IMPROVED DISSOLVED AIR FLOTATION SYSTEM AND METHOD

BACKGROUND

Aspects and embodiments of the present invention are directed towards systems, apparatuses, and methods for water treatment, and more specifically, water clarification. Clarification processes are typically classified as either flotation processes or settling processes.

In flotation clarification processes, contaminants in a treatment water are removed by causing the contaminants to rise to the surface of the water. This process generates a sludge that is removed from, for example, skimmed off the surface of the treated water. Treated water is typically collected from a position below the sludge flotation. Flotation processes may involve mixing light weight flocculants, which may be metal salts, with the treatment water to facilitate flotation separation.

In settling processes, contaminants in a treatment water are removed by causing the contaminants to sink and separate out of the treatment water. Sludge is created on the bottom of the treatment basin. Treated water is collected from a position above the sludge sediment. Settling processes may involve mixing heavier flocculants, such as polymers, with the treatment water to facilitate settling separation.

Aspects and embodiments of the present invention are directed towards systems, apparatuses, and methods for flotation water treatment. In accordance with aspects and embodiments of the present invention, the systems, apparatuses, and methods for flotation water treatment disclosed may be used in seawater desalination plants and processes.

SUMMARY

In accordance with a first aspect, a water treatment system is provided comprising an air dissolving pump having a pump outlet fluidly coupled to a proximal end of a firs fluid conduit, a relaxation pipe having an inlet fluidly coupled to a distal end of the first fluid conduit and an outlet fluidly coupled to a proximal end of a second fluid conduit, where the relaxation pipe has a diameter greater than a diameter of the first fluid conduit and has a diameter greater than a diameter of the second fluid conduit, and a dissolved air flotation unit having a first inlet fluidly coupled to a distal end of the second fluid conduit.

In accordance with some embodiments, the dissolved air flotation unit further comprises a contact chamber having a plurality of contact chamber walls defining an interior volume of the contact chamber a plurality of interleaved baffles, where each of the interleaved baffles extend from one of the plurality of contact chamber walls and into the interior volume of the contact chamber.

In accordance with some embodiments, the dissolved air flotation unit further comprises a flotation chamber including a flotation chamber floor and a raised floor positioned above the flotation chamber floor, where the raised floor includes at least one aperture.

In accordance with some embodiments, the water treatment system further comprises a sludge recycle system having a recycle system inlet in fluid communication with the flotation chamber and a recycle system outlet in fluid communication with a second inlet of the dissolved air flotation unit, and the sludge recycle system is configured to direct recycled sludge into the second inlet of the dissolved air flotation unit.

In accordance with some embodiments, the water treatment system further comprises a treatment water inlet and a source of flocculant fluidly coupled to an inlet of a static mixer comprising one or more baffles, where the static mixer has an outlet in fluid communication with the second inlet of the dissolved air flotation unit.

In accordance with some embodiments, the water treatment system further comprises a membrane filtration unit having an inlet in fluid communication with an outlet of the dissolved air flotation unit.

In accordance with some embodiments, the water treatment system further comprises a fluid delivery sub-system including a gasified fluid delivery conduit positioned within a flocculated feed delivery conduit, where the gasified fluid delivery conduit has a gasified fluid delivery inlet in fluid communication with the pump outlet of the air dissolving pump,

and a mixing conduit has a mixing conduit inlet fluidly coupled to an outlet of the fluid delivery sub-system and a mixing conduit outlet fluidly coupled to an inlet of a contact chamber of the dissolved air flotation unit.

In accordance with some embodiments, the water treatment system further comprises a fluid delivery sub-system including a flocculated feed delivery conduit positioned within a gasified fluid delivery conduit, where the gasified fluid delivery conduit has a gasified fluid delivery inlet in fluid communication with the pump outlet of the air dissolving pump, and a mixing conduit has a mixing conduit inlet fluidly coupled to an outlet of the fluid delivery sub-system and a mixing conduit outlet fluidly coupled to an inlet of a contact chamber of the dissolved air flotation unit.

In accordance with another aspect, there is provided a dissolved air flotation apparatus comprises a fluid inlet, a flocculation chamber in fluid communication downstream of the fluid inlet, a contact chamber in fluid communication downstream of the flocculation chamber, where the contact chamber comprises a plurality of interleaved baffles extending into an interior volume of the contact chamber from walls of the contact chamber, a gasified fluid inlet positioned below the plurality of baffles and in fluid communication with the contact chamber, a flotation chamber in fluid communication downstream of the contact chamber, and an effluent outlet in fluid communication downstream of the flotation chamber.

In accordance with some embodiments, the dissolved air flotation apparatus further comprises an air dissolving pump having a pump outlet fluidly coupled to a proximal end of a first fluid conduit, and a relaxation pipe having an inlet fluidly coupled to a distal end of the first fluid conduit and an outlet fluidly coupled to the gasified fluid inlet through a second fluid conduit, the relaxation pipe having a diameter greater than a diameter of the first fluid conduit and having a diameter greater than a diameter of the second fluid conduit.

In accordance with some embodiments, the dissolved air flotation apparatus further comprises a sludge recycle system having a recycle system inlet in fluid communication with the flotation chamber and a recycle system outlet in fluid communication with the flocculation chamber, where the sludge recycle system is configured to direct recycled sludge from the flotation chamber into the flocculation chamber.

In accordance with some embodiments, the flotation chamber of the dissolved air flotation apparatus further comprises tube settlers positioned proximate a lower portion of the flotation chamber, where the tube settlers are configured to restrict a flow of fluid from the flotation chamber to the effluent outlet.

In accordance with some embodiments, the flotation chamber of the dissolved air flotation apparatus further comprises a flotation chamber floor and a raised floor positioned at a distance above the flotation chamber floor, where the raised floor includes at least one floor plate including at least one aperture.

In accordance with some embodiments, the raised floor plate is substantially parallel to the flotation chamber floor.

In accordance with some embodiments, the raised floor further comprises a plurality of inclined plates positioned below the at least one floor plate, the plurality of inclined plates each having at least a portion inclined relative to the at least one floor plate.

In accordance with another aspect, a method of facilitating the removal of contaminants from a treatment water is provide comprising introducing the treatment water into a first inlet of a dissolved air flotation unit, producing a pressurized gasified fluid in an air dissolving pump, flowing the pressurized gasified fluid from an outlet of the air dissolving pump through a first conduit to an inlet of a relaxation pipe, where the relaxation pipe has a diameter greater than a diameter of the first conduit, flowing the pressurized gasified fluid from an outlet of the relaxation pipe into an inlet of a second conduit, where the second conduit has a diameter smaller than the diameter of the relaxation pipe, flowing the pressurized gasified fluid through an outlet of the second conduit positioned within a contact chamber of the dissolved air flotation unit; and reducing a pressure of the pressurized gasified fluid; and forming micro-bubbles within the contact chamber.

In accordance with some embodiments, the method further comprises flowing the treatment water through the contact chamber and into a flotation chamber of the dissolved air flotation unit, where the micro-bubbles facilitate the removal of suspended solids from the treatment water and the formation of a sludge including at least a portion of the removed suspended solids, removing a portion of the sludge from a surface of the treatment water in the flotation chamber, and recycling the sludge into a flocculation chamber of the dissolved air flotation unit, where the flocculation chamber is in fluid communication upstream of the contact chamber.

In accordance with some embodiments, the method further comprises directing the treatment water in a serpentine flow path about a plurality of interleaved baffles in the contact chamber.

In accordance with some embodiments, the method further comprises passing the treated water over a plurality of inclined plates positioned below a raised floor of the flotation chamber.

In accordance with some embodiments, the method further comprises filtering the treated water through a membrane filtration unit downstream of the dissolved air flotation unit.

In accordance with another aspect, a method of desalinating seawater is provided, the method comprising introducing the seawater into a first inlet of a dissolved air flotation unit, where the seawater includes a quantity of total suspended solids, producing a pressurized gasified fluid in an air dissolving pump, flowing the pressurized gasified fluid from an outlet of the air dissolving pump through a first conduit to an inlet of a relaxation pipe, where the relaxation pipe has a diameter greater than a diameter of the first conduit, flowing the pressurized gasified fluid from an outlet of the relaxation pipe into an inlet of a second conduit, where the second conduit has a diameter smaller than the diameter of the relaxation pipe, flowing the pressurized gasified fluid through an outlet of the second conduit positioned within a contact chamber of the dissolved air flotation unit, reducing a pressure of the pressurized gasified fluid, and forming micro-bubbles within the contact chamber removing contaminants from the seawater and forming a treated seawater, discharging the treated seawater out of an outlet of the dissolved air flotation unit, and directing the treated seawater from the outlet of the dissolved air flotation unit to a downstream desalination unit.

In accordance with some embodiments, the method further comprises discharging a product water having a concentration of about 500 mg/L TDS from the downstream desalination unit.

In accordance with some embodiments, the downstream desalination unit comprises an electrically-driven separation apparatus.

In accordance with some embodiments, forming the treated seawater comprises removing greater than about 90% of the quantity of total suspend solids from the seawater.

In accordance with another aspect, a seawater treatment system is provided comprising a dissolved air flotation system including an air dissolving pump having a pump outlet fluidly coupled to a proximal end of a first fluid conduit, a relaxation pipe having an inlet fluidly coupled to a distal end of the first fluid conduit and an outlet fluidly coupled to a proximal end of a second fluid conduit, where the relaxation pipe has a diameter greater than a diameter of the first fluid conduit and has a diameter greater than a diameter of the second

fluid conduit, a dissolved air flotation unit having a first inlet fluidly coupled to a distal end of the second fluid conduit, and a desalination unit having an inlet in fluid communication with an outlet of the dissolved air flotation system.

In accordance with some embodiments, the desalination unit is an electrically-driven separation apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

FIG. 1 is a flow diagram of a conventional dissolved air flotation (DAF) water treatment system;

FIG. 2 is a flow diagram of a DAF water treatment system in accordance with an embodiment of the present invention;

FIG. 3 is a flow diagram of a DAF water treatment system in accordance with another embodiment of the present invention;

FIG. 4 is a flow diagram of a DAF water treatment system in accordance with another embodiment of the present invention;

FIG. 5 is a flow diagram of a DAF water treatment system in accordance with another embodiment of the present invention;

FIG. 6 presents a flow diagram of a portion of a seawater treatment plant in accordance with another embodiment of the present invention;

FIG. 7 presents a modified DAF apparatus in accordance with an embodiment of the present invention;

FIG. 8 presents a modified DAF apparatus in accordance with another embodiment of the present invention;

FIGS. 9A and 9B present a plan and isometric view, respectively, of a DAF apparatus modification in accordance with embodiments of the present invention;

FIGS. 10A-10C present isometric and plan views of a DAF apparatus modification in accordance with other embodiments of the present invention;

FIG. 11 presents a modified DAF apparatus in accordance with another embodiment of the present invention;

FIGS. 12A and 12B are isometric views of DAF system modifications in accordance with embodiments of the present invention;

FIG. 13 is a flow diagram of a DAF water treatment system in accordance with another embodiment of the present invention;

FIGS. 14A-14C are plan and cross-sectional views of DAF system modifications in accordance with embodiments of the present invention;

FIG. 15 presents data from a pilot study of a DAF system in accordance with embodiments of the present invention;

FIG. 16 presents data from an additional pilot study of a DAF system using ferric chloride flocculant in accordance with embodiments of the present invention; and

FIG. 17 presents data from the additional pilot study of a DAF system using aluminum sulfate flocculant in accordance with embodiments of the present invention.

