the water when it first exits the well is often significantly lower than the temperature inside the building served by the well, or inside the laboratory or process unit where the LSI measurement is made. The resulting increase in temperature can cause scaling, especially in hot water heaters.

[0021] Examples of electrochemical deionization units include electrodialysis (ED), electrodialysis reversal (EDR), electrodeionization (EDI), capacitive deionization, continuous electrodeionization (CEDI), and reversible continuous electrodeionization (RCEDI).

[0022] Electrodeionization (EDI) is one process that may be used to demineralize, purify, or treat water. EDI is a process that removes ionizable species from liquids using electrically active media and an electrical potential to influence ion transport. The electrically active media may function to alternately collect and discharge ionizable species, or to facilitate the transport of ions continuously by ionic or electronic substitution mechanisms. EDI devices can include media having a permanent or temporary charge, and can be operated to cause electrochemical reactions designed to achieve or enhance performance. These devices may also include electrically active membranes such as semi-permeable ion exchange or bipolar membranes.

[0023] Continuous electrodeionization (CEDI) is a process where the primary sizing parameter is the transport through the media, instead of the ionic capacity of the media. A CEDI device includes one or more electroactive semi-permeable anion and cation selective membranes. The spaces between the membranes are configured to create liquid flow compartments with inlets and outlets. A transverse DC electrical field is imposed by an external power source using electrodes at the bounds of the membranes and compartments.

[0024] A capacitive deionization ("CapDI") device is used to remove an ionic material from, for example, a medium such as hard water, by applying a voltage to a pair of electrodes having nanometer-sized pores to polarize the pair of electrodes. This allows ionic material to be adsorbed onto a surface of at least one of the pair of electrodes. In the CapDI device, when a low DC voltage is applied to the pair of electrodes and the medium containing dissolved ions then flows between the two electrodes, anions dissolved in the medium are adsorbed and concentrated in the positive electrode, and cations dissolved in the medium are adsorbed and concentrated in the negative electrode. When a current is supplied in a reverse direction, for example, by electrically shorting the two electrodes, the concentrated ions are desorbed from the negative electrode and the positive electrode. Since the CapDI device does not use a high potential difference, the energy efficiency is high. The CapDI device may remove detrimental ions, as well as hardness components, when ions are adsorbed onto the electrodes. The CapDI device does not use a chemical to regenerate the electrodes, and therefore the CapDI device has a relatively low environmental impact.

[0025] Frequently, electrochemical water treatment devices are designed to remove as many ions as possible. For many industrial and commercial uses, this highly purified water may be beneficial, however, this level of purity may be undesirable for other applications, for example, in a household water supply where some level of cation content may be beneficial. Furthermore, highly purified water may be corrosive and may attack copper pipes that are often present in water distribution systems. Some water distribution systems may include lead soldered joints, and heavy metals, such as lead, may also leach into water passing through the pipes.

[0026] The systems and methods described here are directed to water treatment or purification systems and methods of providing treated water in industrial, commercial, residential, and household settings. One or more embodiments will be described using water as the fluid but should not be limited as such. For example, where reference is made to treating water, it is believed that other fluids can be treated according to the systems and methods described herein. Moreover, the systems and apparatuses described here are believed to be applicable in instances where reference is made to a component of the system or to a method that adjusts, modifies, measures or operates on the water or a property of the water. The fluid to be treated may also be a fluid that is a mixture comprising water.

[0027] As used herein, the term "treated" in reference to water or fluid, refers to low TDS, low LSI water, and/or low conductivity water. In certain embodiments disclosed here, low conductivity water has a TDS ranging from a value of about 180 μS/cm to about 300 μS/cm. As used herein, low LSI water has a value of less than about 2, preferably, less than about 1, and more preferably, less than or about zero.

[0028] As used herein, the term “softening device” pertains to an ion exchange device that is capable of producing low TDS water, low LSI water, and/or low conductivity water using a salt based technology.

[0029] As used herein, the terms "treatment device," "purification device," and “apparatus” pertain to any device that can be used to remove or reduce the concentration level of any undesirable species from a fluid to be treated. Examples of suitable treatment apparatuses include, but are not limited to, ion-exchange resin devices, reverse osmosis, electrodeionization, electrodialysis, ultrafiltration, microfiltration, and capacitive deionization devices.

[0030] As used herein, the phrase "electrochemical water treatment device" refers to any number of electrochemical water treatment devices, non-limiting examples including, but not limited to, electrodeionization devices, electrodialysis devices, capacitive deionization devices, and any combination thereof, and may include any device that may be used in accordance with the principles of the systems and methods described herein so long as they are not inconsistent or contrary to the operation of devices and/or the techniques of the systems and methods described herein.

[0031] As used herein, "hardness" refers to a condition that results from the presence of polyvalent cations, for example calcium, magnesium, or other metals in water, that adversely affect the cleansing capability of the water and the "feel" of the water, and may increase scaling potential. Hardness is usually quantified by measuring the concentration of calcium and magnesium species. In certain embodiments, undesirable species can include hardness ion species.

[0032] As used herein, the term "system yield" may also refer to treatment system recovery, meaning the measure of waste versus production. System yield/recovery rates may be determined using the following calculation: System yield = [Product volume/ (Waste volume + Product volume)]*100.

[0033] As used herein, the term "monitoring" in relation to the methods and systems disclosed here, refers to any activity including detecting, measuring, calculating, and any other action that embraces test information or data or any other measures for obtaining information concerning an operation or process.

[0034] Electrical conductivity (EC) is a measure of water's ability to "carry" an electrical current, and, indirectly, a measure of dissolved solids or ions in the water. Deionized water has a very low conductivity value (nearly zero); hence, the more dissolved solids and ions occurring in the water, the more electrical current the water is able to conduct. A conductivity probe in conjunction with a temperature sensor is capable of determining the electrical resistance of a liquid. Fresh water usually reflects electrical conductivity in units of micro Siemens (μS/cm).

[0035] Total Dissolved Solids (TDS) are the total amount of mobile charged ions, including minerals, salts, or metals dissolved in a given volume of water, expressed in units of mg/L or ppm. TDS is directly related to the purity and quality of water and water purification systems and affects everything that consumes, lives in, or uses water, whether organic or inorganic. The term "dissolved solids" refers to any minerals, salts, metals, cations or anions dissolved in water, and includes anything present in water other than the pure water molecule and suspended solids. In general, the total dissolved solids concentration is the sum of the cations and anions in the water. TDS is based on the electrical conductivity (EC) of water, with pure water having virtually no conductivity.

[0036] The treatment systems in accordance with one or more embodiments of the systems and methods described here receive water from a source and subsequently pass it through a treatment process to produce a product stream of water possessing targeted characteristics. The treatment system may have a water storage system in line with at least one or more treatment devices, non-limiting examples including: electrochemical water treatment devices, reverse osmosis devices, electrodialysis devices, ion exchange resin devices, capacitive deionization devices, microfiltration devices, and/or ultrafiltration devices.

[0037] In accordance with one or more embodiments, the systems and methods described here combine a non-salt based electrochemical water treatment technology, non-limiting examples including, electrodeionization, capacitive deionization, or bipolar deionization, in combination with one or more salt based softeners to produce water with a hardness of about 0 to about 1 gpg. This combined treatment method comprises a hybrid softener suitable for a wide variety of uses. Suitable applications for the hybrid softener include, but are not limited to, industrial, commercial, residential, and household applications.

[0038] Electrochemical water treatment devices are efficient to a certain value or percent reduction of hardness. For example, an electrochemical water treatment device may reduce the hardness level from 20 gpg (feed stream) to approximately 4 gpg (product stream) efficiently. Electrodeionization devices, for example, are able to efficiently remove 75-80% of the hardness species. Reducing hardness even further requires significantly longer processing times and consumes significantly larger volumes of water, which subsequently discharges larger volumes of waste water. In certain non-limiting embodiments, a salt-based softener is placed downstream from the electrochemical water treatment device. This allows treated water from the electrochemical water treatment device, with a hardness of approximately 4 gpg, to be fed into the salt-based softener, thereby producing treated water with a hardness of about 0 to about 1 gpg. This arrangement allows the overall hardness removal process to become very efficient. In addition, a significantly lower amount of salt is discharged from the system using the hybrid softener treatment method when compared to other treatment methods using only a traditional water softener. Additionally, treatment systems comprising the hybrid softener may discharge significantly less waste water than other treatment systems without the hybrid softener. In certain embodiments, the treatment system may discharge less than 80 percent of the feed volume of the water stream to be treated. In other embodiments, the treatment system may discharge less than 60 percent of the feed volume of the water to be treated. In certain instances, the treatment system may discharge less than 50 percent of the feed volume of the water to be treated. In some embodiments, the treatment system may discharge less than 40 percent of the feed volume of the water to be treated. In at least one embodiment, the treatment system may discharge less than 30 percent of the feed volume of the water to be treated. In another embodiment, the treatment system may discharge less than 20 percent of the feed volume of the water to be treated. In some instances, the treatment system may discharge less than 10 percent of the feed volume of the water to be treated. Depending on desired process or environmental conditions, the treatment system may discharge in between about 0 and about 100% of the feed volume of the water to be treated, or any range of percentages in between these percentages.

