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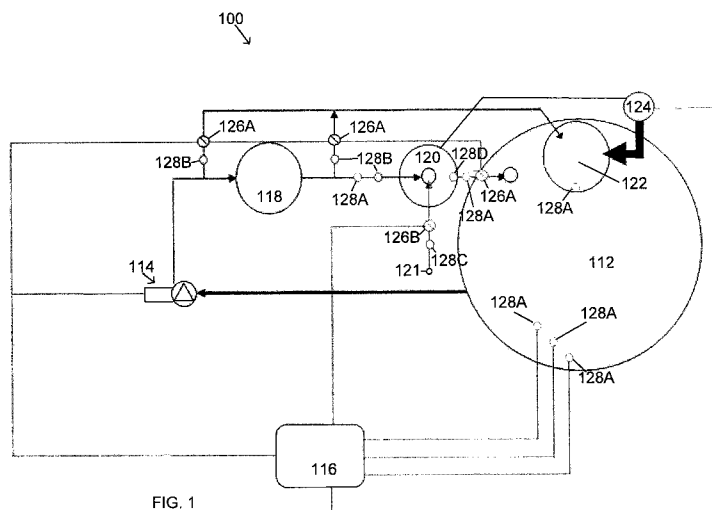


FIG. 1

(57) Abstract: Some embodiments provide a recirculating aquaculture system for aquatic life. The system includes a culture tank, a first sensor configured to measure a current ammonia concentration in the culture tank, a biofilter in fluid communication with the culture tank, a variable speed pump configured to circulate water through the culture tank and the biofilter, and a controller in communication with the first sensor and the variable speed pump. The controller is configured to retrieve a maximum ammonia concentration, retrieve the current ammonia concentration from the first sensor, and compare the current ammonia concentration to the maximum ammonia concentration. The controller is also configured to control the variable speed pump to increase a current water flow rate through the system when the current ammonia concentration is greater than the maximum ammonia concentration.

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## AMMONIA CONTROL SYSTEM FOR AQUACULTURE

## CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of United States Provisional Patent Application No. 61/788,316 filed on March 15, 2013, the entire contents of which is incorporated herein by reference.

## BACKGROUND

[0002] Pumps may be used to recirculate water in aquatic farms, such as recirculating aquaculture systems in which fish and other aquatic life are raised. Recirculating aquaculture systems generally include one or more tanks (*e.g.*, culture tank) to contain the fish, one or more water inlets into the tank(s), and one or more water outlets out of the tank(s). The water outlets are typically in communication with an inlet of a variable speed pump. The variable speed pump generally propels water through a filter and back into the tank through the water inlets.

[0003] Conventional recirculating aquaculture systems usually have a sizable upfront cost to design and build, and also have high operating costs that make it difficult for recirculating aquaculture farmers to compete with other types of aquaculture farms, such as ponds and net pen operations. Conventional recirculating aquaculture systems usually provide manually adjusted oxygen flow into a culture tank and manually adjusted water flow through the culture tank, depending upon the size or requirements of the aquatic life. As a result, typical recirculating aquaculture farms usually spend anywhere from about \$50,000 to about \$500,000 in electrical costs and about \$12,000 to about \$100,000 in oxygen costs on an annual basis. In fact, usually the highest operating costs for recirculating aquaculture farms are generally feed, electricity, and oxygen.

[0004] In conventional recirculating aquaculture systems, there are several parameters that are typically frequently monitored by the farmers in order to determine when feed rates for the fish may be increased. Presently, aquaculture farmers monitor ammonia and nitrogen output of the fish daily (by measuring the concentration of ammonia and nitrogen in the culture tank). In particular, the farmers monitor the amount of feed the fish may consume over a time period of about every 30 minutes to about 2 hours. In addition, the

farmers monitor oxygen consumption of the fish and oxygen concentration of the water in the system constantly.

[0005] In light of the above obstacles, a need exists for a way in which to lower the production cost and operating cost of recirculating aquaculture systems.

## SUMMARY

[0006] Some embodiments provide a method of operating a pump in an aquaculture system that includes a culture tank that houses aquatic life. The method includes retrieving a maximum ammonia concentration, retrieving a current ammonia concentration, and comparing the current ammonia concentration to the maximum ammonia concentration. The method also includes increasing a current water flow rate through the aquaculture system when the current ammonia concentration is greater than the maximum ammonia concentration by increasing a speed of a variable speed pump.

[0007] Other embodiments provide a recirculating aquaculture system for aquatic life. The system includes a culture tank, a first sensor configured to measure a current ammonia concentration in the culture tank, a biofilter in fluid communication with the culture tank, a variable speed pump configured to circulate water through the culture tank and the biofilter, and a controller in communication with the first sensor and the variable speed pump. The controller is configured to retrieve a maximum ammonia concentration, retrieve the current ammonia concentration from the first sensor, and compare the current ammonia concentration to the maximum ammonia concentration. The controller is also configured to control the variable speed pump to increase a current water flow rate through the system when the current ammonia concentration is greater than the maximum ammonia concentration.