DETAILED DESCRIPTION

Aspects and embodiments of the present invention are directed towards systems, apparatuses, and methods for treating water. As used herein, the term "treatment water" includes surface water, for example, reservoir water or ground water, flowing waters, for example, lake water or river water, seawater, and wastewater, for example, municipal wastewater, industrial wastewater, agricultural wastewater, and other forms of liquid containing undesirable contaminants. Aspects and embodiments of the present invention may be utilized for primary water treatment systems, secondary water treatment systems, or both. Aspects and embodiments of the present invention may remove sufficient contaminants, for example, suspended solids, dissolved organic carbon, algae and sand from a treatment water to produce product water that may be used for, for example, irrigation water, potable water, cooling water, boiler water, tank water, or for other purposes.

In some embodiments, the systems, apparatuses, and methods disclosed herein provide advantages with regard to, for example, capital costs, operational costs, and/or environmental impact, as compared to conventional DAF water treatment systems. In some embodiments, the systems, apparatuses, and methods disclosed herein provide advantages over conventional DAF systems with regard to, for example, the type and amount of treatment water capable of being treated in a system having a given footprint, and/or the amount, type, size, and weight of contaminants the system is capable of removing from the

treatment water. In some embodiments, the systems, apparatuses, and methods disclosed herein may provide advantages with regard to, for example, the desalination of seawater.

In some embodiments, the systems, apparatuses, and methods disclosed herein provide advantages with regard to, for example, efficiency, as compared to conventional DAF water treatment systems. DAF efficiency is typically measured in terms of the gallons per minute per square foot (gpm/ft^2) of feed having a given level of contaminants, for example, a given amount of total suspended solids (TSS), capable of being treated in the DAF unit to a desired purity. This square footage comprises the footprint of the DAF basin that includes the area of a flotation chamber floor. Typically, DAF units comprise a contact chamber upstream of, and in fluid communication with, the flotation chamber. Some DAF units may include other chambers, for instance, a flocculation chamber upstream of, and in fluid communication with, the contact chamber. These chambers are typically not factored in to the DAF efficiency calculation.

A conventional DAF system, indicated generally at 100, is illustrated in FIG. 1. Treatment water from a source of treatment water 105 is directed into a mixing tank 115 through an inlet of the mixing tank. Though treatment water from a source of water to be treated undergoes various chemical and physical changes in a DAF system, for simplicity, the water passing through a DAF system will be referred to herein as "treatment water" up and until it exits the system as "treated water," also referred to herein as "effluent." Treatment water entering a DAF unit may also be referred to herein as "feed." The treatment water is mixed in flocculation tank 115 with one or more flocculants from a source of flocculant 110. A mechanical mixer 175 may be provided in the flocculation tank 115 to facilitate mixing of the treatment water and flocculant(s). The flocculant(s) agglomerate with the contaminants in the treatment water to form flocs. The flocculated treatment water is then directed through conduit 120 to DAF unit 160. DAF unit 160 comprises two chambers; contact chamber 160B and flotation chamber 160C.

Treatment water enters DAF unit 160 through an inlet in fluid communication with contact chamber 160B. DAF unit 160 receives gas, for example, air dissolved in a fluid (referred to herein as a "gasified fluid" or "gasified liquid"), for example, water, from conduit 125 at an inlet in fluid communication with mixing chamber 160B. As used herein, the terms "gas" and "air" are used interchangeably, and are not limited to typical atmospheric air but may also refer to any type of gas useful in DAF treatment, for example, nitrogen or natural gas. A plurality of nozzles are typically utilized to distribute the gasified fluid into contact

chamber 160B. The gasified fluid received from conduit 125 is typically produced by dissolving air from a source of compressed air 150 into a liquid. A portion of treated water 130 may serve as the dissolving liquid. The treated water to be used to form the gasified fluid may be directed from an outlet of the DAF unit 160 through conduit 135 to recycle pump 140. Recycle pump 140 directs the liquid through conduit 145. Air from a source of compressed air 150 is also received by conduit 145. The air-liquid mixture is fed to saturator 155. Saturator 155 dissolves the compressed air into the liquid. Saturator 155 typically includes a vent 170 for use in controlling pressure within the saturator. Liquid containing dissolved air exits the saturator through conduit 125 and is received at a gasified fluid inlet of the DAF unit. The gasified fluid is allowed to expand through a valve 165 and/or a plurality of nozzles as it enters mixing chamber 160B. Air bubbles are released from solution and into the mixing chamber 160B. Floc in the treatment water contacts and attaches to the air bubbles. The bubbles, and the contaminants, such as suspended solids or oils, attached to the bubbles, rise to the surface of flotation chamber 160C. A sludge forms above the treatment water in chamber 160C. The sludge is removed from the surface of the treatment water, for example, with a skimmer. Treated water 130 is collected from an outlet in fluid communication with flotation chamber 160C.

Conventional DAF systems are limited by the multiple components the systems require to produce micro-bubbles. As shown in FIG. 1, the mechanisms used to create gasified fluid in conventional DAF systems typically comprise a recycle pump, a saturator tank, a compressor, and a corresponding network of nozzles to produce and deliver bubbles to the DAF unit. These components need to work harmoniously and in unison for proper operation, which makes DAF operations complex. Additionally, because the system requires multiple components, the footprint of the DAF system must be large to accommodate the gasified fluid producing components. The high number of components and large system footprint of conventional DAF systems contribute to high capital costs associated with the systems.

Conventional DAF systems are further limited by the ability of the bubble distribution mechanism to produce a sufficient quantity, size, and density of micro-bubbles. The efficiency of a DAF process is largely based on the amount and density of micro-bubbles formed in the DAF unit. A greater, rather than a lesser, amount of contact between bubbles and floc in the mixing chamber allows the DAF system to remove a required amount of contaminants at higher loading rates at a given separation efficiency. The bubble distribution

mechanisms of conventional DAF systems typically cannot produce a sufficient amount and density of micro-bubbles to treat highly contaminated water, for instance, water having turbidity of greater than about 25 Nephelometric turbidity units (NTU) at certain higher loading rates. Conventional DAF systems are typically capable of treating water having a turbidity of 20 to 30 NTU and can remove only about 20 mg/L to about 30 mg/L of TSS, from the treatment water at a loading rate of about 14 gpm/ft^2. Furthermore, conventional DAF systems are typically only capable of removing up to about 50% of the Total Organic Carbon (TOC) in a treatment water having a TOC concentration of 3 mg/L. Conventional DAF units are thus typically used only to separate out light solids, for example algae, and like organic particulates from treatment water. Conventional DAF systems are therefore often limited to treating surface water or stagnant water such as reservoir water. Conventional DAF systems are therefore not often used as a pre-treatment for seawater, where the removal of heavier suspended solids is essential to successful desalination. Conventional DAF systems are also limited by the system's inability to remove high amounts of TOC in a treatment water. Furthermore, conventional DAF systems perform inefficiently when treating flowing waters, like river water or seawater, that contain both organic solids like algae, and inorganic solids, for example, sand. When both algae and sand need to be removed, it is often necessary to treat the water with a conventional DAF system to remove the algae and to also treat the water with a settler system to remove the sand. Settling processes generally use polymers to attach to, and cause heavier particles such as sand to sink and separate out of treatment water. Residual polymer in the treated water may present an obstacle to performing further treatment operations on the treated water. Membrane filtration units, for instance, tend to foul where even a small amount of residual polymer is present in water treated therein. Not only are conventional DAF systems inefficient at removing sand, the necessary sand-removing treatments add further capital and operating costs and inhibit downstream processing of the treated water.

Aspects and embodiments of the present invention are directed to an improved DAF system that may require less equipment, lower capital cost, have a smaller footprint, and operate more efficiently than conventional systems. In some embodiments, the improved DAF systems may be capable of removing about 250 mg/L or more of TSS from treatment water at a particular loading rate whereas typical conventional DAF systems are only capable of removing about 20 mg/L to about 30 mg/L of contaminants at a lesser or comparable loading rate. An improved DAF system in accordance with aspects and embodiments of the

present invention may also be capable of removing heavier, inorganic particles, such as sand having a dimension of up to about 300μm, from treatment water. Embodiments of the improved system may reduce or eliminate the need to use polymers in the separation process and enable downstream treatment operations incompatible with polymer separation processes, such as membrane filtration.

In one embodiment, indicated generally at 200 in FIG. 2, DAF unit 260 comprises three chambers; a flocculation chamber 260A, a contact chamber 260B, and a flotation chamber 260C. A treatment water 105 and one or more flocculants from a source of flocculant 110 undergo in-line mixing in in-line mixing unit 215. In-line mixing unit 215 may in some embodiments comprise a portion of conduit 220 which may have an increased diameter relative to the remainder of conduit 220. In-line mixing unit 215 may, for example, comprise a SPIRALSEP™ centrifugal coalescing unit manufactured by Siemens Industry, Inc. In-line mixing unit 215 may in some embodiments comprise a static mixer including baffles to enhance mixing. The flocculants may include one or more of ferric chloride, aluminum sulphate, or any other suitable flocculant. In some embodiments, chemical agents may be dosed in addition to, or in place of, flocculants. Feed including the flocculants mixed in treatment water 105 enters DAF unit 260 via conduit 220 at an inlet in fluid communication with flocculation chamber 260A. The flocculants, treatment water, and any floc or recycled sludge (discussed below) present in the flocculation chamber 260A are mixed in the flocculation chamber 260A to form freshly coagulated floc. Suspended solids and other contaminants present in the treatment water may coalesce and form floc particles in the flocculation chamber 260A and/or may adhere to existing floc particles in the flocculation chamber 260A. Contaminants may form or adhere to floc particles in the flocculation chamber 260A by processes such as chemical absorption, adsorption, or other processes.