[0039] In accordance with one or more embodiments, the systems and methods described here provide for a hybrid softener comprising a portable ion exchange device. A portable ion exchange device may be, for example, a cylinder containing regenerated ion exchange resin. The portable ion exchange device may be sent, for example, to a customer's site and installed for use. In certain embodiments, the portable cylinder's performance is monitored, either from an external location, or locally. Various properties and conditions of the portable cylinder may be monitored, such as, for example, the presence of the ion exchange resin, the usable volume remaining in the cartridge, and the number of days remaining before the cartridge is exhausted and needs to be replaced. When the ion exchange medium is exhausted, the cylinders are replaced with fresh, charged cylinders. The exhausted cylinders are subsequently recharged and put into queue for later use, or, optionally, the exhausted cylinders are taken out of service. Various benefits of a hybrid softener comprising a portable ion exchange device include an overall reduced frequency in exchanging the portable cartridge, contributing to reductions in the costs and the inconvenience associated with transporting and exchanging the cartridges.

[0040] Non-limiting examples of salt-based softeners suitable for use in the methods and systems described here include one or more softeners available from Rayne Corporation (San Diego, California) and Culligan (Rosemont, IL). Non-limiting examples of exchange resins suitable for use in the salt-based softeners described here include the ion exchange resin with the tradename CGS, available from ResinTech (West Berlin, NJ) and Dowex™ softening resins, available from Dow Chemical (Midland, MI).

[0041] In one aspect, the systems and methods described here provide purified or treated water from a variety of source types. Possible non-limiting examples of water sources include well water, surface water, municipal water, and rain water. The treated product may be for general industrial or municipal use, or may be for human consumption or other domestic uses, for example, bathing, laundering, and dishwashing.

[0042] One or more embodiments of the treatment systems disclosed here may include one or more fluid control devices, such as pumps, valves, regulators, sensors, pipes, connectors, controllers, power sources, and any combination thereof.

[0043] In accordance with one or more embodiments, the treatment systems disclosed here further comprise one or more pumps. A variety of pumps for pumping and/or recirculating fluid may be used in conjunction with the treatment system. Pumps may be internal and/or external to one or more of the components of the treatment system, and/or may be otherwise integrated with the treatment system. Non-limiting examples of pumps include electrical pumps, air driven pumps, and hydraulic pumps. The pump may be driven by a power source that can be any conventional power source, for example, gasoline driven motors, diesel driven motors, solar-powered motors, and electric motors, and any combination thereof.

[0044] In another embodiment of the systems and methods described here, the treatment system comprises one or more flow regulators for regulating liquid flow. For example, a flow regulator can regulate the amount or volume of fluid discharged into a waste stream. According to another embodiment of the systems and methods described here, the flow regulator is a valve that can be intermittently opened and closed according to a predetermined schedule for a predetermined period of time to allow a predetermined volume to flow. The amount or volume of flowing fluid can be adjusted or changed by, for example, changing the frequency at which the flow regulator is opened and closed, or by changing the duration during which the flow regulator is open or closed. In one embodiment, the flow regulator can be controlled or regulated by a controller, through, for example, an actuation signal. Thus, in one embodiment of the invention, the controller provides an actuation signal, such as a radio, current or a pneumatic signal, to an actuator, with, for example, a motor or diaphragm that opens and closes the flow regulator. The fluid regulated by a valve or flow regulator can be any fluid in any circuit or stream in the treatment system.

[0045] In accordance with one or more embodiments, the methods and systems disclosed here further comprise one or more valves. Non-limiting examples of valves suitable for control according to one or more embodiments include, but are not limited to, check valves, gate valves, bypass valves, solenoid valves, other types of hydraulic valves, other types of pneumatic valves, relief valves, and any combination thereof. Examples of valves include one-way and/or multi-way valves. In certain non-limiting embodiments, the valve can be a pilot valve, a rotary valve, a ball valve, a diaphragm valve, a butterfly valve, a flutter valve, a swing check valve, a clapper valve, a stopper-check valve, a lift-check valve, and any combination thereof. The valves may be manually actuated (for example, by an operator) and/or hydraulically, pneumatically, solenoid, or otherwise actuated, including control actuated by a process controller. The valves may be an on/off type of valve, or may be a proportional type of valve.

[0046] The treatment system, in some embodiments described here, further comprises one or more sensors or monitoring devices configured to measure at least one property of the water or an operating condition of the treatment system. Non-limiting examples of sensors include composition analyzers, pH sensors, temperature sensors, conductivity sensors, pressure sensors, and flow sensors. A few non-limiting examples of sensors suitable for use in one or more embodiments include optical sensors, magnetic sensors, radio frequency identification (RFID) sensors, Hall effect sensors, and any combination thereof. In certain embodiments, the sensors provide real-time detection that reads, or otherwise senses, the properties or conditions of interest.

[0047] In one or more embodiments, an RFID antenna can be used to provide positional and other information regarding the treatment system, such as one or more water properties. The RFID antenna senses the targeted information and an associated RFID antenna control processor can transmit the information to a system processor, thereby providing in-line real-time process control.

[0048] In certain non-limiting embodiments of the systems and methods described here, the treatment system further comprises a flowmeter for sensing the flow of fluid. A non-limiting example of a flowmeter suitable for certain aspects of the treatment system disclosed here includes a Hall effect flowmeter. Other exemplary flowmeters suitable for certain aspects of the treatment system include mechanical flowmeters, including a mechanical-drive Woltman-type turbine flowmeter.

[0049] One or more aspects of the systems and methods disclosed here include a control system disposed or configured to receive one or more signals from one or more sensors in the treatment system. The control system can be further configured to provide one or more output or control signals to one or more components of the treatment system. One or more control systems can be implemented using one or more computer systems. The computer system may be, for example, a general-purpose computer such as those based on an Intel PENTIUM®-type processor, a Motorola PowerPC® processor, a Sun UltraSPARC® processor, a Hewlett-Packard PA-RISC® processor, or any other type of processor or combinations thereof. Alternatively, the computer system may include PLCs, specially-programmed, special-purpose hardware, for example, an application-specific integrated circuit (ASIC), or controllers intended for analytical systems.

[0050] In some embodiments, the control system can include one or more processors typically connected to one or more memory devices, which can comprise, for example, any one or more of a disk drive memory, a flash memory device, a RAM memory device, or other device for storing data. The one or more memory devices can be used for storing programs and data during operation of the treatment system and/or a control subsystem. For example, the memory device may be used for storing historical data relating to the parameters over a period of time, as well as current operating data. Software, including programming code that implements embodiments of the invention, can be stored on a computer readable and/or writeable nonvolatile recording medium, and then copied into the one or more memory devices where it can then be executed by the one or more processors. Such programming code may be written in any of a plurality of programming languages, for example, ladder logic, Java, Visual Basic, C, C#, or C++, Fortran, Pascal, Eiffel, Basic, COBOL, or any of a variety of combinations thereof.

[0051] Components of a control system may be coupled by one or more interconnection mechanisms, which may include one or more busses, for example, between components that are integrated within a same device, and/or one or more networks, for example, between components that reside on separate discrete devices. The interconnection mechanism enables communication, for example, data, instructions, to be exchanged between components of the system.

[0052] The control system can further include one or more input devices, for example, a keyboard, mouse, trackball, microphone, touch screen, and one or more output devices, for example, a printing device, display screen, or speaker. In addition, the control system may contain one or more interfaces that can connect to a communication network, in addition to or as an alternative to the network that may be formed by one or more of the components of the control system.