[0008] Further embodiments provide a method of controlling ammonia in an aquaculture system including a culture tank that houses aquatic life. The method includes retrieving a maximum ammonia concentration, retrieving a current ammonia concentration, and comparing the current ammonia concentration with the maximum ammonia concentration. When the current ammonia concentration is greater than the maximum ammonia concentration, an efficiency of a biofilter is determined. The method further includes the step of increasing a current water flow rate through the aquaculture

system when the efficiency of the biofilter is about 100% by increasing a speed of the pump. The method further includes increasing a current water flow rate when the efficiency of the biofilter is below about 100%.

[0009] These and other aspects of the invention will become apparent in light of the following detailed description.

#### DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a schematic view of an aquaculture system according to one embodiment;

[0011] FIG. 2 is an isometric view of a culture tank for use in the system of FIG. 1;

[0012] FIG. 3 is an isometric view of a variable speed pump for use in the system of FIG. 1;

[0013] FIG. 4 is an exploded isometric view of the variable speed pump of FIG. 3;

[0014] FIG. 5 is a front elevational view of a controller for use with the variable speed pump of FIG. 3;

[0015] FIG. 6 is an isometric view of an external controller for use with the system of FIG. 1;

[0016] FIG. 7 is a front isometric view of an oxygen cone for use with the system of FIG. 1;

[0017] FIG. 8 is a schematic representation of a gas diffusing column or gas diffuser for use with the system of FIG. 1;

[0018] FIG. 9A is a flow chart illustrating a method for controlling ammonia in a recirculating aquaculture system; and

[0019] FIG. 9B is a flow chart illustrating another method for controlling ammonia in a recirculating aquaculture system.

#### DETAILED DESCRIPTION

[0020] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of “including,” “comprising,” or “having” and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms “mounted,” “connected,” “supported,” and “coupled” and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, “connected” and “coupled” are not restricted to physical or mechanical connections or couplings.

[0021] The following discussion is presented to enable a person skilled in the art to make and use embodiments of the invention. Various modifications to the illustrated embodiments will be readily apparent to those skilled in the art, and the generic principles herein may be applied to other embodiments and applications without departing from embodiments of the invention. Thus, embodiments of the invention are not intended to be limited to embodiments shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein. The following detailed description is to be read with reference to the figures, in which like elements in different figures have like reference numerals. The figures, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of embodiments of the invention. Skilled artisans will recognize the examples provided herein have many useful alternatives and fall within the scope of embodiments of the invention.

[0022] Embodiments of the present disclosure provide systems and methods for operating a pump in an aquaculture recirculation system. Aquaculture recirculation systems include components and methods to support aquatic life including one or more of a culture tank, a water pump, a method of removing solid waste, a method of nitrification, and a method of gas exchange. In the present disclosure, the aquaculture system includes systems and methods for providing an efficient method of gas exchange. Aquatic life

consume oxygen and produce carbon dioxide in molar equivalents during respiration. Specifically, the system disclosed herein is directed to monitoring the water quality for proper gas exchange, removing ammonia from the culture tank, and maintaining a sustainable and healthy aquatic environment for the aquatic life.

[0023] FIG. 1 illustrates an aquaculture system 100 according to one embodiment. The aquaculture system 100 may include one or more culture tanks 112 capable of housing aquatic life, a variable speed pump 114, a controller 116, a biofilter 118, an oxygen cone 120, an oxygen gas inlet 121, a degasser 122, an air blower 124, a plurality of control valves 126, and a plurality of sensors 128.

[0024] As depicted in FIG. 2, the culture tank 112 is designed to support and hold aquatic life and is provided in the form of a substantially cylindrical container 200 defined by a bottom surface 210 and a cylindrical sidewall 212 extending upwardly from the bottom surface 210. Although a specific culture tank 112 is depicted in FIG. 2, other culture tanks 112 may be used consistent with the functions described herein. Additionally, one or more culture tanks 112 may be provided in parallel and/or in series, or otherwise be in communication with each other to form the aquaculture system 100.

[0025] One or more portions of the culture tank 112 may be made of suitable materials that are inert and not reactive with water. For example, one or more portions of the culture tank 112 may be constructed of metal, vinyl, polymer, glass, fiberglass, steel, concrete, ceramic, wood, or of any combination thereof. One or more portions of the culture tank 112 may be constructed of clear materials, translucent materials, opaque materials, and/or of any combination thereof. The culture tank 112 may be configured to be circular, octagonal, rectangular, polygonal, irregular, D-shaped, crescent-shaped, or any combination thereof. In some embodiments, the culture tank 112 may include a cover (not shown) that includes portions that are clear, light filtering, light blocking, translucent, and/or combinations thereof.