An air dissolving pump 265 is used to provide a gasified fluid including a high density of dissolved gas to DAF unit 260. A portion of effluent 130 from the DAF unit 260 is fed to air dissolving pump 265 through conduit 235. The amount of effluent 130 recycled to the air dissolving pump 265 is in part dependant on the loading rate of solids from the treatment water. Air dissolving pump 265 does not require a compressor to provide compressed air, in contrast with the gasified liquid supply units of conventional DAF systems. The portion of effluent recycled to the air dissolving pump 265 may be in a range of from about 5% to about 20%, and in some embodiments may be in a range of from about 8% to about 10% of the effluent output from the DAF unit. Air dissolving pump 265 receives

atmospheric air 280 and liquid, for example water from conduit 235, and dissolves the air into the liquid. Gasified fluid from pump 265 passes through conduit 225 and is received by the DAF unit 260. Conduit 225 is arranged to introduce gasified fluid into DAF unit 260 at a gasified fluid inlet 275, which may be constructed from, for example, a portion of conduit 225 extending into the DAF unit through a lower wall thereof. The gasified fluid inlet 275 may be positioned at a low point in contact chamber 260B. In some embodiments, the gasified fluid is introduced into contact tank 260B by inlet 275 at a position about four inches above the floor of contact chamber 260B. In contrast to conventional DAF systems, which typically require nozzles to deliver micro-bubbles to the DAF unit, flow of gasified fluid through inlet 275 may be controlled by a pressure release valve 285 positioned immediately before, or at, the junction of contact chamber 260B and conduit 225. Typically, nozzles in conventional DAF systems not only contribute to capital costs, but become clogged and require cleaning. Cleaning may require the system to be taken off-line and is often a time and labor intensive process. Gasified fluid inlet 275 and pressure release valve 285 beneficially replace the system of nozzles used in traditional DAF systems and may reduce the capital cost and cost of operating and maintaining the DAF system. Furthermore, the location of gasified fluid inlet 275 may provide for increased bubble dispersion in contact chamber 260B as compared to other inlet locations, for example, an array of nozzles as typically utilized in conventional DAF systems, and may better contain micro-bubbles in contact chamber 260B.

The pressure of the gasified fluid may be reduced, in part, by pressure release valve 285. In some embodiments, pressure release valve 285 may be a globe valve. The gasified fluid further expands upon entering DAF unit 260 due to a reduced pressure in the DAF unit as compared to the pressure in the conduit 225 and at the gasified fluid outlet 275. The gasified fluid releases micro-bubbles into fluid in contact chamber 260B. The micro-bubbles may adhere to coagulated floc-contaminant particles in the DAF unit and cause them to float to the top of contact chamber 260B and flotation chamber 260C, and separate out from the treatment water. Treated water may be collected from an effluent outlet in communication with flotation chamber 260C.

An air dissolving pump, such as pump 265, may advantageously replace the compressors, pumps, and saturators used in a conventional DAF system. In some embodiments, the air dissolving pump may be capable of reducing the energy demand of micro-bubble production by about 20% as compared to conventional systems. In some embodiments, dry compressed air may be fed to air dissolving pump 265 to further improve

air saturation. Because gasified fluid for the production of micro-bubbles in the DAF unit can be generated using a single piece of equipment, the DAF system footprint may be reduced. The air dissolving pump employed in some aspects and embodiments of the present invention may be described as a dissolved gas flotation pump or a fluid/gas pump. The air dissolving pump may be a fluid/gas pump manufactured by EDUR Pumpenfabrik Eduard Redlien GmbH & Co. of Kiel, Germany.

The air dissolving pump may operate at a pressure in the range of from about 4.50 bar to about 6.50 bar, and in some embodiments, at about 5.50 bar and produce gasified fluid pressurized to a pressure in this range. The air dissolving pump may produce gasified fluid which releases micro-bubbles in the DAF unit having sizes in a range of from about 1μm to about 175μm, and in some embodiments, in a range of from about 10μm to about 100μm. The air dissolving pump advantageously facilitates generation of a higher density of bubbles as compared to conventional saturator-based technologies. The air dissolving pump in some aspects and embodiments of the present invention is capable of dissolving more air in a volume of liquid than the bubble distribution mechanisms used in conventional DAF processes. The air dissolving pump may dissolve an amount of air in liquid that equals up to about 100% of the maximum solubility of air in the liquid, as compared to conventional systems that typically can only dissolve an amount of air up to about 80% or up to about 90% of the maximum solubility of air in the liquid. As a result, more surface contact may occur between micro-bubbles and floc particles in the DAF unit. This allows DAF systems in accordance with embodiments of the present invention to run at higher loading rates than conventional DAF systems without sacrificing separation efficiency.

In some embodiments, features may be incorporated into the DAF system to increase the amount and/or density of micro-bubbles produced in the contact chamber, thus improving separation efficiency. In an embodiment of a DAF system indicated generally at 300 in FIG. 3, a relaxation pipe 370 receives gasified fluid containing dissolved air from air dissolving pump 265. Relaxation pipe 370 is positioned immediately after the air dissolving pump 265 or is fluidly coupled to air dissolving pump 365 by a conduit 380. Relaxation pipe 370 is configured to provide a retention time sufficient to allow for the gas to more completely dissolve in liquid and may facilitate the generation of a higher density of micro-bubbles in DAF unit 260, as compared to the density of micro-bubbles produced in a system without a relaxation pipe. Relaxation pipe 370 provides gasified fluid containing dissolved air to DAF unit 260 via conduit 325. Relaxation pipe 370 may be designed to allow expansion of the air-

saturated gasified fluid received from air dissolving pump 265. The entire relaxation pipe 370, or a portion thereof, may have a diameter that is greater than a diameter of conduit 325 and/or conduit 380.

Relaxation pipe 370 and the various conduits and pipes described herein are not limited to cylinders. Relaxation pipe 370 may comprise, for example, a vessel having one or more curved or planar walls. Thus, as used herein, the term "diameter" refers to a cross sectional area of an internal volume of relaxation pipe 370 or of any of the various conduits or pipes described herein in a plane normal to the direction of the passage of fluid therethrough.

The pressure drop across relaxation pipe 370 may be in a range of from about 0.1 bar to about 1.0 bar, in a range of from about 0.25 bar to about 0.75 bar, and in some embodiments, about 0.5 bar. The pressure in the relaxation pipe may be in a range of from about 3 bar to about 5.5 bar. Relaxation pipe 370 may be designed to have a hydraulic retention time of between about 1 minute and about 4 minutes, and in some embodiments, of about 2 minutes. Relaxation pipe 370 may increase the load capacity of DAF 260 without hindering performance, and thus may increase the efficiency of the system as compared to a comparable DAF system without a relaxation pipe by, for example, about 20%.

In accordance with some embodiments, the performance of a DAF system may be enhanced by recycling a portion of the sludge removed from the flotation chamber to the feed stream. With reference to the system 400 of FIG. 4, a portion of sludge generated by DAF unit 260 is collected from flotation chamber 260C and directed through conduit 475. The sludge is then introduced into conduit 220 either upstream or downstream of mixing unit 215 and enters DAF unit 260 with the floc-containing treatment water. Pump 480 may be provided at an outlet of the DAF unit 260 or in the conduit 475 to facilitate transport of the sludge to conduit 220. The recycle of sludge to the DAF unit enables DAF unit 260 to operate at higher rates of loading without any detrimental effects on performance. Recycling the sludge may increase bubble-floc particle collisions and, consequently, more bubble-floc particle binding may occur. Particles of sludge may act as "seeds" to which contaminants may attach to and form floc particles. The amount of sludge that is created in the DAF unit and that is recycled may be dependent on the treatment water turbidity and/or the loading rate of the DAF unit. In some embodiments, the turbidity of the treatment water and sludge entering the DAF unit may be in the range of from about 50 NTU to about 150 NTU. The portion of sludge recycled may be in the range of from about 0.00% to about 5.0% of the

flow rate of treatment water entering the DAF system, and in some embodiments, may be in the range of from about 1% to about 2% of the flow rate of treatment water entering the DAF system. The portion of sludge recycled may automatically or manually be varied and adjusted during system operations to maintain a desirable feed turbidity. In accordance with some embodiments, the amount of sludge recycle is inversely proportional to the treatment water's turbidity.

In accordance with embodiments of a DAF system indicated generally at 500 in FIG. 5, treated water from a DAF system may be further treated by a downstream water purification process unit 580. Process unit 580 may be, for example, an activated carbon process unit, a UV irradiation process unit, or a membrane or filtration process unit, an electrodialysis or electrodeionization unit, or any other processing unit.

Treatment water 105 may comprise a source of seawater having a range of TSS for example, from about 1 mg/L to about 100 mg/L, and in some embodiments, from about 5 mg/L to about 20 mg/L, and may have a Total Dissolved Solids (TDS) of, for example, about 30,000 mg/L to about 50,000 mg/L, or, in some embodiments, about 35,000 mg/L. Treatment water 105 comprising a source of seawater may have a turbidity in the range from about 10 NTU to about 50 NTU, but may vary due to the geographical origin of the seawater being treated. Depending on the geographical location of the seawater intake, treatment water comprising a source of seawater may contain oil, grease, phytoplankton, zooplankton, marine larvae, and other contaminants that may not typically be present in other types of treatment waters. In accordance with embodiments, seawater may be treated in a desalination plant comprising an improved DAF system, for example, the improved DAF systems illustrated in FIGS. 2-5 and 13 to a potable quality, or for example, a purity of less than about 500 mg/L TDS. The improved DAF system used in a desalination plant in accordance with embodiments may include a modified DAF unit, for example, the modified DAF units illustrated in FIGS. 7, 8 and 11.

In accordance with embodiments of an improved desalination system indicated generally at 1000 in FIG. 6, seawater 1005 may be desalinated by a treatment plant comprising improved DAF system 1020. A source of seawater 1005 may be filtered by screen 1010. Screen 1010 may have apertures sized to reject debris from entering DAF unit 1020. Screen 1010 may have apertures having a diameter of about 1 inch (2.54 cm) to less than about 300μm. The apertures of screen 1010 are not limited to circular geometries and may have a cross-sectional area equivalent to a circular aperture having a given diameter. In

some embodiments, a plurality of screens 1020 may be used to facilitate the stage-wise rejection of debris of varying sizes. The apertures of screen 1020 may have a diameter and/or cross-sectional area sized to facilitate the rejection of rocks, vegetation, and aquatic life. In some embodiments, screen 1020 may be a coarse screen, for example, a drum screen having apertures with a diameter of between about 1mm to about 5mm. In some embodiments, screen 1020 may be a fine screen, for example, a screen having apertures having a diameter and/or cross-sectional area sized to reject smaller debris, including, for example, large sand particles having a dimension greater than about 300 μm. Screen 1020 may further be designed to accommodate a desired throughput of water to DAF unit 1020. Screened seawater may then be introduced into DAF system 1020. In accordance with some embodiments, seawater 1005 may be introduced into DAF unit 1020 without first being screened.