[0053] According to one or more embodiments, one or more input devices may include one or more sensors for measuring one or more parameters of the fluids in the treatment system. Alternatively, the sensors, the metering valves and/or pumps, or all of these components, may be connected to a communication network that is operatively coupled to the control system. For example, sensors may be configured as input devices that are directly connected to the control system. Additionally, metering valves and/or pumps of the one or more sources of treating compositions may be configured as output devices that are connected to the control system, and any one or more of the above may be coupled to another ancillary computer system or component so as to communicate with the control system over a communication network. Such a configuration permits one sensor to be located at a significant distance from another sensor or allows any sensor to be located at a significant distance from any subsystem and/or the controller, while still providing data therebetween.

[0054] In certain embodiments, a computer can be coupled to a server and to a plurality of different input devices. The input devices may include, for example, a wireless communication device (for example, a radio frequency identification (RFID) antenna), one or more sensors, a touch screen having a virtual keyboard, and one or more monitoring devices. In addition, the RFID antenna, any of the sensors, and/or the touch screen, may be configured to operate both as input devices and/or output devices. The touch screen is optional and may alternatively include other known input devices such as a keyboard, mouse, touch pad, joystick, remote control (either wireless or with a wire), track ball, mobile device, etc.

[0055] In certain non-limiting embodiments, a computer is wirelessly coupled to a server and an RFID antenna and one or more other sensors. The RFID antenna may receive input from an RFID device, such as a tag device, secured to one or more components of the treatment system. The RFID device can be programmed to include a wide range of information, and additional monitoring information collected during one or more water treatment cycles can be added to the RFID device. When the RFID device is in communication with the RFID antenna, any information programmed into the RFID device can be downloaded onto the computer and transferred to the server. The RFID device may also include an encryption device.

[0056] The control system can include one or more types of computer storage media such as readable and/or writeable nonvolatile recording medium in which signals can be stored that define a program to be executed by one or more processors. The storage or recording medium may be, for example, a disk or flash memory. In typical operation, the processor can cause data, such as code that implements one or more embodiments of the invention, to be read from the storage medium into a memory device that allows for faster access to the information by the one or more processors. The memory device is typically a volatile, random access memory such as a dynamic random access memory (DRAM), or static memory (SRAM), or any other suitable devices that facilitate information transfer both to and from the one or more processors.

[0057] In certain embodiments, the treatment system also includes a controller for adjusting, monitoring, or regulating at least one operating parameter and its components of the treatment system. A controller comprises a microprocessor-based device, such as a programmable logic controller (PLC) or a distributed control system that receives or sends input and output signals to one or more components of a treatment system. In certain embodiments, the controller regulates the operating conditions of the treatment system in an open-loop or closed-loop control scheme. For example, the controller, in open-loop control, can provide signals to the treatment system such that water is treated without measuring any operating conditions. The controller can also control the operating conditions in closed-loop control so that any one or more operating parameters can be adjusted based on an operating condition measured by, for example, a sensor. In yet another embodiment, the controller can further comprise a communication system, for example, a remote communication device, for transmitting or sending the measured operating condition or operating parameter to a remote station.

[0058] The controller, or components or subsections thereof, may alternatively be implemented as a dedicated system or as a dedicated programmable logic controller (PLC) in a distributed control system. Further, it should be appreciated that one or more features or aspects of the disclosed methods and systems may be implemented in software, hardware or firmware, and any combination thereof. For example, one or more segments of an algorithm executable by the one or more controllers can be performed in separate computers, which in turn, can be communicated through one or more networks.

[0059] One or more embodiments of the systems and methods described here will be described below by way of example and with reference to FIGS. 1-2.

[0060] FIG. 1 illustrates a schematic flow diagram of a treatment system comprising an electrochemical water treatment device. Feed stream 1 enters treatment system 400 and passes through pre-treatment device 2, which may be, for example, a carbon filter. Treatment system 400 may comprise one or more electrochemical water treatment devices 19 and one or more storage systems 20. Electrochemical water treatment device 19 may be in communication and positioned downstream from pre-treatment device 2. Storage system 20 may be in communication and positioned downstream from at least one of pre-treatment device 2 and electrochemical water treatment device 19. Storage system 20 may have internal components, such as baffles, that are positioned to disrupt any internal flow currents or areas of stagnation, and/or relief valves, to prevent unwanted pressure. Storage system 20 may be in fluid communication with electrochemical water treatment device 19 through outlet 22 and dilution stream 11. Fluid exiting pre-filter device 2 may enter conduit 3 and enter storage system 20 through inlet 28. Fluid exiting pre-filter device 2 may also enter conduits 26 and 27 before passing through electrochemical water treatment device 19 to produce a treated stream. The treated stream may exit electrochemical water treatment device 19 through conduit 10 and then pass through inlet 21 and outlet 24 of storage system 20 before proceeding to product stream 25. Treatment system 400 may also comprise a concentration loop that fluidly connects to an outlet of electrochemical water treatment device 19. For example, the concentration loop may fluidly connect to an inlet of electrochemical water treatment device 19 through conduit 27, and further comprise waste stream 6. The concentration loop may also be in fluid communication with at least one of fluid exiting pre-filter device 2 and feed stream 1 through conduit 7. The concentration loop may connect to a manifold outlet (not shown), which collects liquid exiting various compartments, for example, depleting or concentrating compartments, of electrochemical water treatment device 19. The concentration loop may also be in fluid communication with feed water through conduit 26. Treatment system 400 may be capable of processing feed stream 1, with an initial hardness of 20 gpg, to produce product stream 25, exiting with a hardness of 2 – 4 gpg. The corresponding system recovery rate, may be, for example 80% (by volume).

[0061] FIG. 2A illustrates a schematic flow diagram of a hybrid softening treatment system in accordance with one or more embodiments of the methods and systems described herein. A treatment system is illustrated where feed stream 1 is provided to treatment system 300A. In certain non-limiting embodiments, feed stream 1 provides or fluidly communicates with water from a water source to the treatment system. Non-limiting examples of suitable water sources include potable water sources, for example, municipal water, well water, non-potable water sources, for example, brackish or salt-water, pre-treated semi-pure water, and any combination thereof. In some instances, a treatment or treatment system, and/or a chlorine removal system for example, a purification system, treats the water before it fluidly communicates to feed stream 1. Feed stream 1 may contain dissolved salts or ionic or ionizable species including sodium, chloride, chlorine, calcium ions, magnesium ions, carbonates, sulfates or other insoluble or semi-soluble species or dissolved gases, such as silica and carbon dioxide. The feed stream may also contain additives, such as fluoride, chlorate, and bromate species.

[0062] In accordance with one or more embodiments, treatment system 300A includes a fluid distribution system. The distribution system can comprise components that are fluidly connected to provide, for example, water, typically treated water, from storage system 20 to product stream 25, or from softening device 18 to product stream 33. The distribution system can comprise any arrangement of pipes, valves, tees, pumps, and manifolds to provide fluid communication throughout treatment system 300A and throughout one or more product streams or storage systems available to a user. For example, a fluid distribution system can provide fluid communication from storage system 20 or softening device 18 to one or more product streams, or to any one or more components of treatment system 300A. In certain embodiments, the distribution system further comprises a household or residential water distribution system including, but not limited to, connections to one or more points of use such as, but not limited to, a sink faucet, a showerhead, a washing machine, and a dishwasher. For example, treatment system 300A may be connected to the cold, hot, or both, water distribution systems of a household. Pumps and vacuum sources may be in fluid communication with various components of the fluid distribution system for purposes of controlling liquid flow by pressurizing the liquid. The pressurized liquid stream may further comprise a regulator where the pressure can be more readily controlled. Fluid may also be caused to flow by gravity.