[0026] The culture tank 112 is in fluid communication with the variable speed pump 114. The variable speed pump 114 provides circulation of water within the culture tank 112 by moving slower water from the bottom of the tank where carbon dioxide is rich. The variable speed pump 114 may have any suitable construction and/or configuration for

providing the desired force to move the water. In one embodiment, the variable speed pump 114 is a common centrifugal pump of the type known to have impellers extending radially from a central axis. Vanes defined by the impellers create interior passages through which the water passes as the impellers are rotated. Rotating the impellers about the central axis imparts a centrifugal force on water therein, and thus imparts the force flow to the water. A return line directs the return flow of water to the culture tank 112. Although centrifugal pumps are well suited to pump a large volume of water at a continuous rate, other motor-operated pumps may also be used within the scope of the present invention.

[0027] FIGS. 3 and 4 illustrate an embodiment of the variable speed pump 114 for use with the aquaculture system 100. The variable speed pump 114 may include a housing 312, a motor 314, and a controller 316 (which may include a variable frequency drive controller). The housing 312 may further include an inlet 318 for receiving water, an outlet 320 for expelling water, a basket 322, a lid 324, and a stand 326.

[0028] FIG. 4 depicts the internal components of the variable speed pump 114 according to one embodiment. The variable speed pump 114 may include a seal plate 434, an impeller 436, a gasket 438, a diffuser 440, and a strainer 442. The strainer 442 may be inserted into the basket 322 and may be secured by the lid 324. In some embodiments, the lid 324 may include one or more of a cap 444, an O-ring 446, and a nut 448. The cap 444 and the O-ring 446 may be coupled to the basket 322 by screwing the nut 448 onto the basket 322. The O-ring 446 may seal the connection between the basket 322 and the lid 324. An inlet 452 of the diffuser 440 may be fluidly sealed to the basket 322 with a seal 450. In some embodiments, the diffuser 440 may enclose the impeller 436. An outlet 454 of the diffuser 440 may be fluidly sealed to the seal plate 434 and the seal plate 434 may be sealed to the housing 312 with the gasket 438. The motor 314 may include a shaft 456, which may be coupled to the impeller 436. The motor 314 may rotate the impeller 436, drawing fluid from the inlet 318 through the strainer 442 and the diffuser 440 to the outlet 320.

[0029] Still referring to FIG. 4, drive force is provided to the variable speed pump 114 via the variable speed pump motor 314. In one example, the drive force is provided in the form of rotational force provided to rotate the impeller 436 of the variable speed pump

114. In one specific embodiment, the variable speed pump motor 314 is a permanent magnet motor. In another specific embodiment, the variable speed pump motor 314 is a three-phase motor. The variable speed pump motor 314 operation is infinitely variable within a range of operation (*i.e.*, zero to maximum operation). In one specific example, the operation is indicated by the RPM of the rotational force provided to rotate the impeller 436 of the variable speed pump 114. In one embodiment, the motor 314 may be driven at four or more different speeds. In another embodiment, the motor may range from about 1/2 hp to about 11 hp, or more than about 11 hp. The stand 326 may support the motor 314 and may be used to mount the variable speed pump 114 on a suitable surface (not shown).

[0030] As shown in FIG. 4, the motor 314 may include a coupling 458 used to connect to a the controller 316. The controller 316 may be associated with the variable speed pump 114, or may be provided separately (*e.g.*, the controller 116). Each of the controllers discussed herein may be designed to control one or more operations and/or parameters of the aquaculture system 100, alone, or in conjunction with each other. In some embodiments, the controller 316 may automatically operate the variable speed pump 114 according to at least one schedule (*e.g.*, an on-peak schedule, an off-peak schedule, a feeding schedule, an aquatic life rest schedule, etc.). In additional embodiments, the controller 316 may allow a manual operation of the variable speed pump 114. In other embodiments, the controller 316 may monitor the operation of the variable speed pump 114 and may indicate abnormal conditions of the variable speed pump 114 (*i.e.*, through audible or visual alarms). In some embodiments, the controller 316 is configured within aquaculture system 100 to operate simultaneously or in conjunction with another controller 116. In other embodiments, the controller 316 is configured within the aquaculture system 100 to operate independently. In yet other embodiments, at least one of controller 316 may be configured as an operating component of the aquaculture system 100.

[0031] The controller 316 may be enclosed in a case 328 (see FIGS. 3 and 4). The case 328 may include a field wiring compartment 330 and a cover 332. The cover 332 may be opened and closed to allow access to the controller 316 and protect the controller 316 from moisture, dust, and other environmental influences. The case 328 may be

mounted on the motor 314 and/or another portion of the pump 104. In some embodiments, the field wiring compartment 330 may include a power supply (not shown) to provide power to the motor 314 and the controller 316.