Seawater entering DAF unit 1020 may, in some embodiments, have a TSS of about 8 mg/L. In accordance with various embodiments, improved DAF system 1020 may be capable of removing up to about 250 mg/L of TSS in a treatment water and may remove greater than about 99% of the TSS in seawater 1005, and in some embodiments, may remove 100% of the TSS in the seawater. Improved DAF 1020 may consume less than about 0.04 kWh/m^3 of DAF-treated seawater. DAF-treated seawater may then be directed to one or more downstream processing and desalination units. A downstream unit may be, for example, an activated carbon process unit, a UV irradiation process unit, or a filtration process unit. More specifically, a downstream desalination filtration unit may be an ultrafiltration membrane unit or a microfiltration membrane unit. In some embodiments, downstream desalination units may be arranged in parallel, series, or a combination thereof. System 1000 of FIG. 6 has, for example, downstream desalination units 1030 and 1040 fluidly connected in series. In accordance with some embodiments, desalination unit 1030 may be an ultrafiltration unit and desalination unit 1040 may be a reverse osmosis unit. Ultrafiltration unit 1030 may remove any remaining TSS, turbidity, and microbes from the seawater. Reverse osmosis unit 1040 may desalt seawater 1005 to a desired purity, and in accordance with some embodiments, to potable quality. Product water 1050 may, in some embodiments, have a purity of about 500 mg/L TDS. In accordance with other embodiments, desalination unit 1030 may be a media filtration unit and desalination unit 140 may be a reverse osmosis unit. Desalination units 1030 and 1040 may be upstream of other units, for example, a UV disinfection unit. In accordance with embodiments, DAF-treated seawater

may be desalinated by electrodesalination units, including, for example, electrodeionization units and/or electrodeionization units. One or more electrodesalination units may purify DAF-treated seawater to about 500 mg/L TDS by consuming less than about 1.5 kWh/m^3 of product water to about 2.0 kWh/m^3 of product water. In some embodiments, seawater 1005 may be desalinated to product water 1050 having a potable purity in a plant comprising an improved DAF unit by consuming less than about 2.0 kWh/m^3 product water.

In desalination processes, it is typically desirable to remove as much contaminant as possible from the seawater prior to passing it through a desalination unit. Many desalination processes use reverse osmosis, microfiltration, or ultrafiltration membranes to remove dissolved solids from the seawater to render the water to a desired purity, often potable purity. Membrane units are particularly sensitive to feed quality and can easily become clogged when the purity of feed entering the membrane unit contains too high a level of contaminants, including suspended and dissolved solids.

Membrane desalination processes typically employ one, or a plurality of, pre-treatment processes upstream of the desalination unit or units to remove a portion of contaminants from the raw seawater. Seawater pre-treatment processes commonly include sand filters, cartridge filters, or other types of filters, the pores of which may become obstructed when operating on a water having a high concentration of contaminants. Seawater having a high concentration of contaminants may clog traditional desalination pre-treatment processes causing a reduction in or total blockage of throughput. Filtration-type pre-treatment processes typically must also be regularly cleaned to dislodge fouling materials that may decrease throughout and reduce the lifespan of the filter. Regular and emergency cleanings may require the entire desalination system to be taken offline and require additional equipment, energy, and labor. Filters tend to foul and degrade over time and may require frequent replacement, particularly when operating on seawater having a high TSS, which may increase the cost of operating the desalination plant.

In accordance with some embodiments, an improved desalination plant may desalinate seawater to potable quality the use of filter-type pretreatment processes. The improved desalination plant may thus reduce the cost of operating and maintaining the plant by eliminating the need to periodically clean and replace filters. The improved desalination plant may also better ensure constant throughput and production of product water. The improved desalination plant may be capable of staying online longer than plants with filter-type pretreatment systems and the improved desalination plant may produce more product

water over a given period of time. Because contaminants may continuously be removed from the pre-treatment DAF in accordance with some embodiments, for example, by using a sludge skimmer, the pre-treatment system may experience less fouling than typical pre-treatment systems and may require less frequent cleanings.

In accordance with some embodiments, the improved desalination plant may allow operation of desalination plants and the production of potable water from seawater in locations not previously suitable for desalination processes. Because desalination processes are sensitive to feeds having high TSS, the location of desalination plants is often dictated by the concentration of TSS in seawater at a given location. Traditional desalination plants must often be situated in a geographic location where the seawater to be treated contains a low concentration of TSS. The improved desalination plant in accordance with some embodiments may be capable of removing up to about 250 mg/L TSS at a loading rate of more than about 25 gpm/ft^2 of seawater prior to contacting the seawater with downstream desalination units. The DAF pre-treatment system of the improved desalination plant may be capable of removing a higher concentration of TSS from a throughput of seawater than traditional pre-treatment systems and may thus advantageously allow for the location of improved desalination plants where traditional plants are not feasible.

In accordance with some embodiments, the DAF pre-treatment system of the improved desalination plant may be capable of removing marine larvae from seawater prior to contacting the seawater with downstream unit operations. Marine larvae present a serious obstacle to efficient desalination. While mollusks and other invertebrates may be rejected from the seawater by an initial screen unit, marine larvae typically pass through traditional pre-treatment systems and often adhere to and thrive in the plumbing of desalination plants. The larvae may develop and cause severe obstructions and blockages in conduits. The desalination system may need to be cleaned with lethal doses of cleaning agents, for example, chemicals such as chlorine, to prevent larvae evolution and blockages. Chemical dosing typically requires additional equipment and chemical costs that increase the cost of desalination. Additionally, membranes used in desalination processes, for example, reverse osmosis membranes, may be extremely sensitive to cleaning agents, such as chlorine, and residual amounts of chlorine may damage the membrane and reduce its usable lifespan. Cleaning agents dosed to the system must typically therefore be removed upstream of the desalinating units. Removing chemical cleaning agents typically requires additional equipment and operating expense. In accordance with some embodiments, the DAF pre-

treatment system may advantageously remove marine larvae from the seawater, eliminating the need to dose and subsequently remove cleaning agents from the system.

In some embodiments, a contact chamber of a DAF unit comprises at least one baffle. Referring to the embodiment of DAF unit 10 in FIG. 7, contact chamber 25 comprises a plurality of baffles 30 that extend from the walls of contact chamber 25. The baffles may extend from any one or more of the upper, lower, or side walls of contact chamber 25. The baffles may be planar plates that are substantially parallel to the floor of contact chamber 25, or may be constructed and arranged to extend from the upper, lower, or side walls of the contact chamber at an acute or obtuse angle. The baffles may include planar or bended plates that extend from any one or more of the upper, lower, or side walls of contact chamber 25. In accordance with some embodiments and referring specifically to FIG. 7, planar baffles 30 may be vertically interleaved, arranged to alternately extend from opposite side walls of contact chamber 25 along a vertical direction. Baffles 30 may also be horizontally interleaved, arranged to alternately extend from the top and bottom walls of contact chamber 25 along a horizontal direction. One or more of baffles 30 may horizontally or vertically overlap another one or more of baffles 30. Baffles 30 may be constructed and arranged such that they direct treatment water in a serpentine flow path through the contact chamber 25. Baffles 30 inside contact chamber 25 may restrict the flow of micro-bubbles and floc particles, which may cause the rate of collisions between bubbles and floc particles to increase, thereby increasing the binding of bubbles with floc particles. Baffles 30 may also increase a flow path of fluid though the contact chamber, providing more time for micro-bubbles and floc particle to come into contact with one another. The baffles 30 may consequently enable DAF unit 10 to operate at greater loading rates as compared to a comparable DAF unit without baffles 30 in a contact chamber, which may increase the amount and purity of treated water 60 produced from DAF unit 10 including baffles 30 as compared to a comparable DAF unit without baffles 30. Baffles 30 may be constructed of material that facilitates separation of contaminants from fluid flowing through the contact chamber. Contaminants may adhere to baffles 30 for a time sufficient for micro-bubbles to contact the contaminants and facilitate flotation of the contaminants, which may increase the purity of the treated water.

In accordance with some embodiments and referring to the embodiment of DAF unit 10 in FIG. 7, sludge may accumulate across zone 55 of DAF unit 10 between contact chamber wall 15 and flotation chamber divider 75, as indicated by the dotted lines.

Treatment water downstream of flotation chamber divider 75 may have the same purity as treated water 60. In some embodiments, a skimming device may operate to intermittently, or continuously, remove accumulated sludge from zone 55. In accordance with other embodiments, accumulated sludge may be removed from the surface of a treatment water by directing the accumulated sludge into sludge chamber 70.

DAF unit 10 may comprise a sludge recycle. Sludge may be pumped directly from DAF 10 by conduit 40. Conduit 40 may extend into the sludge mat that accumulates in zone 55, and conduit 40 may introduce sludge into conduit 42 using, for example, pump 80 configured to facilitate the transport of sludge. In some embodiments, conduit 40 may extend into sludge accumulation chamber 70. In accordance with other embodiments, sludge may be skimmed from the flotation zone by a skimmer and then introduced into either of conduit 40 or conduit 42. Conduits 40 and 42 may be positioned above flotation chamber 35, although the position of the conduits is not critical and conduits 40 and 42 may be located beside, within, or beneath the flotation chamber 35. Conduit 42 may introduce recycled sludge from zone 55 into feed 45, such that the feed entering the DAF unit comprises a treatment water, flocculant, and sludge as floc. The amount of sludge recycled may depend on the turbidity of the treatment water and/or the loading rate of the DAF system. In some embodiments, the turbidity of the sludge and treatment water entering the DAF may be in the range of from about 50 NTU to 150 NTU. The sludge recycle of DAF unit 10 may increase bubble-floc collisions and allow DAF 10 to operate at higher loading rates. Particles of sludge may act as "seeds" which contaminants may attach to and form floc particles. The sludge recycle may thus advantageously increase the amount and purity of treated water 60.

In some embodiments, the purity of treated water 60 may be enhanced by treatment with a flotation sub-system within the DAF unit. The flotation sub-system may comprise baffles, planar plates, bent plates, slotted plates, inclined plate settlers, lamella plate settlers, tube settlers, or any other module capable of further removing contaminants from the treatment water. Referring to FIG. 7, flotation chamber 35 of DAF unit 10 comprises tube settlers 65. Tube settlers 65 may comprise multiple tubular channels which combine to form a surface above the floor of flotation chamber 35. The tubular channels may be sloped at an angle and positioned adjacent to one another to form corrugated sheets. The tubular channels may be sloped at, for example a 45° angle or a 60° angle relative to horizontal, although in some embodiments, the tubular channels may be sloped at greater or lesser angles than these examples. Tube settlers 65 may comprise a plurality of such corrugated sheets that may be

adjacent to one another to form a module of desired height, length, and width. Tube settlers 65 may be constructed of resilient, self-supporting, resin material, such as acrylonitrile butadiene styrene or polyvinyl chloride, or may be constructed from a metal such as stainless steel, or from any other suitable material. Tube settlers 65 may be constructed and arranged to have an area less than or equal to that of that of walls of flotation chamber 35. Tube settlers 65 may occupy substantially the entire volume of flotation chamber 35 or any fraction thereof. In some embodiments, tube settlers 65 may extend from contact chamber wall 25 to flotation chamber divider 75. As treatment water flows to an effluent outlet of DAF unit 10, treatment water passes through tube settlers 65. Tube settlers 65 may increase the retention time and/or restrict the flow of floc particles and micro-bubbles within the flotation chamber, providing for a greater chance of collision between the floc particles and micro-bubbles. In some embodiments, tube settlers 65 restrict effluent flow which results in a circular or vortex flow pattern inside the flotation chamber. The modified flow pattern increases product water purity by increasing the probability that contaminant particles will adhere to existing sludge and separate out from the treatment water.