[0063] Feed stream 1 may be pre-treated by pre-treatment device 2 before being introduced into storage system 20 through conduit 3 and inlet 28. Pre-filter device 2 may be a preliminary filter or pre-treatment device designed to remove a portion of any undesirable species from the water before the water is further introduced into one or more components of the treatment system 300A. Non-limiting examples of pre-filter devices include, for example, carbon or charcoal filters that may be used to remove at least a portion of any chlorine, including active chlorine, or any species that may foul or interfere with the operation of any of the components of the treatment system process flow. Additional examples of pre-treatment devices include, but are not limited to, ionic exchange devices, mechanical filters, and reverse osmosis devices. Pre-treatment systems can be positioned upstream or downstream of storage system 20, or positioned upstream or downstream of electrochemical water treatment device 19. For example, water that enters storage system 20 after being treated in electrochemical water treatment device 19 may contain little or no chlorine (or alternative disinfectant). To retain a residual chlorine level in storage system 20, the water can be mixed with untreated water from feed stream 1. Preferably, the chlorinated water is added at a rate adequate to result in mixed water that contains enough chlorine to inhibit bacterial activity. Active chlorine refers to chlorine containing species that exhibit anti-microbial activity. An effective chlorine concentration is defined herein as a concentration of active chlorine compounds, for example, sodium hypochlorite, that inhibits the growth of bacteria, such as e-coli, in storage system 20. The ratio at which the feed water and treated water are mixed in storage system 20 may be dependent upon a number of factors, including the efficiency of electrochemical water treatment device 19, the desired effective chlorine concentration, the rate at which water contained in storage system 20 is depleted, the temperature of storage system 20, and the source and quality of the feed water. Pre-treatment devices may also be, for example, a particulate filter, aeration device, or a chlorine-reducing filter, and may comprise several devices, or a number of devices arranged in parallel or in a series. One or more pre-treatment systems can be positioned in treatment system 300A so that at least some chlorine species are retained in a storage system or reservoir but are removed before water enters electrochemical water treatment device 19.

[0064] In accordance with certain embodiment of the systems and methods described here, treatment system 300A further comprises a probe or sensor, for example, a water property sensor, capable of measuring at least one physical property. For example, the sensor can be a device that measures water conductivity, pH, temperature, pressure, composition, and/or flow rates. The probe or sensor can be installed or positioned within treatment system 300A to measure a particularly preferred water property. For example, a sensor can be a water conductivity sensor installed in or otherwise placed in fluid communication with storage system 20 so that it measures the conductivity of the water. This can provide an indication of the quality of water available for product stream 25. In another embodiment, the probe or sensor can comprise a series or a set of sensors in any various configurations or arrangements in treatment system 300A. The set of sensors can be constructed, arranged, or connected to a controller so that the controller can monitor, intermittently or continuously, the quality of water in, for example, storage system 20. This arrangement allows for the performance of treatment system 300A to be further optimized.

[0065] In accordance with other embodiments of the systems and methods described here, treatment system 300A can comprise a combination of sets of sensors in various locations in the liquid circuits throughout the system. For example, the probe or sensor can be a flow sensor measuring a flow rate from feed stream 1, and can further include any one or more of a pH meter, a nephelometer, a composition analyzer, a temperature sensor, and a pressure sensor monitoring the operating conditions of treatment system 300A.

[0066] In certain non-limiting embodiments, treatment system 300A comprises one or more ion exchange devices, for example, a salt-based water softening device 18. In certain non-limiting embodiments, softening device 18 is a cation exchange resin device comprising a cation exchange resin. In certain embodiments, multiple softening devices may be used in treatment system 300A. For example, the softening devices may be configured to operate one at a time, in series, in parallel, and any combination thereof.

[0067] In certain non-limiting embodiments, treatment system 300A comprises a regenerable softening device. A non-limiting example of a regenerable softening device includes a regenerable cation exchange device comprising a cartridge containing a cation exchange resin in sodium form. When the cation exchange material reaches or is near exhaustion, it can be regenerated by, for example, a brine solution so as to exchange the previously adsorbed hard ions such as calcium and magnesium onto the active sites of the cation exchange material. Regeneration of the cartridge can be in either a co-current or a counter-current flow direction relative to the normal operating flow direction, or alternatively, may be pulsed. Additionally, a backwashing step may precede regeneration so as to remove any particulate matter that may have been in solution during operation. Following regeneration, the exchange material is preferably rinsed so as to be substantially free of excess regenerant prior to operating the ion exchange device in the normal manner.

[0068] In certain embodiments, treatment system 300A comprises a recirculating concentrate loop that recirculates through electrochemical water treatment device 19. In certain embodiments, the recirculating concentrate stream is in fluid communication with softening device 18. In at least one embodiment, a portion of the recirculating concentrate make-up water is provided by softening device 18. Fluid communication within the recirculating concentrate stream may further be provided by conduits 7 and 8. In certain embodiments, water exiting softening device 18 through outlet 16 is in fluid communication and comprises a portion of the recirculating concentrate stream. At least one advantage of using treated water with a reduced hardness from softening device 18 as recirculating concentrate make-up water is that it extends the period of time between backwashing or other cleaning methods of electrochemical water treatment device 19. In certain embodiments, the recirculating concentrate stream is in fluid communication with waste stream 6, where fluid exits the treatment system.

[0069] Treatment system 300A may comprise one or more electrochemical water treatment devices 19. Electrochemical water treatment device 19 may be positioned upstream or downstream from storage system 20. Fluid contained in storage system 20 may be in communication with electrochemical water treatment device 19 through outlet 22 and dilution stream 11. Fluid treated by electrochemical water treatment device may be in communication with storage system 20 through conduit 12 and inlet 21.

[0070] Treatment system 300A may include one or more storage systems 20. In certain embodiments, the storage system can store or accumulate water from the feed stream and therefore comprise both treated water as well as untreated, or minimally treated, water. Storage system 20 may store treated water for product stream 25 and may provide water to electrochemical water treatment device 19. Storage system 20 may be in fluid communication with electrochemical water treatment device 19 through outlet 22 and dilution stream 11. Storage system 20 may be in fluid communication with softening device 18 through outlet 29, conduit 30 and inlet 31. In accordance with some embodiments of the systems and methods described here, storage system 20 comprises a tank, vessel, or reservoir that has inlets and outlets for fluid flow, for example inlet 21, and outlets 22, 24, and 29. Inlet 21 may be in fluid communication with electrochemical water treatment device 19 and outlet 24 may be in fluid communication with product stream 25. Storage system 20 may comprise one or more vessels that may be used separately or together in at least one of a series, parallel, and any other configuration to produce one or more desired fluid streams. The fluid paths from the inlets and outlets of storage system 20 may further comprise valves, flowmeters, sensors, and any combination thereof.

[0071] In certain non-limiting embodiments, storage system 20 can comprise several tanks or vessels that may be positioned in multiple locations throughout treatment system 300A. Additionally, each tank or vessel, in turn, can have several inlets positioned at various locations. Similarly, outlets can be positioned on each vessel at various locations depending on, among other things, demand or flow rate to the product stream, the capacity or efficiency of the electrochemical water treatment device, and the capacity or hold-up of the storage system. Storage system 20 can further comprise various components or elements that perform desirable functions or avoid undesirable consequences. For example, the tanks or vessels may have internal components, such as baffles, that are positioned to disrupt any internal flow currents or areas of stagnation, and/or relief valves, to prevent unwanted pressure. In some embodiments, storage system 20 comprises a heat exchanger for heating or cooling the stored fluid. For example, storage system 20 can comprise a vessel constructed with a heating coil, which can contain heating fluid at an elevated temperature relative to the temperature of the fluid in the vessel. The heating fluid can be hot water in a closed-loop flow with a furnace or other heat generating unit so that the heating fluid temperature is raised in the furnace. The heating fluid, in turn, raises the vessel fluid temperature by heat transfer. In accordance with further embodiments of the invention, the treatment system can comprise at least two tanks or vessels or two zones in one or more tanks or vessels, each of which can be, at least partially, fluidly isolated from the other. For example, the treatment system can comprise two vessels fluidly connected to a feed stream and to one or more treatment devices. The two tanks or vessels can be fluidly isolated from each other by conduits and valves so that the first can be placed in service with one or more treatment devices while the second can be removed from service for various reasons, for example, maintenance and cleaning. In accordance with one or more embodiments of the systems and methods described here, the tank or reservoir system is connected to, or in thermal communication with, a heat exchanger and, optionally, to a fluid treatment device. The fluid treatment device can be an electrochemical water treatment device, a reverse osmosis device, an ion-exchange resin bed, an electrodialysis device, a capacitive deionization device, or combinations thereof.

[0072] Treatment system 300A may produce a first product stream 25 through outlet 24 of storage system 20. First product stream 25 may comprise water of a predetermined hardness. For example, first product stream 25 may have a hardness of from about 4 gpg to about 10 gpg. In certain embodiments, first product stream 25 may have a hardness of from about 4 gpg to about 7 gpg. In other embodiments, first product stream 25 may have a hardness of about 4 gpg. First product stream may be suitable for a variety of purposes, depending on the intended use and the desired water hardness specified by one or more end users. For example, in at least some aspects, an end user may find product stream 25 suitable as a source for drinking water or for use in certain domestic fixtures, such as toilets.