[0032] Generally, the controllers 116 and/or 316 may adjust the speed of the variable speed pump 114 to maintain a desired flow rate of liquid through the system. More specifically, the variable speed pump 114 may be operated by the controllers 116 and/or 316 according to a flow control algorithm, as disclosed in United States Patent No. 7,845,913 entitled "Flow Control" and issued Dec. 7, 2010, the entire contents of which is herein incorporated by reference. In addition, in some embodiments, the controllers 116 and/or 316 may be in two-way communication with the biofilter 118, one or more of the sensors 128, and/or one or more of the control valves 126. Two-way communication in the aquaculture system 100 may be performed as disclosed in United States Patent No. 7,854,597 entitled "Pumping System with Two-Way Communication" and issued on Dec. 21, 2010, the entire contents of which is herein incorporated by reference in its entirety.

[0033] The controllers 116 and/or 316 may comprise a processor and memory interconnected with the processor via a communication link. An optional RFID module may be interconnected with the processor via a second communication link, and/or an optional "WI-FI" module interconnected with the processor via a third communication link. In some embodiments, microcode, instructions, databases, and/or combinations thereof are encoded in the memory. In certain embodiments, the memory comprises non-volatile memory. In certain embodiments, the memory comprises battery backed up RAM, a magnetic hard disk assembly, an optical disk assembly, an electronic memory, or combinations thereof. The term "electronic memory," can include one or more of a PROM, EPROM, EEPROM, SMARTMEDIA, FLASHMEDIA, and any other suitable memory chips or devices.

[0034] The processor may use the microcode to operate the controllers 116 and/or 316 (independently or in tandem). The processor may use microcode, instructions, databases, and combinations thereof to operate one or more of the variable speed pump 114, the biofilter 118, the oxygen cone 120, the oxygen gas inlet 121, the degasser 122, the air blower 124, the plurality of control valves 126, the plurality of sensors 128, or combinations thereof.

[0035] The controllers 116 and/or 316 may monitor one or more parameters of the system and may automatically execute necessary actions (*e.g.*, adjusting water flow rates, air flow rates, the control valves 126, etc.) to ensure optimal aquatic life conditions within the culture tank 112. Furthermore, the controllers 116 and/or 316 may execute one or more actions to reduce energy consumption of the system. More specifically, substantial costs of maintaining aquaculture systems generally include feed costs, electricity costs, oxygen costs, and combinations thereof. The controllers 116 and/or 316, either as a separate component from the variable speed pump 114 (*i.e.*, the controller 116), or integrated into the variable speed pump 114 (*i.e.*, the controller 316), may control components of the system (*e.g.*, the variable speed pump 114, the blower 124, the control valves 126, combinations thereof, etc.) to maintain optimal aquatic life conditions in addition to minimizing electricity and oxygen costs.

[0036] For example, the controllers 116 and/or 316 may control the variable speed pump 114 to operate at a low speed to maintain a minimum water flow rate necessary to achieve optimal aquatic life conditions and may also increase the speed and, thus, water flow rate only when necessary (such as to increase dissolved oxygen levels during feeding). In contrast to conventional systems with single speed pumps that constantly run at a high speed, the variable speed pump 114 and the controllers 116 and/or 316 of the aquaculture system 100 may greatly minimize electricity and power consumption of the system. Furthermore, automatic execution of necessary actions to variably adjust water and oxygen/air flow may minimize electricity and power consumption in comparison to conventional systems. Moreover, the aquaculture system 100, including automatic control by the controllers 116 and/or 316, allows for rapid and efficient maintenance following startup since the typical learning curve of manual system operators is removed.

[0037] According to one embodiment, the controllers 116 and/or 316 may provide automatic carbon dioxide control for the system. Generally, when the carbon dioxide concentration in the water is too high, the system requires degassing. Degassing may be accomplished by increasing water flow rate via the variable speed pump 114, air flow rate through the degasser 122 via the air blower 124, or any combination of these actions. The controllers 116 and/or 316 may determine which of these actions to execute based on a gas to liquid ratio (G:L) within the degasser 122. The controllers 116 and/or 316 may

calculate the G:L using the current water flow rate and the current air flow rate within the degasser 122. In one embodiment, the current water flow rate and the current air flow rate may be determined from the sensors 128 within the system. In another embodiment, the current water flow rate and the current air flow rate may be determined in a sensor-less manner by measuring one or more characteristics of the variable speed pump 114.

[0038] FIG. 5 illustrates a user interface 560 for the controller 316 according to one embodiment of the invention. The user interface 560 is provided to allow a user to control one or more components, parameters, and/or methods associated with the aquaculture system 100. The user interface 560 may include a display 562, at least one speed button 564, one or more navigation buttons 566, a start-stop button 568, a reset button 570, a manual override button 572, and a “quick clean” button 574. The manual override button 572 may also be called a “time out” button. In some embodiments, the navigation buttons 566 may include a menu button 576, a select button 578, an escape button 580, an up-arrow button 582, a down-arrow button 584, a left-arrow button 586, a right-arrow button 588, and an enter button 590. The navigation buttons 566 and the speed buttons 564 may be used to program a schedule into the controller 316. In some embodiments, the display 562 may include a lower section 592 to display information about a parameter and an upper section 594 to display a value associated with that parameter. In some embodiments, the user interface 560 may include one or more light emitting diodes (LEDs) 596 to indicate normal operation and/or a detected error of the variable speed pump 114, and/or other operational components of the aquaculture system 100.