In accordance with some embodiments, a DAF unit may comprise a flotation raised floor that acts as a flotation sub-system. As indicated generally in FIG. 8, a DAF unit 20 may have a slotted raised floor 85. The slotted raised floor may contain apertures, for example, slots 2 that facilitate the reduction or prevention of any remaining contaminant particles and/or micro-bubbles within the flotation chamber from exiting in the treated water. The slotted raised floor may also increase the retention time and/or restrict the flow of floc particles and/or micro-bubbles within the flotation chamber, providing for a greater chance of collision between the floc particles and micro-bubbles. The slotted raised floor may thus improve the separation efficiency of the DAF unit.

Referring also to FIGS. 9A and 9B, slotted raised floor 85 may comprise floor plate 1. Plate 1 may lie generally parallel to the flotation chamber floor or in some embodiments may be angled with respect to a wall of the flotation chamber to which it is attached or with respect to the flotation chamber floor. Plate 1 may be planar, curved, undulated, and/or may have one or more portions formed at an angle relative to one or more other portions. Plate 1 may have one or more slots or apertures 2 that allow a treatment water to pass through the raised floor. After a treatment water passes through the raised floor, treated water 60 may be collected at an outlet in fluid communication with the flotation chamber. The collective area of apertures 2 may be equal to the cross-sectional area of an outlet and/or conduit that collects

treated water 60. Plate 1 may provide sufficient resistance to the flow of treatment water out of DAF unit 20 such that all, or substantially all, remaining contaminant particles are contacted with and adhere to micro-bubbles, which may cause all, or substantially all, of the remaining contaminant particles to float upward through the flotation chamber and separate out of the treatment water.

Slotted raised floor 85 may include one or more inclined plates 3 positioned below plate 1 that provide further resistance to the flow of treatment water. The resistance to the flow of treatment water out of DAF unit 20 may cause circular or vortex flow within the flotation chamber. The modified flow may increase the retention time of treatment water in the DAF unit and generally facilitate the contact of contaminant particles with micro-bubbles. Inclined plates 3 may thus facilitate improved separation efficiency. Inclined plates 3 may be mechanically connected to plate 1 or may be separately supported in the flotation chamber. Inclined plates 3 may also direct the flow path of treatment water, causing resistance to the flow of treatment water out of DAF unit 10. Treatment water may pass through the slots in slotted plate and then flow down and along inclined plates 3. Inclined plates 3 may be inclined at an angle relative to plate 1, for example, at an angle of 45° or 60°, although the angle of inclination of inclined plates may be greater or lesser than these examples. Inclined plates 3 may be planar, curved, undulated, and/or may have one or more portions formed at an angle relative to one or more other portions, as is shown in FIG. 10A. Inclined plates 3 may be formed of contiguous sheets of material or may include one or more apertures.

FIG. 10A shows an additional slotted raised floor design in accordance with aspects and embodiments of the present invention. FIGS. 10B and 10C show additional slotted raised floor configurations comprising at least one slotted plate and a plurality of inclined plates and flow paths that may be used in a DAF unit to increase separation efficiency. Additional slotted and inclined plates may improve separation efficiency by providing more resistance to the flow of treatment water out of DAF unit 10 and by advantageously modifying the flow path of treatment water. Additional slotted plates and inclined plates may enhance separation efficiency by facilitating further contact between contaminants and micro-bubbles and separation of the contaminants out of the treatment water by flotation.

In some embodiments one or more plates 1 and/or inclined plates 3 may be positioned above or below one or more other plates 1 and/or inclined plates 3. For example, in FIG. 10A, raised floor 70 includes plate 1 and inclined plates 3 positioned below plate 1. The lower portion of the inclined plates is bent relative to the upper plate such that the lower

portion of the inclined plates is approximately parallel with the lower portion of the side walls of the flotation chamber. Now referring to FIG. 10B, inclined plates 3 are positioned between a stack of plates 1. The flow path of a treatment water 45 is shown by the dotted line. Treatment water 45 passes through slots in plate 1, flows down inclined plates 3, then passes through the slots of a second plate 1. FIG. 10C shows a slotted raised floor configuration comprising a first plate 1 positioned above a set of inclined plates 3, a second plate 1 and second set of inclined plates 3 positioned and stacked below the first set of inclined plates, and a third plate 1 positioned below the second set of inclined plates. The flow path of a treatment water 45 is represented by the dotted line. Treatment water 45 flows through the slots of a first plate 1 and down and along a set of inclined plates 3. The treatment water then passes through the slots of the second plate 1, and flows down an additional set of inclined plates. The treatment water then flows through the slots of a third plate 1. When multiple stacks of plates 1 and inclined plates 3 are present, one or more sets of inclined plates 3 may be parallel with or vertically or horizontally angled at any desired angle relative to another of the sets of inclined plates 3. For example, in a configuration with two plates 1, slots 2 in one of plates 1 may be angled at, for example, about a 90° angle relative to the slots in the other plate 1. Similarly, where multiple stacks of inclined plates 3 are present, plates 3 in one layer may have a widthwise axis (an axis parallel to the slots 2 as shown in FIG. 10A) that is rotated, for example, by about 90° relative to inclined plates 3 in another layer.

In accordance with some embodiments of the present invention, a flotation sub-system may comprise a plate having a single aperture. Referring to FIG. 11, flotation sub-system 90 comprises a plate 4 including aperture 5. Plate 4 extends from mixing chamber wall 25 to flotation chamber divider 75 to define a raised floor above the floor of flotation chamber 35. Plate 4 may be planar, curved, undulated, and/or may have one or more portions formed at an angle relative to one or more other portions. Referring to FIG. 12A, plate 4 has circular aperture 5 positioned at about the center of plate 4, equidistance from both the mixing chamber wall 25 and the flotation chamber divider 75. In other embodiments, aperture 5 may have other geometries and other positions relative to mixing chamber wall 25 and flotation chamber divider 75. Referring to FIG. 12B, aperture 5 comprises a slit positioned proximal to mixing chamber wall 25. The area of aperture 5 may be sized in relation to the cross-sectional area of effluent outlet 6 to allow a throughput of treatment water through aperture 5 proportional to the throughput of treated water through effluent

outlet 6. Aperture 5 may have a cross-sectional area greater or less than the cross-sectional area of outlet 6, and in some embodiments, the cross-sectional area of aperture 5 may be equal to the cross sectional area of outlet 6. For example, if effluent outlet 6 is cylindrical with a diameter of four inches, aperture 5 may be cylindrical with a diameter of four inches or, aperture 5 may be a slit having an area equal to 4π, for example, a slit approximately 1 inch (2.54 cm) wide by 12.5 inches (31.75 cm) long. Flotation sub-system 90 may advantageously restrict treatment water flow through flotation chamber 35. Flotation sub-system 90 may cause circular, or vortex flow in the flotation chamber, and may increase the retention time of treatment water in DAF unit 20. As a result of increased retention time and modified flow, more contaminants may be contacted by micro-bubbles and float, and separate out of the treatment water. Flotation sub-system 90 may thus increase the separation efficiency of DAF unit 20.

In accordance with embodiments of the present invention, a DAF system may operate efficiently without a mixer and/or flocculation chamber. As shown in FIG. 1 and in FIGS. 2-7, DAF processes typically involve mixing of flocculants with a treatment water to create coagulated flocs capable of adhering to micro-bubbles. In accordance with some embodiments, for example, wherein the floc formation times in the feed are low, the flocculation chamber may be downsized or omitted entirely by modifying the feed piping. Flocculation may occur within the modified feed piping and before the treatment water enters the DAF system. In some configurations, at least two pipes may replace the single pipe, for example, as illustrated in FIGS. 2-5, that provides the feed to the DAF system.

As shown in the embodiment of DAF system 600 of FIG. 13, treatment water 105 is mixed with one or more flocculants from a source of flocculant 110 by in-line mixing in in-line mixing unit 215. Conduit 620 feeds water and flocculants to dual pipe system 685. Air dissolving pump 265 receives treated water 130 via conduit 235 and atmospheric air 280 and produces gasified fluid containing dissolved air. The gasified fluid containing dissolved air is received by conduit 625 and fed to dual pipe system 685. The floc, treatment water, and gasified fluid containing dissolved air mix within pipe system 685 and enter the DAF unit 660 via conduit 690 as coagulated floc adhered to micro-bubbles. The micro-bubbles rise to the surface of the DAF unit and treated water 130 is collected from the unit. DAF unit 660 comprises contact chamber 660B and flotation chamber 660C. Because the feed entering the DAF unit contains freshly coagulated floc, no flocculation chamber is needed and omitting it from the system does not adversely impact separation efficiency.

Pipe configuration 685 may be a dual pipe system which may be constructed and arranged in one of multiple configurations, as illustrated in FIGS. 14A-14C, wherein the term "pipe," as used herein, may be a conduit of any cross-section and is not limited to tubular pipes. An embodiment of a dual pipe system may be advantageous in systems with feed streams wherein the floc formation times are low. As shown in FIG. 14A, floc-containing treatment water 620 enters feed containing pipe 685A, where "feed" refers to the floc-containing treatment water. Feed pipe 685A receives gasified fluid containing dissolved air from pipe 685B. Pipe 685B may be configured to provide a retention time sufficient to allow for the gas to more completely dissolve in the gasified fluid. Pipe 685B receives gasified fluid containing dissolved air from conduit 625. The cross-sectional area of pipe 685A may be the same or greater than conduit 625 such that the pressure in pipe 685B is less than that of conduit 625, and micro-bubbles may be present or form in pipe 685B. Pipe 685B may have a pressure release mechanism, for example, a globe valve, capable of reducing the fluid pressure and causing micro-bubbles to form in pipe 685B. Contact and mixing of micro-bubbles and floc occurs at a portion of pipe 685A downstream of where the gasified fluid containing dissolved air is introduced, as shown by the dotted line. The floc, treatment water, and micro-bubbles may mix to form freshly coagulated floc in pipe 685A. The flocculated treatment water containing the freshly coagulated floc may be fed to the DAF unit through conduit 690.