[0073] Treatment system 300A may further comprise one or more softening devices 18. Softening device 18 may be in communication with at least one of electrochemical water treatment device 19 and storage system 20. For example, softening device 18 may be positioned downstream from storage system 20. Softening device 18 may be provided and characterized as previously discussed. Fluid contained in storage system 20 may pass through outlet 29 and conduit 30 and enter softening device 18 through inlet 31.

[0074] Softening device 18 may be in communication with electrochemical water treatment device 19 through outlet 16 and conduits 9 and 8. Fluid treated by softening device 18 may exit through outlet 32 to produce a second product stream 33. Second product stream 33 may comprise water of a lower hardness than first product stream 25. For example, second product stream 33 may have a hardness of from about 0 to about 4 gpg. In certain embodiments, second product stream 33 may have a hardness of from about 0 to about 2 gpg. In other embodiments, second product stream 33 may have a hardness of less than about 1 gpg. The second product stream 33 may be suitable for a variety of purposes, depending on the intended use and the desired water hardness specified by one or more end users. For example, in at least some aspects, an end user may find product stream 33 suitable for domestic applications such as bathing, clothes washing, and as a source of hot water. Second product stream may possess very low hardness, making it suitable for plumbing applications where there is a desire to minimize scale-build up. At least one advantage of using treatment system 300A includes the use of fluid exiting softener device 18 to be passed through electrochemical water treatment device 19. Since the concentrate make-up water is less saturated with hard ions, the system does not have to be flushed as frequently as treatment systems that do not have such a configuration. This also results in less waste being discharged from the treatment system. At least another advantage of using treatment system 300A is that the dual product stream configuration allows for a more flexible distribution system. For example, hot water may be supplied to one or more components of a distribution system from softening device 18, while first product stream 25 may supply water to one or more other components of the distribution system. Further, first and second product streams 25 and 33 may be blended or mixed together at any ratio to further allow for flexibility in providing water of a specific hardness to one or more components of a distribution system.

[0075] In accordance with one or more embodiments, water treatment system 300A may provide for a hybrid softener comprising a portable ion exchange device, an example of which is illustrated in treatment system 300B of FIG. 2B. FIG. 2B may be an identical process flow as FIG. 2A, with portable softening device 18A substituting for softening device 18. The portable ion exchange device may be, for example, a cylinder containing regenerated ion exchange resin. The portable ion exchange device may be sent, for example, to a customer's site and installed for use. In certain embodiments, the portable cylinder is monitored, for example, from an external location, or is monitored locally. Various properties and conditions of the portable cylinder may be monitored, for example, for the presence or absence of ion exchange resin, the usable volume remaining in the cartridge, the detection of any leaks or other malfunctions, and/or the number of days remaining before the cartridge is exhausted and needs to be replaced. When the ion exchange medium is exhausted, the cylinder is replaced with a charged cylinder. Additionally, the exhausted cylinders can be recharged and put into queue for later use, or, optionally, the exhausted cylinders can be taken out of service.

[0076] In certain non-limiting embodiments, softening device 18 or 18A can comprise several tanks or vessels, and may be positioned in multiple locations throughout the treatment system. The softening devices may further comprise internal components, such as baffles, that are positioned to disrupt any internal flow currents or areas of stagnation, and/or relief valves, to prevent unwanted pressure. In accordance with further embodiments of the invention, softening device may comprise at least two tanks or vessels or two zones in one or more tanks or vessels, each of which can be, at least partially, fluidly isolated from the other. For example, the softening device may comprise two vessels fluidly connected to other components of the treatment system, including one or more treatment devices. The softening system may comprise one or more tanks that may be pressurized, open to the atmosphere, or a combination thereof. One or more tanks comprising the softening system may be fluidly isolated from each other by conduits and valves so that the first can be placed in service while the second can be removed from service. One or more tanks comprising the softening system may be arranged in a parallel or series configuration. One or more softening devices may be arranged in a series configuration, to allow for sequential processing treatment. For example, a first softening device may function as a “worker” device, capable of reducing the hardness of an incoming stream to a certain level, while a second softening device may function as a “polishing” device, capable of reducing the hardness to a smaller level. At least one advantage of using such a configuration is that it maximizes the use of the capacity of the resin. This may result in allowing the use of smaller softening devices.

[0077] In certain embodiments, portable softening device 18A may comprise a cation exchange resin that may be regenerated externally. For example, portable softening device 18A may be regenerated at a central regeneration station and then exchanged with one or more devices included in treatment system 300B. The advantages of using treatment system 300B include those of 300A, and further include the flexibility of the portable softening device 18A, which may be advantageous in areas were the use of salt-based softeners is restricted or banned.

[0078] Benefits of the hybrid softener describe here include, but are not limited to: reduced sodium content of softened water, the reduction in nitrates, lead and arsenic in treated water, improved taste and texture of drinking water, and the elimination or reduction for the need of an under-the-sink drinking water softening device.

[0079] The treatment systems in FIGS. 2A and 2B are capable of processing feed stream 1 entering the system with an initial hardness of 20 gpg, to produce first product stream 25, exiting with a hardness of about 2 – 4 gpg, and second product stream 33, exiting with a hardness of less than about 1 gpg, with a corresponding system recovery rate of 90% by volume.

[0080] The systems and methods described here further provide a treatment system where a controller can provide a signal so that fluid flow is adjusted based on a variety of operating parameters. These parameters include, but are not limited to, the properties of water from feed stream 1, the properties of water in storage system 20, the properties of water exiting from softening device 18 as product stream 33, the properties of water in the recirculating concentration stream, and any combination thereof. Other parameters may include, the properties of water exiting storage system 20, the demand necessary to provide water to product stream 13, the operating efficiency or capacity of electrochemical water treatment device 19, the operating parameters associated with electrochemical water treatment device 19, the operating efficiency or capacity of softening device 18, and any combination thereof. Specific measured parameters may include, but are not limited to, water conductivity, pH, turbidity, composition, temperature, pressure, flow rate, and any combination thereof.

[0081] In certain embodiments, a controller receives signals from one or more sensors so that the controller is capable of monitoring the operating parameters of the treatment systems disclosed here. For example, a conductivity sensor can be positioned within storage system 20 so that the conductivity of the water within is monitored by the controller. The controller can control, based on, for example, the water quality measured by the sensor, a power source, which may provide power to one or more valves. In operation, the controller can increase, decrease, or otherwise adjust the voltage, current, or both, supplied from the power source to one or more components of the treatment system. The controller includes algorithms that can modify an operating parameter of the treatment system based on one or more measured properties of the liquid flowing in the system. For example, in some embodiments of the systems and methods described here, the controller increases or decreases or otherwise adjusts operating cycles of electrochemical water treatment device 19, for example, operating cycles that require applying a reverse electric field.

[0082] In other embodiments of the systems and methods described here, the controller may reverse the direction of the applied field to electrochemical water treatment device 19 according to a predetermined schedule or according to an operating condition, such as the water quality or any other operating parameter measured by one or more sensors. For example, the controller can be configured to reverse the polarity of the electric field applied to electrochemical water treatment device 19 when a measured parameter reaches a set point. In another embodiment, the systems and methods described here provide a controller that is capable of increasing, decreasing or otherwise adjusting a cycle time based on, for example, measured water properties, non-limiting examples including, but not limited to, total dissolved solids, water quality, and conductivity. The operating cycle can include the period between reversals of the electric field, along with associated changes, reversals, or substitution of fluid flows within electrochemical water treatment device 19.

[0083] The controller can be configured, or configurable by programming, or may be self-adjusting such that it is capable of maximizing any of the service life, the efficiency, or reducing the operating cost of the treatment system. For example, the controller can comprise a microprocessor having user-selectable set points or self-adjusting set points that adjust the applied voltage and current, or both, to one or more valves, softener device, flow rates through the recirculating concentrate loop and the other treated water streams, and the flow rate to waste stream 6.

[0084] In accordance with certain aspects of the systems and methods described here, the controller regulates the operation of the treatment system by incorporating adaptive or predictive algorithms, which are capable of monitoring demand and water quality and adjusting the operation of any one or more components of the treatment system, including the softening device. For example, the controller may be predictive in anticipating higher demand for treated water during early morning hours in a residential application to supply product stream serving a showerhead.