[0039] FIG. 6 illustrates an external controller 600 for the variable speed pump 114. The external controller 600 may communicate with the controllers 116 and 316. The external controller 600 may control the variable speed pump 114, and/or other components of the aquaculture system 100, in substantially the same way as described for the controllers 116 and 316. The external controller 600 may be used to operate the variable speed pump 114 and/or program the controllers 116 and 316, if the variable speed pump 114 is installed in a location where the user interface 560 is not conveniently accessible. The external controller 600 may include one or more of the buttons described herein and may be used to control one or more components, parameters, and/or methods associated

with the aquaculture system 100, either as a standalone controller, or in conjunction with the on-board controller 316.

[0040] Returning again to the aquaculture system 100 shown in FIG. 1, the variable speed pump 114 is in fluid communication with the biofilter 118. Biological filtration and nitrification may be accomplished by the biofilter 118 (*e.g.*, a fluidized bed filter, a mixed bed filter, a trickling filter, a rotating biocontactor, a membrane bioreactor, etc.). The biofilter 118 provides ammonia removal by a biological filter (nitrification) which consists of the successive oxidation of ammonia to nitrite ( $\text{NO}_2^-$ ) and finally to nitrate ( $\text{NO}_3^-$ ). The process is usually actuated by autotrophic bacteria via an aerobic biofilter process. The biofilter 118 may be a submerged biofilter, trickling biofilter, rotating biological contactor, floating bead biofilter, dynamic bead biofilter, fluidized-bed biofilter, and/or other type biofilter that is designed to complete nitrification and is associated with water quality, and combinations thereof. In some embodiments, the biofilter 118 may operate under a low-head moving bed biological reactor concept using bioreactor media to provide efficient biological filtration.

[0041] In one embodiment, the controller 116 may automate and/or assist startup of the biofilter 118. More specifically, the biofilter 118 initially requires a startup period to allow for manual growth before the biofilter 118 is ready for filtering/nitrification. The startup period may take days to weeks, may require monitoring and/or addition of compounds such as ammonia, nitrite, nitrates, etc., (*e.g.*, via chemical pumps), and/or the addition of "sacrificial fish" to activate the biofilter 118. The controller 116 may perform these actions (and/or instruct an operator to perform these actions) until the biofilter 118 is considered ready for use. The biofilter 118 may be considered ready for use when it is able to remove ammonia from water within the biofilter 118 at a desired ammonia removal rate. The controller 116 may monitor water flow rate through the aquaculture system 100, input ammonia, and monitor ammonia concentrations to determine the ammonia removal rate of the biofilter 118. The controller 116 may determine the desired ammonia removal rate of the biofilter 118 based on a number of parameters including, but not limited to, a volume of water within the culture tank 112 and a typical operating temperature of the aquaculture system 100. Once the biofilter 118 is considered ready for use, the controller 116 may alert an operator.

[0042] In some embodiments, the controller 116 may also control the operating temperature of the aquaculture system 100 during the startup period. For example, the controller 116 may operate the aquaculture system 100 at a higher temperature to accelerate bacterial growth during the startup period. Once the biofilter 118 is active, the controller 116 may reduce the temperature of the aquaculture system 100 to provide optimal aquatic life conditions.

[0043] With further reference to the startup period, the biofilter 118 may reduce the alkalinity of the water within the biofilter (*i.e.*, by metabolism of biofilter bacteria) during the startup period. In some embodiments, through stoichiometric methods, the controller 116 may estimate the amount of alkalinity reduction and add a buffer to the water by controlling a proportional control valve 126 connected to a buffer supply (not shown) as needed.

[0044] The biofilter 118 is in fluid communication with the oxygen cone 120 (shown in more detail in FIG. 7). The availability of dissolved oxygen (DO) is one factor that limits increased carrying capacity and production in aquaculture recirculation systems. Using only aeration as a means of providing dissolved oxygen, a typical aquaculture system can support only about 40 kg/m<sup>3</sup> of water. However, by using pure oxygen (*e.g.*, supplied by the oxygen gas inlet 121) and high efficient gas transfer devices (*e.g.*, the oxygen cone 120) to increase the amount of dissolved oxygen in the water column, stocking densities of the aquatic population can be increased to over about 120 kg/m<sup>3</sup> of water. For example, by increasing the DO concentration at gas inlet 121 to the culture tank 112 from about 10 mg/L (aeration alone) to about 18 mg/L using pure oxygen, and assuming a DO concentration of about 6 mg/L at the discharge, the carrying capacity of the system can be increased by a factor of at least about three. Thus, instead of a concentration of DO of about 4 mg/L (10 mg/L minus 6 mg/L) being available for respiration and metabolism by the fish, DO in a concentration of about 12 mg/L becomes available (18 mg/L minus 6 mg/L). Moreover, use of suitable oxygen saturators may result in an increase in stocking densities from about 40 kg/m<sup>3</sup> to about 120 kg/m<sup>3</sup>.