Referring to FIGS. 14B and 14C, pipe system 685 may comprise concentric pipes 685A and 685B. Referring to FIG. 14B, feed pipe 685A surrounds dissolved air pipe 685B. Pipe 685A has a cross-sectional area along at least a portion of its length that is greater than the cross-sectional area of pipe 685B. Pipe 685B receives liquid containing dissolved air from conduit 625. The cross-sectional area of pipe 685B may be equal to or greater than that of conduit 625, but less than the cross-sectional area of at least a portion of pipe 685A. The pressure of the gasified fluid containing the dissolved air in pipe 685B may be adjusted by a pressure release mechanism, for example, a globe valve. The pressure in pipe 685B may be reduced to allow micro-bubbles to form the gasified fluid. The feed in pipe 685A and micro-bubbles from pipe 685B mix in a portion of pipe 685A downstream of pipe 685B, as shown by the dotted line. The floc, treatment water, and micro-bubbles may mix to form freshly coagulated floc. The cross-sectional area of the contact portion of pipe 685A may vary from that of the cross-sectional area of the portion pipe 685A that contains pipe 685B. The

flocculated treatment water containing the freshly coagulated floc may be fed to the DAF unit by conduit 690.

Referring to FIG. 14C, dissolved air pipe 685B may surround feed pipe 685A. Pipe 685B has a cross-sectional along at least a portion of, or along its entirety, that is greater than the cross-sectional area of pipe 685A. Pipe 685B receives gasified fluid containing dissolved air from conduit 625. The cross-sectional area of pipe 685B may be equal to or greater than that of conduit 625, but greater than the cross-sectional area of at least a portion of pipe 685A. The pressure of the gasified fluid containing the dissolved air in pipe 685B may be adjusted by a pressure release mechanism, for example, a globe valve. The pressure in pipe 685B may be reduced so as to allow micro-bubbles to form in the liquid. The floc, treatment water, and micro-bubbles may mix in a portion of pipe 685B downstream of pipe 685A, as shown by the dotted line, and form freshly coagulated floc. The cross-sectional area of the contact portion of pipe 685B may be larger or smaller than the cross-sectional area of the portion of pipe 685B that contains pipe 685A. The flocculated treatment water containing the freshly coagulated floc may be fed to the DAF unit through conduit 690.

In accordance with some embodiments of DAF systems including dual pipe mixing systems as described above, the flocculation chamber may be either downsized or omitted from the system without negatively impacting system performance. Other chambers of the DAF may also be capable of being downsized without negatively impacting system performance. The modified pipe configuration advantageously allows flocculation to occur before a feed enters the DAF. The omission of the flocculation chamber may advantageously reduce the DAF system energy requirement. The footprint of the DAF system may also be reduced.

In some embodiments a controller may facilitate or regulate the operating parameters of the treatment system. For example, a controller may be configured to adjust a rate of supply of treatment water, a rate and/or amount of gasified fluid supplied to a DAF unit, an amount or rate of flocculant supplied, a rate of removal of sludge from the flotation zone of a DAF unit, an amount of sludge recycle, and/or other parameters associated with any of the unit operations of the treatment system.

The controller may respond to signals from timers (not shown) and/or sensors (not shown) positioned at any particular location within the treatment system. For example, one or more sensors may monitor one or more operational parameters such as pressure, temperature, one or more characteristics of the treatment water, feed, and/or one or more

characteristics of effluent from the DAF system or a effluent from a desalination system comprising a DAF system. Similarly, a sensor disposed in or otherwise positioned within a sludge recycle stream may provide an indication of a flow rate thereof. The controller may respond to signals provided by the sensor by generating a control signal causing an increase or decrease in the sludge recycle flow rate. The target recycle flow rate of the sludge may be dependent on an operating parameter of the treatment system. For example, the target recycle flow rate may be a multiple of, or a fraction of, the influent flow rate of the incoming treatment water. In some embodiments, the sludge recycle rate may be adjusted to achieve one or more target characteristics of the treated water. Other control schemes may involve varying the flow rates of gasified fluid into the DAF unit or of flocculants or other chemical additives into the treatment water.

The system and controller of one or more embodiments of the invention provide a versatile unit having multiple modes of operation, which can respond to multiple inputs to increase the efficiency of the water treatment system.

The controller may be implemented using one or more computer systems which may be, for example, a general-purpose computer such as those based on an Intel PENTIUM® or Core® processor, a Motorola PowerPC® processor, a Hewlett-Packard PA-RISC® processor, a Sun UltraSPARC® processor, or any other type of processor or combination thereof. Alternatively, the computer system may include specially-programmed, special-purpose hardware, for example, an application-specific integrated circuit (ASIC) or controllers intended for water treatment systems.

The computer 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 memory may be used for storing programs and data during operation of the system. For example, the memory may be used for storing historical data relating to the parameters over a period of time, as well as 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 memory wherein it can then be executed by one or more processors. Such programming code may be written in any of a plurality of programming languages, for example, Java, Visual Basic, C, C#, or C++, Fortran, Pascal, Eiffel, Basic, or any of a variety of combinations thereof.

Components of the computer 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 a network, and/or between components that reside on separate discrete devices. The interconnection mechanism may enable communication of, for example, data and/or instructions, to be exchanged between components of the system.

The computer system can also include one or more input devices, for example, a keyboard, mouse, trackball, microphone, touch screen, and other man-machine interface devices as well as one or more output devices, for example, a printing device, display screen, or speaker. In addition, the computer system may contain one or more interfaces that can connect the computer system to a communication network, in addition or as an alternative to the network that may be formed by one or more of the components of the system.

According to one or more embodiments of the invention, the one or more input devices may include sensors for measuring any one or more parameters of any of the embodiments of systems disclosed herein and/or components thereof. Alternatively, the sensors, metering valves and/or pumps, or all of these components may be connected to a communication network that is operatively coupled to the computer system. Any one or more of the above may be coupled to another computer system or component to communicate with the computer system over one or more communication networks. Such a configuration permits any sensor or signal-generating device to be located at a significant distance from the computer system and/or allow any sensor to be located at a significant distance from any subsystem and/or the controller, while still providing data therebetween. Such communication mechanisms may be affected by utilizing any suitable technique including but not limited to those utilizing wireless protocols.

The controller can include one or more 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 medium may, for example, be a disk or flash memory. In typical operation, the one or more processors 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 that allows for faster access to the information by the one or more processors than does medium.

Although the computer system is described by way of example as one type of computer system upon which various aspects of the invention may be practiced, it should be appreciated that the invention is not limited to being implemented in software, or on the

computer system as exemplarily shown. Indeed, rather than implemented on, for example, a general purpose computer system, the controller, or components or subsections thereof, may alternatively be implemented as a dedicated system or as a dedicated programmable logic controller (PLC) or in a distributed control system. Further, it should be appreciated that one or more features or aspects of the invention may be implemented in software, hardware or firmware, or any combination thereof. For example, one or more segments of an algorithm executable by the controller can be performed in separate computers, which can be in communication with one another through one or more networks.

Feed back control may be utilized in some embodiments of the control system. One or more sensors or meters for measuring any one or more of chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), total dissolved solids (TDS), dissolved organic carbon (DOC), total organic carbon (TOC), NTU, pH, salinity and/or other parameter(s) of interest may be utilized to measure one or more characteristics of effluent leaving the DAF unit and supply the controller with an information regarding these one or more characteristics. When any of measured characteristics of the effluent is outside of a desired range, the controller may react by causing the system to adjust various operating parameters, for example, residence time in any of the unit operations, an amount of sludge recycle, an amount of gasified fluid supplied to the DAF, a rate of inflow of treatment water (a loading rate of the system), an amount of flocculent or other chemical supplied to the treatment water, or any other desired operating parameter of the system.

Feed forward control may be utilized in some embodiments of the control system. One or more sensors or meters for measuring any one or more of chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), total dissolved solids (TDS), dissolved organic carbon (DOC), total organic carbon (TOC), NTU, pH, salinity and/or other parameter(s) of interest may be utilized to measure one or more characteristics of treatment water entering the system (or at any other location within the system) and supply the controller with information regarding these one or more parameters. Depending on the levels of any one of the measured parameters of the treatment water, the controller may cause the system to adjust various operating parameters, for example, residence time in any of the unit operations, an amount of sludge recycle, an amount of gasified fluid supplied to the DAF, a rate of inflow of treatment water (a loading rate of the system), an amount of flocculent or other chemical supplied to the treatment water, or any other desired operating parameter of the system.

Further aspects of the invention may involve or be directed to computer-readable media, or providing computer-readable media, that facilitates the various features of the treatment approaches described herein.

For example, the computer-readable media can comprise instructions implementable on a computer system or a controller that performs a method of treating water in a water treatment system in accordance with any one or more of the embodiments described above.

In other configurations, the computer-readable media can comprise instructions implementable on a computer system or a controller that performs a method of facilitating the removal of solids from a treatment water. In accordance with some embodiments, the treatment water may comprise a source of seawater. The method may comprise introducing the treatment water into an inlet of a DAF unit. The DAF unit may include a contact chamber in fluid communication downstream of the inlet, and a flotation chamber in fluid communication downstream of the contact chamber. The method may further comprise producing a pressurized gasified fluid in an air dissolving pump, flowing the pressurized gasified fluid from an outlet of the air dissolving pump to an inlet of a relaxation pipe and introducing the pressurized gasified fluid from the relaxation pipe into the treatment water in the contact chamber, removing solids from a surface of the treatment water in the flotation chamber, forming a treated water, and collecting the treated water from an outlet of the dissolved air flotation unit. The method may further comprise recycling the solids removed in the flotation chamber into a flocculation chamber in fluid communication upstream of the contact chamber and downstream of the inlet. The method may further comprise directing the treatment water in a serpentine flow path about a plurality of interleaved baffles in the flocculation chamber. The method may further comprise passing the treated water over a plurality of inclined plates positioned below a raised floor of the flotation chamber. The method may further comprise filtering the treated water through a membrane filtration unit downstream of the dissolved air flotation unit.

The modifications and enhancements of the present invention may be used individually, or in combination. Existing desalination systems and existing DAF systems may be retrofitted by providing and implementing the modifications discussed herein in accordance with one or more embodiments.

The function and advantages of these and other embodiments can be further understood from the examples below, which illustrate the benefits and/or advantages of the

one or more systems, methods, and techniques but do not exemplify the full scope of the invention.