[0085] In accordance with one or more embodiments of the invention, when the polarity of the anode and cathode are switched, the function of the concentrating and depleting compartments are also switched. In certain non-limiting embodiments, a polarity reversal system or technique is used, and the previously described streams can be switched. Reverse polarity cycles may be based on a number of factors, including time, feed stream quality, temperature, treated water quality, desired water quality, and water use rates, and any combination thereof.

[0086] In certain non-limiting embodiments, radio frequency identification (RFID) is utilized to provide real-time detection of certain properties or conditions in the treatment system. In certain embodiments, a plurality of inline identifying tag readers or optical sensors are configured to track or sense certain properties or conditions of the liquid as it is transported through the treatment system. The RFID may be combined with one or more additional sensors, for example, a flowmeter. An embedded tag may be placed in the cartridge of the softening device and used in combination with a flowmeter to determine various properties or conditions, for example, the presence of the cartridge, the usable volume remaining in the cartridge, and the number of days remaining before the cartridge is exhausted and needs to be replaced.

[0087] In certain non-limiting embodiments, valves may be actuated to provide liquid from storage system 20 to electrochemical water treatment device 19 or transfer treated liquid to storage system 20. In some arrangements, the liquid circuit can comprise connections so that untreated liquid can be mixed with liquid that would exit any of the electrode compartments. In another embodiment, the liquid circuit can further comprise connections to and from storage system 20 so that, for example, treated liquid exiting the depleting compartment of electrochemical water treatment device 19 can be transferred to storage system 20 and mixed with untreated liquid from feed stream 1. The resulting mixture may be delivered to a product stream, and/or to the electrode compartments of the electrochemical water treatment device 19 in parallel or series flow path configurations.

[0088] In accordance with another embodiment of the systems and methods described here, a controller, through a sensor or set of sensors, may monitor or measure at least one water property of water storage system 20 and also measure a flow rate of at least one product stream. The controller may adjust an operating parameter of electrochemical water treatment device 19 and one or more valves based on the measured properties. In one or more embodiments of the systems and methods described here, at least one or more sensors may measure at least one property of the feed stream 1, product stream 33, and water in storage system 20.

[0089] In certain non-limiting embodiments, softening device 18 may be bypassed. This arrangement can provide, for example, a “safe mode” for when the softening device is malfunctioning or the cartridge is exhausted. In addition, the softening device may be bypassed to allow for flushing of the concentrate loop at the end of one or more treatment cycles or prior to a reverse cleaning cycle, thereby conserving the exchange capacity of the resin in the cartridge. Softening device 18 may also be bypassed to accommodate situations where softened water is otherwise not needed for the concentrate make-up water or the product water. In certain embodiments, when the water in storage system 20 has a conductivity value within a certain range of values, water from the softening device is not needed.

[0090] In accordance with further embodiments of the systems and methods described here, disinfecting and/or cleaning apparatuses or systems may be utilized with the treatment system. Such disinfecting or cleaning systems can comprise any apparatus that destroys or renders inactive, at least partially, any microorganisms, such as bacteria, that can accumulate in any component of the treatment system. Examples of such cleaning or disinfecting systems include those that can introduce a disinfectant or disinfecting chemical compounds, such as halogens, halogen-donors, acids or bases, as well as systems that expose wetted components of the treatment system to hot water at a temperature capable of sanitization. In accordance with certain embodiments of the systems and methods described here, the treatment system can include final stage or post treatment systems or subsystems that provide final purification of the fluid prior to delivery at a point of use. Examples of such post treatment systems include, but are not limited to, those that expose the fluid to actinic radiation or ultraviolet radiation, and/or ozone or remove undesirable compounds by microfiltration or ultrafiltration. Thus, in accordance with one or more embodiments, the treatment system may be utilized for household service and installed, for example, under a sink to provide water treated by exposure to ultraviolet radiation, before being delivered to a point of use, such as a faucet.

[0091] In accordance with further embodiments of the invention, the treatment system can comprise systems and techniques that permit disinfection of any component of the treatment system. For example, the treatment system can be exposed to a disinfecting solution or a disinfectant. The disinfectant can be any material that can destroy or at least render inactive at least a portion of any viable microorganisms, such as bacteria, present in any component or subsystem of the treatment system. Examples of a disinfectant can include any base, acid, or sanitizer, such as a halogen or halogen-donating compounds, peroxygen or peroxygen-donating compounds that destroy or render bacteria inactive. The disinfectant can be introduced into the treatment system by any suitable device or technique. For example, the disinfectant can be introduced into a treatment system by introducing chlorine into the storage system. The introduction of chlorine can be performed by injecting a hypochlorate species from a disinfectant reservoir fluidly connected to any suitable portion of the treatment system. The chlorinated water can be further circulated through at least a portion of the treatment system thereby exposing wetted portions of the system to disinfectant.

[0092] In accordance with another embodiment of the systems and methods described here, discharge water comprising, for example, water exiting waste stream 6, can be used for auxiliary purposes to serve or provide additional or secondary benefits. For example, waste water may be used to provide, for example, irrigation water to residential, commercial, or industrial uses, or for recycling, or for recovery of collected or concentrated salts.

[0093] In yet another embodiment, the treatment system includes a mixing system that is fluidly connected to at least one of a fluid distribution system and a storage system. The mixing or blending system can include a connection in the fluid distribution system as well as a connection to a feed stream. The mixing system can provide fluid mixing of, for example, untreated water with treated water to produce service water that can be fed to the product stream. The mixing system may also be configured to combine water exiting from an electrochemical water treatment device with water exiting from a softening device. The mixing system can include at least one tee and a mixing tank, or both, that fluidly connect an outlet of a storage system and a feed stream or one or more product streams. The mixing system, in some cases, can include a valve that regulates the flow of any of the untreated water stream and the treated water stream flowing to one or more product streams. In another embodiment, the valve can be a proportional valve that mixes treated water with untreated water according to a predetermined ratio, or mixes two differently treated sources of water. In another embodiment, the valve can be actuated by at least one of a controller depending on the flow rate, the water property, and the particular service associated with the product stream. For example, if low hardness water is required for the product stream, then the controller can regulate the amount of untreated water, if any, that can be mixed with treated water by actuating a valve, which regulates the flow rate of the untreated water, in closed-loop control with a sensor measuring the conductivity of the mixed water stream. In another embodiment, the valve can regulate the flow rate of the treated water that would be mixed with the untreated water according to the requirements of the product stream. In another embodiment, the treatment device can be operated to reach a set-point that is lower than any required by one or more product streams so that any mixing of treated water with untreated water can produce service water that satisfies the particular requirements of each product stream. Those of ordinary skill should recognize that the treatment system can be adjusted to accommodate fluctuations in demand as well as variations in water quality requirements. For example, the systems and methods described here can provide a treatment system that can produce low LSI water, which would be available to the system as a whole, during extended idle periods. Low LSI water, in some embodiments, can be used to flush the wetted components of the treatment system, which can reduce the likelihood of scaling and should increase the service life of the components, individually, and the treatment system as a whole. In accordance with some embodiments, the systems and methods described here provide a system for producing treated liquids, such as water, having a low conductivity. The treatment system can comprise a fluid circuit that can provide treated or, in some cases, softened water or, in other cases, low conductivity water or low LSI water, to an electrode compartment of the electrochemical water treatment device.

EXAMPLES

[0094] The systems and methods described herein will be further illustrated through the following examples, which are illustrative in nature and are not intended to limit the scope of the disclosure.

[0095] Example 1 – Hybrid Softener Performance Comparison Analysis

[0096] Table 1 below illustrates a performance comparison analysis between typical salt-based softeners and a hybrid softener system in accordance with one or more aspects of the systems and methods disclosed herein.

Table 1 – Performance Comparison Analysis between Different Softening Systems

	Typical Softener		**Typical Portable Exchange Cartridge**		**Hybrid Softener System**	
	Capacity	**Hardness (GPG)**	**Capacity**	**Hardness (GPG)**	**Capacity**	**Hardness (GPG)**
	24000	**20**	24000	**30**	24000	**4**
Household Usage Daily gals	days	grains	days	grains	days	grains
200	**6**	4000	**4**	6000	**30**	800
250	**4.8**	5000	**3.2**	7500	**24**	1000
300	**4**	6000	**2.7**	9000	**20**	1200

*Assume 1 cu/ft resin at 8 lbs salt

True Soft Water < 1 GPG

The data presented in Table 1 indicates that the Hybrid Softener System is capable of drastically increasing the length of time before capacity is reached. For example, when compared to the Typical Softener, the Hybrid Softener lasted nearly five times longer.