[0045] The aquaculture system 100 includes the oxygen cone 120 and/or oxygen saturators that may efficiently optimize gas transfer (*e.g.*, of oxygen or ozone) in the water of the culture tank(s) 112. More specifically, the oxygen cone 120 uses the change in

water velocity that occurs in different diameter pipes to ensure complete or substantially complete diffusion of pure oxygen bubbles. As shown in FIG. 7, water and oxygen flow downward (represented by 710) through the oxygen cone 120 decreasing water velocity as the diameter of the body of the oxygen cone 120 widens. Simultaneously, oxygen bubbles (represented by 720) from the downward oxygen flow (or that are injected into the bottom of the oxygen cone 120) rise upwardly against the counter flowing water 710 until the velocity of the downward flowing water 710 equals the speed of the oxygen bubbles rising 720, which allows the oxygen gas to slowly diffuse into the water. The oxygen cone 120 automatically generates a range of velocities of water and gas flow, which even with small fluctuations in water and gas flow, allows the oxygen gas to diffuse into the water.

[0046] The oxygen cone 120 further functions to increase gas pressure in order to overcome surface water tension and enable the oxygen to diffuse more easily into the water. The oxygen cone 120 comprises a cone shaped cylinder 700 (see FIG. 7) or a series of pipes with reducing diameters (not shown), constructed of fiberglass or other suitable material. The oxygen cone 120 includes an inlet 730 to provide fluid water and gas flow into the oxygen cone 120 from the biofilter 118. The oxygen cone 120 further includes an outlet 740 to provide fluid communication with the air blower 124. Absorption efficiency of the oxygen cone 120 may range from about 95% to about 100% with effluent concentrations from about 30 mg/L to about 90 mg/L. In some systems, the oxygen cone 120 may transfer from about 0.2 kilograms of oxygen per hour to about 4.9 kilograms of oxygen per hour at about 25 mg/L, at oxygen flow rates from about 170 L/min to about 2,300 L/min.

[0047] The aquaculture system 100 further includes the regenerative air blower (*e.g.*, the air blower 124) that is in fluid communication with the oxygen cone 120. Diffuser-based aeration increases gas exchange by providing increased surface area of the gas/water interface at the bubble surface. Diffuser-based aeration also stirs the water, which thins the stagnant boundary layer at the bubbles and the top of the water. A primary method of creating diffuser-based aeration is to move the air. The air blower 124 is designed to provide large volumes of air (*e.g.*, from about 0.37 m<sup>3</sup>/min to about 36.1 m<sup>3</sup>/min) at low pressures (less than about 27.58 KPa) and is commonly used in conjunction with one or more of air diffusers and/or air lifts. The combination of the air blower 124 with one or

more air diffusers adds oxygen and removes carbon dioxide with relatively low power consumption. The air blower 124 uses energy to move more air at lower pressure rather than less air at higher pressure. For example, the air blower 124 may include a motor having about 2.5 hp (not shown) that moves air at about 3.4 m<sup>3</sup>/min at about 103.4 KPa, or may operate in corrosive environments and deliver oil-free air, for example, to water in the biofilter 118. The air blower 124 may comprise an outer casing with a corrosion resistant metal fan and includes both input and output valves. The input and output valves of the air blower 124 may be provided with filtering baffles and materials that aid in the elimination of noise and vibration reduction.

[0048] The air blower 124 is in fluid communication with a degassing column (*e.g.*, the degasser 122). As shown in FIG. 8, the degasser 122 generally includes at least one of a plurality of subsegments 810 that is filled with a packing medium 820. The subsegment 810 may be manufactured of suitable materials that are inert and not reactive with water. For example, subsegment 810 may be manufactured of rubber, polymers, polyethylene, heavy duty polyethylene, heavy duty UV-resistant polyethylene, or the like, and/or combinations thereof. The subsegment 810 may be in fluid communication with at least one other of the plurality of subsegments 810. The packing medium 820 may have a large (above about 90 percent) void or empty space per unit volume and may be packed in a way that allows the water flow 830 to break up randomly into a thin film that trickles down through the degasser 122 and follows a circuitous pathway. A perforated support plate (not shown) supports the medium within the subsegment 810 at the bottom of the degasser 122. Near the top of the degasser 122, a water distribution plate (not shown) with a plurality of holes is placed over the packing medium 820.