EXAMPLE 1

This example describes an improved DAF system in accordance with one or more embodiments that successfully treated water having an influent turbidity of 400 NTU to a purity of less than 1 NTU. Conventional DAF systems typically can only treat water having influent turbidities of less than about 25 NTU. Further, the improved DAF system successfully operated at a loading rate of 25 gpm/ft^2, as compared to conventional DAF systems which typically can only operate at loading rates of up to 14 gpm/ft^2, and the improved DAF system removed TOC at removal rates higher than typically possible in conventional DAF systems. The improved DAF system successfully used a bubble release mechanism that did not require nozzles, as compared to conventional DAF bubble release mechanisms that typically require a network of nozzles that are often prone to clogging and can interrupt operations. The improved system thus advantageously enhanced the ease in which the system could be operated. The improved system also operated using less energy per unit water treated than conventional DAF units.

A reservoir was selected as the study site for the improved DAF system in accordance with one or more embodiments. The reservoir water was rich in algae and organic matter. The turbidity of the water was in the range of from about 30 NTU to about 500 NTU, having an average turbidity in the range of from about 50 NTU to about 150 NTU. The reservoir water had an alkalinity of about 35-45 mg/L, contained 20-200 mg/L TSS, had a pH in a range of about 7 to about 10, contained about 4.5 mg/L to about 6.5 mg/L DOC, had an algae count of about 55,000 cells/mL to about 192,000 cells/mL, and had an average temperature of 30-33° C. The goal of the study was to operate the improved DAF system at loading rates higher than typically possible with conventional DAF systems and to do so while maintaining effluent turbidities of less than 1 NTU.

FIG 2. shows the process flow diagram of the improved DAF system used in the study. The study further comprised a DAF unit including a raised flotation floor, as illustrated, for example, in FIG. 11. The treatment water 105 consisted of reservoir water. The reservoir water was treated by DAF system 200 comprising air dissolving pump 265. Ferric chloride flocculant was mixed in-line with reservoir treatment water 105 at in-line mixing unit 215. The floc-containing treatment water was introduced into DAF unit 260

through conduit 220. It was then flocculated in flocculation chamber 260A to form freshly coagulated floc. Gasified fluid containing dissolved air, produced by air dissolving pump 265, was introduced into the DAF unit by conduit 225. Conduit 225 was constructed and arranged to introduce the gasified liquid containing dissolved air at gasified fluid inlet 275. The treatment water containing freshly coagulated floc and air micro-bubbles mixed in contact chamber 260B. The micro-bubbles adhered to the floc and caused the floc to float to the surface of the treatment liquid. Treated water 130 having a turbidity of less than 1 NTU was collected from the flotation chamber 260C. Data was collected over a 90 day period. FIG. 15 shows the treatment water influent turbidity, the treated water effluent turbidity, and the DAF system loading rates as a function of time. Effluent turbidity was consistently less than 1 NTU, regardless of loading rate. The influent presented as a dark green liquid with little translucence. In contrast, the effluent was clear and colorless. Table 1 summarizes the solids, organic matter, and algae removal at different loading rates.

Table 1

Loading Rate		TSS, mg/L			DOC, mg/L			TOC, mg/L			Algae Count, cells/mL		
m/hr	gpm/ft2	INF	EFF	Removal	INF	EFF	Removal	INF	EFF	Removal	INF	EFF	Removal
29	12	118	1.0	99.2%	5.8	1.9	67%	NA	NA	NA	192,354	31	99.98%
37	15	98	1.0	99.0%	4.8	1.9	61%	7.9	1.7	79%	55,122	19	99.97%
42	17	58	0.3	99.6%	5.0	1.8	64%	NA	NA	NA	NA	NA	NA
49	20	42	1.6	96.2%	5.5	2.4	57%	4.7	2.0	58%	36,801	333	99.10%
56	23	36	1.2	96.8%	5.7	2.5	57%	5.4	1.3	75%	121,710	58	99.95%
61	25	38	3.0	92.0%	4.3	2.4	46%	4.1	1.7	60%	186,840	770	99.59%

The average removal efficiency of total suspended solids was about 97%, the average removal efficiency of dissolved organic carbon was about 59%, the average removal efficiency of total organic carbon was about 68%, and the average removal efficiency of algae was greater than about 99%.

Table 2 summarizes the solids and dissolved organic carbon removal verses energy consumption.

Table 2

Loading Rate		kg of Solids & DOC Removed per Day		kWh/kg Solids Removed	Energy per Unit Volume of Water Treated
m/hr	gpm/ft^2	Solids	DOC		kWh/m^3
29	12	137	4.6	0.88	0.10
37	15	142	4.3	0.85	0.08
42	17	96	5.3	1.21	0.07
49	20	60	7.1	1.98	0.06
56	23	79	7.2	1.33	0.05
61	25	84	4.9	1.17	0.04

The results of the study demonstrated that the improved DAF system successfully operated at loading rates of 25 gpm/ft^2. This result indicated that the system was more than 40% more efficient than typical conventional DAF units. Additionally, conventional DAF systems are typically only capable of removing 50% TOC from an influent containing 3 mg/L TOC. The results indicated that the improved DAF system was capable of removing over 68% of TOC while operating at higher flow rates than typically possible in conventional DAF systems, and while treating water with over 5 mg/L TOC. The improved system operated at lower energies per kg of solids removed than conventional DAF systems, and at optimal conditions, consumed less than about 0.04 kWh/m^3. The improved system also advantageously had a smaller footprint than typical conventional DAF systems due to the compact size of the air dissolving pump as compared to the bubble distribution mechanisms of conventional DAF systems.

EXAMPLE 2

The system of Example 1 was then tested for its ability to remove heavier organic contaminants from a treatment water, such as sand. River bed sand was dosed to the reservoir water to mimic river water collected from a flowing water source. The sand-containing treatment water was treated by the system of Example 1. The goal of the study was to treat the sand-containing treatment water, which had a higher TSS than typically

capable of treatment with a conventional DAF, with the improved DAF system, to treat the sand-containing treatment water in the improved DAF system at higher loading rates than are typically possible with conventional DAF systems, and to do so while maintaining an effluent turbidity of less than 1 NTU. The system successfully operated at loading rates of nearly 1.5 times the maximum loading rates of typical conventional DAF systems. A further objective of the study was to determine the effect of different flocculants on system performance.

In a first trial, ferric (ferric chloride) was used as the flocculant. Data on the treatment water influent turbidity, the treated water effluent turbidity, and system loading rates was collected over the course of a 30 day period. This data is presented in FIG. 16. The treated water effluent turbidity was consistently less than 1 NTU, regardless of loading rate.

Tables 3 and 4 below present data on the different removal rates for TSS, VSS, River bed send (calculated by TSS-VSS), DOC, TOC, and algae count using ferric as a flocculant.

Table 3

Loading Rate		TSS, mg/L			VSS, mg/L			TSS - VSS (River Bed Sand)		
m/hr	gpm/ft2	INF	EFF	Removal	INF	EFF	Removal	INF	EFF	Removal
20	8	43	0.0	100.0%	35.5	NA	NA	8	NA	NA
24	10	185	1.8	99.1%	175.5	1.8	99%	10	0	100.0%
29	12	52	0.3	99.5%	40	0.3	99%	12	0	100.0%
37	15	97	0.6	99.4%	78.0	0.6	99%	19	0	100.0%
44	18	244	4.9	98.0%	111.3	3.4	97%	133	1.5	98.9%
49	20	96	3.3	96.6%	54.0	2.5	95%	42	0.8	98.2%

Table 4

Loading Rate		DOC, mg/L			TOC, mg/L			Algae Count, cells/mL		
m/hr	gpm/ft2	INF	EFF	Removal	INF	EFF	Removal	INF	EFF	Removal
20	8	5.5	2.9	48%	3.4	1.25	63%	80,597	0	100.0%
24	10	5.6	2.5	56%	11.6	1.5	87%	1,189,711	2,505	99.8%
29	12	4.8	2.4	51%	3.9	1.44	63%	117689	231	99.8%
37	15	5.0	2.5	50%	10.4	1.7	84%	285,860	606	99.8%
44	18	4.8	2.2	54%	7.8	1.8	77%	523,550	274	99.95%
49	20	5.0	2.1	57%	6.4	1.6	75%	167,310	30	99.98%

The average removal efficiency of total suspended solids was about 99%, the average removal efficiency of dissolved organic carbon was about 53%, the average removal efficiency of total organic carbon was about 75%, and the average removal efficiency of algae was greater than about 99%.

The results demonstrated that the improved DAF system using ferric flocculant successfully removed about 99% of the sand and produced treated water having the goal purity at loading rates of 20 gpm/ft^2. The portion of total suspended solids attributable to the river bed sand during the study averaged 43 mg/L, however the system successfully removed about 99% of 133 mg/L of sand at a loading rate of 18 gpm/ft^2 from a treatment watering having a TSS of 244 mg/L. Conventional DAF systems are only capable of purifying water to 1 NTU at loading rates of less than about 14 gpm/ft^2 and are only capable of removing about 20 mg/L TSS to about 30 mg/L TSS. The results of the study demonstrated that the improved DAF system successfully removed about 250% more TSS than are typically capable of being removed by conventional DAF systems, and that the improved DAF system successfully removed this high amount of TSS while operating at loading rate of about 130% greater than the maximum loading rate typically possible in conventional DAF systems.

In a second trial, alum (aluminum sulphate) was used as the flocculant. Data on the influent turbidity, effluent turbidity, and loading rate was collected over the course of a 45 day period. This data is represented in FIG. 17. The effluent turbidity was consistently less than 1 NTU.

Table 5 summarizes the TSS, DOC, TOC, and algae removal efficiencies with alum at different loading rates.

Table 5

Loading Rate		TSS, mg/L			DOC, mg/L			TOC, mg/L			Algae Count, cells/mL		
m/hr	gpm/ft2	INF	EFF	Removal	INF	EFF	Removal	INF	EFF	Removal	INF	EFF	Removal
34	14	10	0.5	95%	4.5	2.4	46%	5.0	1.3	73%	5,559	134	97.59%
39	16	336	0.0	100%	5.0	2.8	45%	7.7	1.4	81%	2,640,255	0	100.00%
49	20	62	1.0	98%	5.0	3.3	34%	4.4	1.4	70%	487,714	223	98.17%
56	23	19	1.2	94%	4.7	2.8	39%	4.7	1.9	59%	285,006	100	99.96%
59	24	21	1.9	91%	5.0	3.0	41%	4.8	2.3	52%	187,509	151	99.92%

The average removal efficiency of total suspended solids was about 96%, the average removal efficiency of dissolved organic carbon was about 41%, the average removal efficiency of total organic carbon was about 67% and the average removal efficiency of algae was greater than about 97%.

Table 6 compares the performance of the improved DAF system when ferric and alum are used as flocculants.