[0097] Example 2 – Hybrid Softener Performance Comparison Analysis

[0098] Table 2 below illustrates a performance comparison analysis between typical salt-based softeners and a hybrid softener system in accordance with one or more aspects of the systems and methods disclosed herein.

Table 2 – Exchange Frequency Comparison Analysis between Hybrid Softener and Typical Portable Exchange Device

	Typical Portable Exchange Cartridge		**Hybrid Softener System**	
	Capacity	**Hardness (GPG)**	**Capacity**	**Hardness (GPG)**
	60000	**30**	102000	**4**
Household Usage Daily gals	days	grains	days	grains
200	**15**	6000	**127.5**	800
250	**12**	7500	**102**	1000
300	**10.0**	9000	**85**	1200

The data presented in Table 2 indicates that the Hybrid Softener System is capable of reducing the exchange rate of cartridges by a significant amount.

[0099] The systems and methods described herein are not limited in their application to the details of construction and the arrangement of components set forth in the description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," "involving," "having," "containing," "characterized by," "characterized in that," and variations thereof herein is meant to encompass the items listed thereafter, equivalents thereof, as well as alternate embodiments consisting of the items listed thereafter exclusively. Use of ordinal terms such as "first," "second," "third," and the like in the claims to modify a claim element does not by itself connote any priority.

[00100] Those skilled in the art would readily appreciate that the various parameters and configurations described herein are meant to be exemplary and that actual parameters and configurations will depend upon the specific application for which the systems and methods directed toward water treatment processes and systems using hybrid softening devices of the present disclosure are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments described herein. For example, those skilled in the art may recognize that the apparatus, and components thereof, according to the present disclosure, may further comprise a network of systems or be a component of a water treatment processes using hybrid softening devices. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, the disclosed water treatment processes using hybrid softening devices may be practiced otherwise than as specifically described. The present apparatus and methods are directed to each individual feature or method described herein. In addition, any combination of two or more such features, apparatus or methods, if such features, apparatus or methods are not mutually inconsistent, is included within the scope of the present disclosure.

[00101] Further, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and scope of the disclosure. For example, an existing facility may be modified to utilize or incorporate any one or more aspects of the disclosure. Thus, in some cases, the apparatus and methods may involve connecting or configuring an existing facility to comprise a water treatment process using hybrid softening devices. Accordingly, the foregoing description and figures are by way of example only. Further, the depictions in the figures do not limit the disclosures to the particularly illustrated representations.

[00102] While exemplary embodiments of the disclosure have been disclosed many modifications, additions, and deletions may be made therein without departing from the spirit and scope of the disclosure and its equivalents, as set forth in the following claims.

What is claimed is:

1. A method of treating water comprising:

passing a portion of a water stream to be treated through an electrochemical water treatment device to produce a first treated water stream; and

passing a first portion of the first treated water stream through an ion exchange device to produce a second treated water stream.

2. The method of claim 1, further comprising recirculating a concentrate stream through the electrochemical water treatment device.

3. The method of claim 2, further comprising passing a second portion of the first treated water stream through the ion exchange device to produce make-up water in fluid communication with the recirculating concentrate stream.

4. The method of claim 3, further comprising discharging a portion of the recirculating concentrate stream.

5. The method of claim 4, further comprising monitoring a feed volume of the water stream to be treated.

6. The method of claim 5, further comprising discharging less than 30 percent of the feed volume of the water stream to be treated.

7. The method of claim 1, further comprising measuring at least one property of the ion exchange device.

8. The method of claim 7, further comprising controlling removal of ion exchange media based on the at least one measured property of the ion exchange device.

9. A water treatment system comprising:

an electrochemical water treatment device having an inlet and an outlet;

a first water stream in fluid communication with the inlet of the electrochemical water treatment device;

a second water stream in fluid communication with the outlet of the electrochemical water treatment device; and

an ion exchange device having an inlet and an outlet, and positioned downstream and in fluid communication with the second water stream.

10. The system of claim 9, further comprising a first product stream in fluid communication with the outlet of the ion exchange device.

11. The system of claim 9, further comprising a recirculating concentrate stream in fluid communication with the inlet and the outlet of the electrochemical water treatment device.

12. The system of claim 9, further comprising a second product stream in fluid communication with the outlet of the electrochemical water treatment device.

13. The system of claim 9, further comprising a waste stream in fluid communication with the recirculating concentrate stream.

14. The system of claim 9, wherein the ion exchange device comprises a removable cartridge.

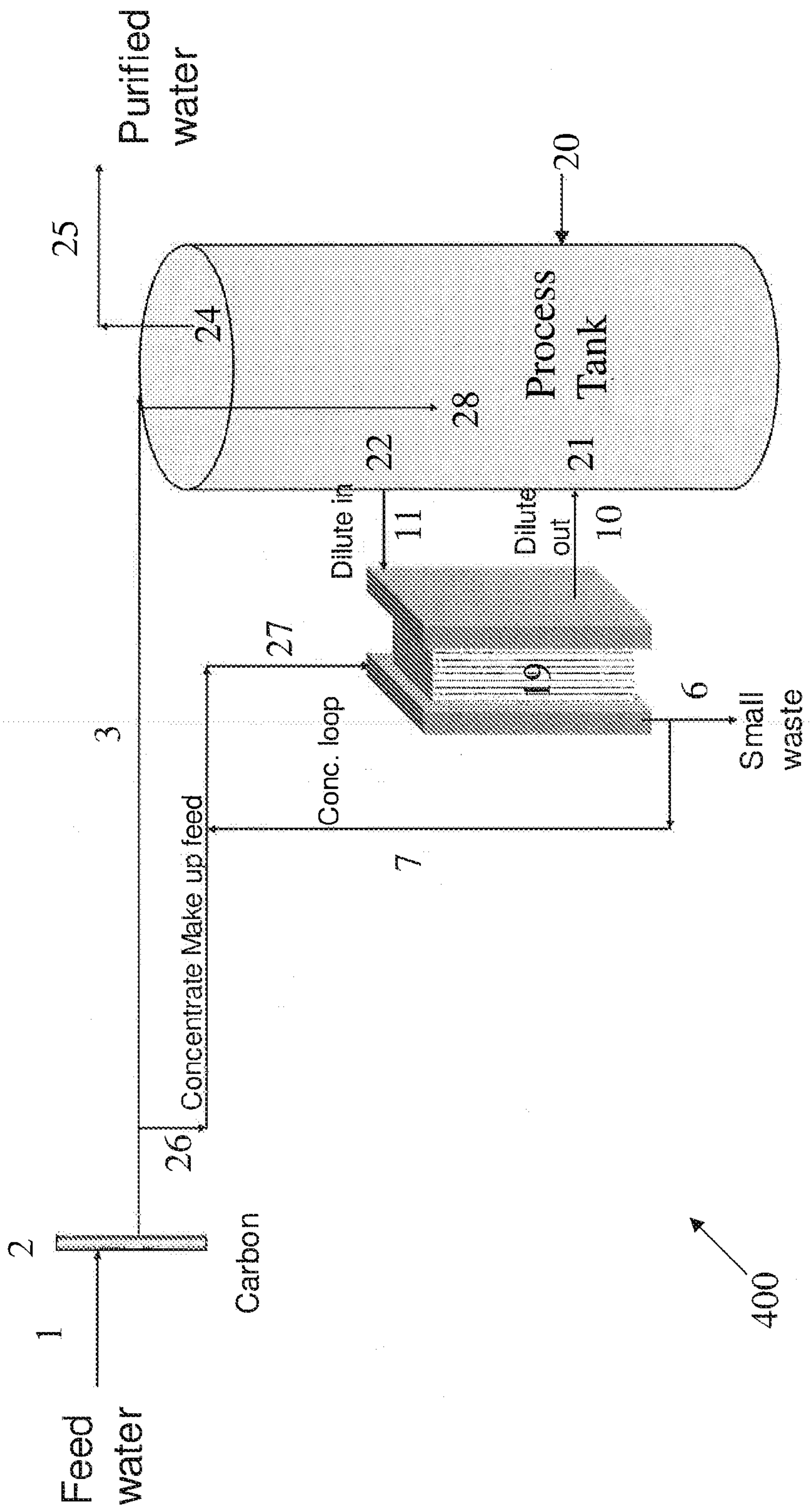
Purified water
25
24
20
Process Tank
28
22
21
Dilute in
11
Dilute out
10
27
19
6
Small waste
3
Conc. loop
7
Concentrate Make up feed
26
2
Carbon
1
Feed water
400