[0049] The degasser 122 may have a height parameter 850 that may be based on a number of design criteria and may be dependent upon the characteristics of the incoming water. For example, the height parameter 850 may be selected for the degasser 122 to provide at least 90 percent saturation of water with dissolved oxygen. Similarly, a required segment diameter 860 of the degasser 122 depends on water flow rate. For example, water flow rates to the degasser 122 may range from about 0.15 m<sup>3</sup>/min to about 0.57 m<sup>3</sup>/min, with the segment diameter 860 generally up to about 30.5 cm or up to about 45.7 cm. For example, the degasser 122 may have a water flow rate of about 0.38 m<sup>3</sup>/min

to about 0.57 m<sup>3</sup>/min and a segment diameter 860 of about 30.5 cm to about 45.7 cm. In one embodiment, each subsegment 810 of the degasser 122 may have a segment height 840 of about 45.7 cm, a segment diameter 860 of about 40.6 cm with a water flow loading capacity of about 0.57 m<sup>3</sup>/min, and may be substantially packed with about 0.017 m<sup>3</sup> of suitable packing medium 820 such as plastic, polyethylene, black polyethylene, or the like, and/or combinations thereof. In additional embodiments, each subsegment 810 of the degasser 122 may have a segment height 840 of about 20 cm, about 30 cm, about 40 cm, about 50 cm, or about 60 cm; each subsegment 810 of the degasser 122 may have a segment diameter 860 of about 30 cm, about 40 cm, about 50 cm, about 60 cm, or about 70 cm with a water flow loading capacity of about 0.10 m<sup>3</sup>/min, about 0.20 m<sup>3</sup>/min, about 0.30 m<sup>3</sup>/min, about 0.40 m<sup>3</sup>/min, about 0.50 m<sup>3</sup>/min, about 0.60 m<sup>3</sup>/min, or about 0.70 m<sup>3</sup>/min and may be substantially packed with about 0.005 m<sup>3</sup>, about 0.010 m<sup>3</sup>, about 0.020 m<sup>3</sup>, or about 0.025 m<sup>3</sup>, of suitable packing medium 820.

[0050] The degasser 122 is used for removing nitrogen, hydrogen sulfide, carbon dioxide, other gases, and/or a combination thereof from water. The degasser 122 may also add oxygen to undersaturated water. In the recirculating aquaculture system 100, where oxygen is used, carbon dioxide levels may rise to narcotic or toxic levels. The packed segments 810 of the degasser 122 may serve two roles, depending upon the quality of incoming water. For example, if water is supersaturated with dissolved gases, the degasser 122 may substantially relieve the supersaturated condition. Additionally, for instances where the dissolved oxygen concentration of the water is low, the degasser 122 may substantially saturate the water with dissolved oxygen.

[0051] The aquaculture system 100 includes the plurality of valves 126, which are used to regulate the flow and/or pressure of water and/or gas within the culture tank 112. The plurality of valves 126 may include, but are not limited to, water proportional control valves 126A (see FIG. 1), oxygen gas proportional control valves 126B (see FIG. 1), and other control valves that are designed to regulate the flow and/or pressure of water and/or gas or air associated with water quality, and combinations thereof. For example, each of the plurality of valves 126 may include actuators and/or positioners to open and close the valves in order to regulate the flow and/or pressure therethrough.

[0052] The aquaculture system 100 also includes the plurality of sensors 128. The plurality of sensors 128 are used to detect levels of at least one of oxygen, nitrite, ammonia, carbon dioxide, other analytes, and the like, and combinations thereof, within the water of, or related to, the culture tank 112. The plurality of sensors 128 may be positioned throughout the system and are in communication with the controllers 116 and/or 316 for monitoring one or more parameters of the system. Parameters of the system may include, but are not limited to, dissolved oxygen, nitrite, ammonia, carbon dioxide, water flow rate, oxygen gas flow rate, oxygen gas pressure, water pressure, suspended solids, undissolved oxygen, nitrate, temperature, pH, salinity, conductivity, oxidation-reduction potential (ORP), turbidity, atmospheric pressure, water level, saturation, alkalinity, and other water quality parameters known in the art. Some parameters, such as dissolved oxygen, carbon dioxide, ammonia, temperature, may be measured directly from the sensors 128 (*e.g.*, digital probes or potentiometers). Other parameters, such as alkalinity, saturation, etc. may be measured or calculated indirectly by the controllers 116 and/or 316 (*e.g.*, through equations and/or stored lookup tables) using outputs from the sensors 128 (*e.g.*, optical sensors, ultrasonic sensors, infrared sensors, etc.). The plurality of sensors 128 may include, but are not limited to, water quality probes 128A, water flow rate sensors 128B, oxygen gas flow rate and pressure sensors 128C, water pressure sensors 128D, and other sensors that are designed to detect one or more analytes or parameters associated with water quality, and combinations thereof.