Table 6

Loading Rate		TSS Removal		DOC Removal		TOC Removal		Algae Removal	
m/hr	gpm/ft2	Ferric	Alum	Ferric	Alum	Ferric	Alum	Ferric	Alum
29	12	99.2%	NA	67%	NA	NA	NA	99.98%	NA
34	14	NA	95%	NA	46%	NA	73%	NA	97.59%
37	15	99.0%	NA	61%	NA	79%	NA	99.97%	NA
39	16	NA	100%	NA	45%	NA	81%	NA	100.00%
42	17	99.6%	NA	64%	NA	NA	NA	NA	NA
49	20	96.2%	98%	57%	34%	58%	70%	99.10%	98.17%
56	23	96.8%	94%	57%	39%	75%	59%	99.95%	99.96%
59	24	NA	91%	NA	41%	NA	52%	NA	99.92%
61	25	92.0%	NA	46%	NA	60%	NA	99.59%	NA

The data demonstrates that total suspended solids removal and algae removal using ferric and alum are comparable, however dissolved organic carbon removal with ferric is consistently higher than with alum. Total organic carbon removal is inconsistent. These results are most likely due to varying dissolved organic content in the treatment water in response to natural fluctuations. Given the lower cost of alum and the similar operating performance of alum in the DAF as compared to ferric, it may be preferable to operate the improved DAF system using alum. The projected percentage in annual cost savings for a 7 MGD water treatment plant using an improved DAF system in accordance with one or more embodiments using alum as opposed to ferric may be about 38%.

It is to be appreciated that embodiments of the systems, apparatuses and methods discussed herein are not limited in application to the details of construction and the arrangement of the apparatus components and system operations as set forth in the above description or illustrated in the accompanying drawings. The apparatus modifications, systems and methods are capable of implementation in other embodiments and of being

practiced or of being carried out in various ways. Examples of specific implementations are provided herein for illustrative purposes only and are not intended to be limiting. In particular, systems, apparatuses and features discussed in connection with any one or more embodiments are not intended to be excluded from a similar role in any other embodiment.

Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. Any references to embodiments or elements or acts of the apparatus and methods herein referred to in the singular may also embrace embodiments including a plurality of these elements, and any references in plural to any embodiment or element or act herein may also embrace embodiments including only a single element. The use herein of "including," "comprising," "having," "containing," "involving," and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Any references to positional or spatial orientation are intended for convenience of description, not to limit the present apparatus and methods or their components.

Having described above several aspects of at least one embodiment, it is to be appreciated that 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 scope of the invention. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is:

CLAIMS

1. A water treatment system comprising:

an air dissolving pump having a pump outlet fluidly coupled to a proximal end of a first fluid conduit;

a relaxation pipe having an inlet fluidly coupled to a distal end of the first fluid conduit and an outlet fluidly coupled to a proximal end of a second fluid conduit, the relaxation pipe having a diameter greater than a diameter of the first fluid conduit and having a diameter greater than a diameter of the second fluid conduit; and

a dissolved air flotation unit having a first inlet fluidly coupled to a distal end of the second fluid conduit.

2. The water treatment system of claim 1, wherein the dissolved air flotation unit further comprises:

a contact chamber having a plurality of contact chamber walls defining an interior volume of the contact chamber; and

a plurality of interleaved baffles, each of the interleaved baffles extending from one of the plurality of contact chamber walls and into the interior volume of the contact chamber.

3. The dissolved air flotation apparatus of claim 2, wherein the dissolved air flotation unit further comprises a flotation chamber including a flotation chamber floor and a raised floor positioned above the flotation chamber floor, the raised floor including at least one aperture.

4. The water treatment system of claim 3, further comprising a sludge recycle system having a recycle system inlet in fluid communication with the flotation chamber and a recycle system outlet in fluid communication with a second inlet of the dissolved air flotation unit, the sludge recycle system configured to direct recycled sludge into the second inlet of the dissolved air flotation unit.

5. The water treatment system of claim 4, further comprising a treatment water inlet and a source of flocculent fluidly coupled to an inlet of a static mixer comprising one or more baffles, the static mixer having an outlet in fluid communication with the second inlet of the dissolved air flotation unit.

6. The water treatment system of claim 5, further comprising a membrane filtration unit having an inlet in fluid communication with an outlet of the dissolved air flotation unit.

7. The water treatment system of claim 1, further comprising:

a fluid delivery sub-system including a gasified fluid delivery conduit positioned within a flocculated feed delivery conduit, the gasified fluid delivery conduit having a gasified fluid delivery inlet being in fluid communication with the pump outlet of the air dissolving pump; and

a mixing conduit having a mixing conduit inlet fluidly coupled to an outlet of the fluid delivery sub-system and a mixing conduit outlet fluidly coupled to an inlet of a contact chamber of the dissolved air flotation unit.

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

a fluid delivery sub-system including a flocculated feed delivery conduit positioned within a gasified fluid delivery conduit, the gasified fluid delivery conduit having a gasified fluid delivery inlet being in fluid communication with the pump outlet of the air dissolving pump; and

a mixing conduit having a mixing conduit inlet fluidly coupled to an outlet of the fluid delivery sub-system and a mixing conduit outlet fluidly coupled to an inlet of a contact chamber of the dissolved air flotation unit.

9. A dissolved air flotation apparatus comprising:

a fluid inlet;

a flocculation chamber in fluid communication downstream of the fluid inlet;

a contact chamber in fluid communication downstream of the flocculation chamber, the contact chamber comprising a plurality of interleaved baffles extending into an interior volume of the contact chamber from walls of the contact chamber;

a gasified fluid inlet positioned below the plurality of baffles and in fluid communication with the contact chamber;

a flotation chamber in fluid communication downstream of the contact chamber; and

an effluent outlet in fluid communication downstream of the flotation chamber.

10. The dissolved air flotation apparatus of claim 9, further comprising:

an air dissolving pump having a pump outlet fluidly coupled to a proximal end of a first fluid conduit; and

a relaxation pipe having an inlet fluidly coupled to a distal end of the first fluid conduit and an outlet fluidly coupled to the gasified fluid inlet through a second fluid conduit, the relaxation pipe having a diameter greater than a diameter of the first fluid conduit and having a diameter greater than a diameter of the second fluid conduit.

11. The dissolved air flotation apparatus of claim 9, further comprising a sludge recycle system having a recycle system inlet in fluid communication with the flotation chamber and a recycle system outlet in fluid communication with the flocculation chamber, the sludge recycle system configured to direct recycled sludge from the flotation chamber into the flocculation chamber.

12. The dissolved air flotation apparatus of claim 9, wherein the flotation chamber further comprises tube settlers positioned proximate a lower portion of the flotation chamber, the tube settlers configured to restrict a flow of fluid from the flotation chamber to the effluent outlet.

13. The dissolved flotation apparatus of claim 9, wherein the flotation chamber further comprises a flotation chamber floor and a raised floor positioned at a distance above the flotation chamber floor, the raised floor including at least one floor plate having including at least one aperture.

14. The dissolved flotation apparatus of claim 13, wherein the raised floor plate is substantially parallel to the flotation chamber floor.

15. The dissolved flotation apparatus of claim 14, wherein the raised floor further comprises a plurality of inclined plates positioned below the at least one floor plate, the plurality of inclined plates each having at least a portion inclined relative to the at least one floor plate.

16. A method of facilitating the removal of contaminants from a treatment water, the method comprising:

introducing the treatment water into a first inlet of a dissolved air flotation unit;

producing a pressurized gasified fluid in an air dissolving pump;

flowing the pressurized gasified fluid from an outlet of the air dissolving pump through a first conduit to an inlet of a relaxation pipe, the relaxation pipe having a diameter greater than a diameter of the first conduit;

flowing the pressurized gasified fluid from an outlet of the relaxation pipe into an inlet of a second conduit, the second conduit having a diameter smaller than the diameter of the relaxation pipe;

flowing the pressurized gasified fluid through an outlet of the second conduit positioned within a contact chamber of the dissolved air flotation unit;

reducing a pressure of the pressurized gasified fluid; and

forming micro-bubbles within the contact chamber.

17. The method of claim 16, further comprising flowing the treatment water through the contact chamber and into a flotation chamber of the dissolved air flotation unit, the micro-bubbles facilitating removal of suspended solids from the treatment water and the formation of a sludge including at least a portion of the removed suspended solids;

removing a portion of the sludge from a surface of the treatment water in the flotation chamber; and

recycling the sludge into a flocculation chamber of the dissolved air flotation unit, the flocculation chamber being in fluid communication upstream of the contact chamber.

18. The method of claim 16, further comprising directing the treatment water in a serpentine flow path about a plurality of interleaved baffles in the contact chamber.

19. The method of claim 16, further comprising passing the treated water over a plurality of inclined plates positioned below a raised floor of the flotation chamber.

20. The method of claim 16, further comprising filtering the treated water through a membrane filtration unit downstream of the dissolved air flotation unit.

21. A method of desalinating seawater, the method comprising:

introducing the seawater into a first inlet of a dissolved air flotation unit, the seawater including a quantity of total suspended solids;

producing a pressurized gasified fluid in an air dissolving pump;

flowing the pressurized gasified fluid from an outlet of the air dissolving pump through a first conduit to an inlet of a relaxation pipe, the relaxation pipe having a diameter greater than a diameter of the first conduit;

flowing the pressurized gasified fluid from an outlet of the relaxation pipe into an inlet of a second conduit, the second conduit having a diameter smaller than the diameter of the relaxation pipe;

flowing the pressurized gasified fluid through an outlet of the second conduit positioned within a contact chamber of the dissolved air flotation unit;

reducing a pressure of the pressurized gasified fluid;

forming micro-bubbles within the contact chamber removing contaminants from the seawater and forming a treated seawater;

discharging the treated seawater out of an outlet of the dissolved air flotation unit; and

directing the treated seawater from the outlet of the dissolved air flotation unit to a downstream desalination unit.

22. The method of claim 21, further comprising discharging a product water having a concentration of about 500 mg/L TDS from the downstream desalination unit.

23. The method of claim 22, wherein the downstream desalination unit comprises an electrically-driven separation apparatus.

24. The method of claim 21, wherein forming the treated seawater comprises removing greater than about 90% of the quantity of total suspend solids from the seawater.

25. A seawater treatment system comprising:

a dissolved air flotation system including:

an air dissolving pump having a pump outlet fluidly coupled to a proximal end of a first fluid conduit;

a relaxation pipe having an inlet fluidly coupled to a distal end of the first fluid conduit and an outlet fluidly coupled to a proximal end of a second fluid conduit, the relaxation pipe having a diameter greater than a diameter of the first fluid conduit and having a diameter greater than a diameter of the second fluid conduit;

a dissolved air flotation unit having a first inlet fluidly coupled to a distal end of the second fluid conduit; and

a desalination unit having an inlet in fluid communication with an outlet of the dissolved air flotation system.

26. The seawater treatment system of claim 25, wherein the desalination unit is an electrically-driven separation apparatus.