FIG. 1

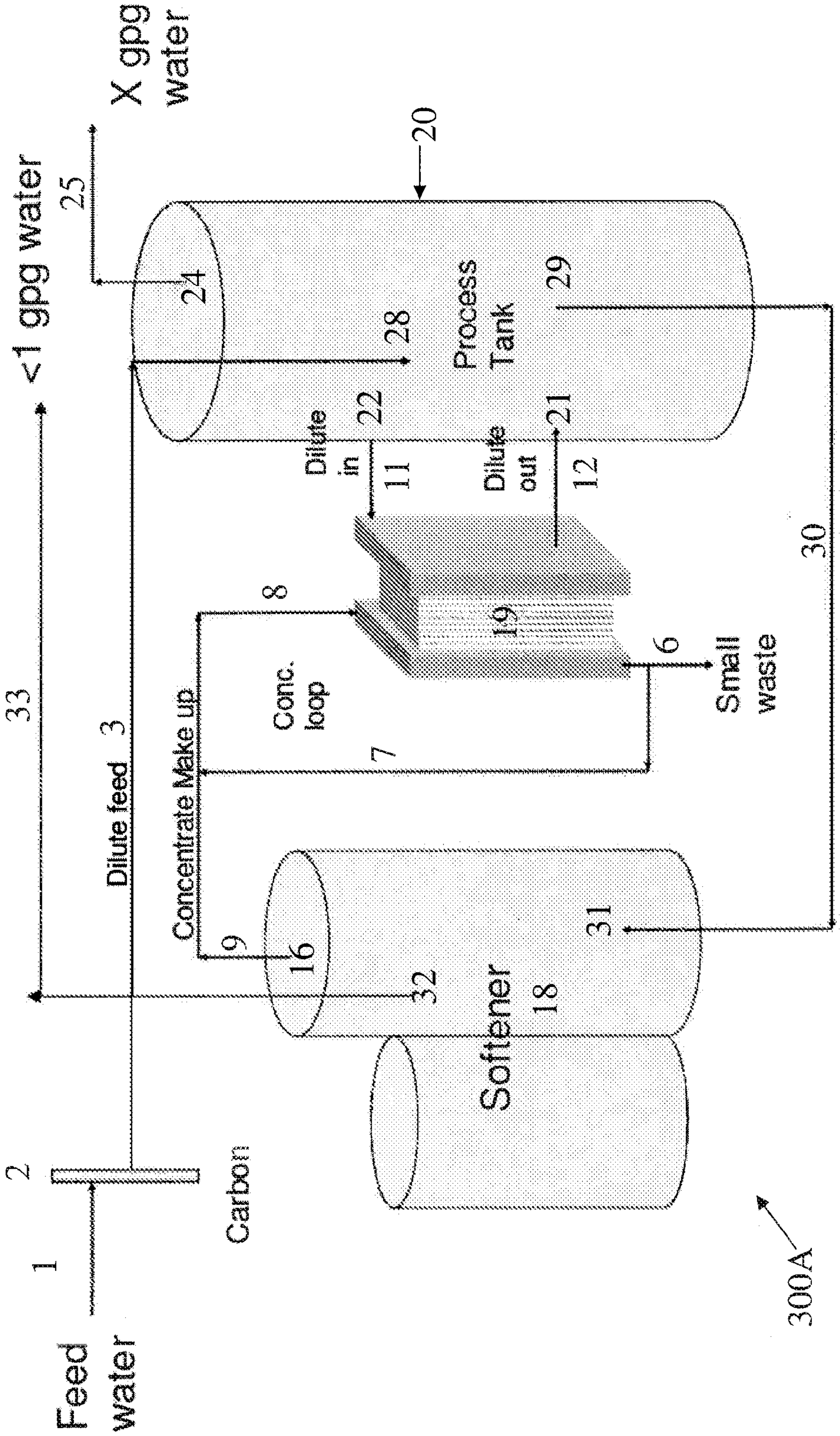
Feed
water
1
2
Carbon
Dilute feed 3
<1 gpg water
33
32
Softener
18
16
9
31
Concentrate Make up
7
Conc.
loop
8
19
6
Small
waste
Dilute
in
11
Dilute
out
12
22
21
28
24
25
X gpg
water
Process
Tank
29
30
20
300A

FIG. 2A

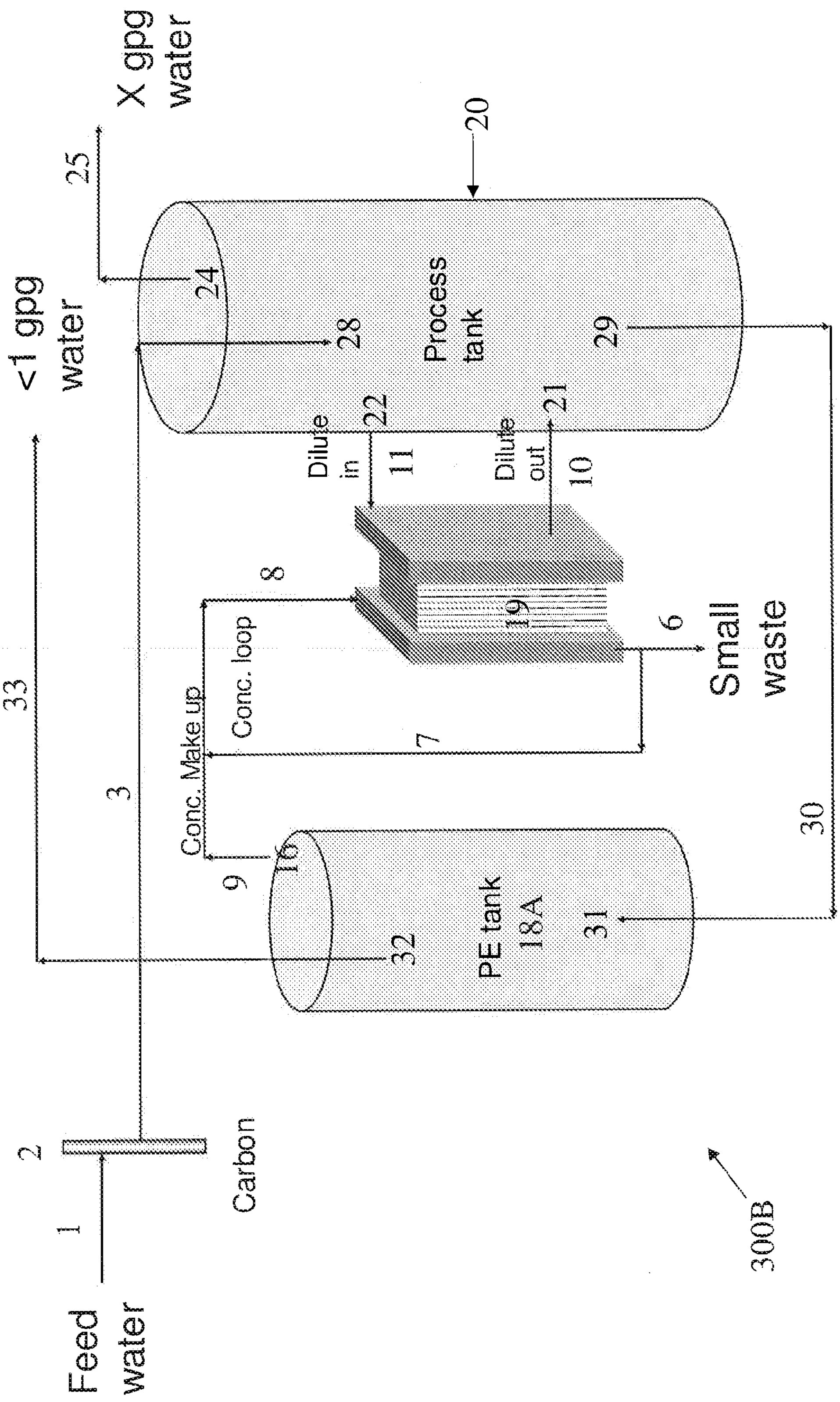
X gpg water
25
20
24
<1 gpg water
28
Process tank
29
22
21
Dilute in
11
Dilute out
10
8
19
6
Small waste
Conc. loop
Conc. Make up
7
33
3
30
Conc.
9
16
PE tank 18A
31
32
2
Carbon
1
Feed water
300B

FIG. 2B