[0053] In some embodiments, the water quality probes 128A may include bare electrode cell and membrane cell analytical sensors. For example, for disinfectant measurement, the water quality probes 128A may include a three-electrode sensor that eliminates the need for zero-adjustment as in conventional sensors. Hydrodynamic grit cleaning of the electrode surfaces maintains sensitivity to extend the intervals between calibrations. In another embodiment, the water quality probes 128A may include an internally buffered membrane type sensor to eliminate the need for separate reagents for free and substantially total chlorine measurement, or when water exhibits fluctuating pH. In yet another embodiment, the water quality probes 128A may include a flow cell assembly comprising a corrosion-proof acrylic housing, a transparent flow chamber, a pressure gauge, a sample valve, a flow switch, isolation valves, and combinations thereof for pH and oxidation-reduction potential (ORP) measurements.

[0054] The water flow rate sensors 128B and the oxygen gas flow rate sensors 128C may comprise mechanical flow meters that use positive-displacement flow meters to accumulate a fixed volume of fluid or gas and then count the number of times the volume is filled to measure flow. The water flow rate sensors 128B and the oxygen gas flow rate sensors 128C may comprise pistons reciprocating in cylinders, gear teeth mating against the internal wall of the meter through a progressive cavity created by rotating oval gears, a helical screw, other suitable water/gas flow rate sensor, or combinations thereof. For example, the water flow rate sensors 128B and the oxygen gas flow rate sensors 128C may comprise mechanical flow meters such as piston meters, gear meters, oval gear meters, helical gear meters, nutating disk meters, variable area meters, turbine flow meters, Woltmann meters, single jet meters, paddle wheel meters, multiple jet meters, Pelton wheels, current meters, other suitable water/gas flow rate sensors, or combinations thereof.

[0055] In another embodiment, the water flow rate sensors 128B and the oxygen gas flow rate sensors 128C may comprise sensors that rely on forces produced by the flowing stream as the water or gas flow overcomes a known constriction to indirectly calculate flow rate. In yet another embodiment, the water flow rate sensors 128B and the oxygen gas flow rate sensors 128C may measure flow by measuring the velocity of fluid or gas over a known area. In other embodiments, the water flow rate sensors 128B and the oxygen gas flow rate sensors 128C may comprise pressure-based meters, optical flow meters, open channel flow meters, thermal mass flow meters, vortex flow meters, electromagnetic flow meters, ultrasonic flow meters, Coriolis flow meters, laser Doppler flow meters, other suitable water flow rate or gas flow rate sensors associated with water quality, or combinations thereof.

[0056] The oxygen gas pressure sensors 128C and the water pressure sensors 128D may comprise force collector type sensors or other suitable pressure sensors. Force collector type sensors use a force collector such as a diaphragm, piston, bourdon tube, bellows, or combinations thereof to measure strain (or deflection) due to applied pressure force over an area. The oxygen gas pressure sensors 128C and the water pressure sensors 128D may comprise piezoresistive strain gauges that use the piezoresistive effect of bonded or formed strain gauges to detect strain due to applied pressure. Piezoresistive strain gauges employ a few common types of technologies including silicon

(monocrystalline), polysilicon thin film bonded metal foil, thick film, sputtered thin film, or the like, or combinations thereof. Generally, the strain gauges are connected to form a Wheatstone bridge circuit to maximize the output of the sensors and to reduce sensitivity to errors. Generally, these technologies are suited to measure absolute, gauge, vacuum, differential pressures, or combinations thereof. In other embodiments, the oxygen gas pressure sensors 128C and the water pressure sensors 128D may comprise capacitive sensors, electromagnetic sensors, piezoelectric sensors, optical sensors, potentiometric sensors, resonant sensors, thermal sensors, ionization sensors, other suitable water pressure or gas pressure sensors, or combinations thereof.

[0057] The component parts having been described, operation of the aquaculture system 100 will now be discussed. More particularly, water may be recirculated through the aquaculture system 100 using the variable speed pump 114, (*i.e.*, through the fluid circuit) for treatment to ensure optimal aquatic life conditions within the culture tank 112.

[0058] Components of the aquaculture system 100 including the culture tank 112, the variable speed pump 114, the biofilter 118, the degasser 122, and the oxygen cone 120 may form a fluid circuit in which the treated water is circulated. In addition, one or more components of the aquaculture system 100 including the variable speed pump 114, the biofilter 118, the oxygen cone 120, the oxygen gas inlet 121, the degasser 122, the air blower 124, the plurality of control valves 126, the plurality of sensors 128, or any combination thereof may be in fluid communication with and/or automatically operated by one or more of the controllers 116, 316, 600.

[0059] FIG. 9A illustrates a first method 900 (*e.g.*, as executed by the controller 116) for controlling ammonia in the aquaculture system 100. As shown in FIG. 9A, the method 900 may include the step of retrieving a maximum ammonia concentration (at step 932). The controller 116 may retrieve the maximum ammonia concentration from lookup tables, for example based on aquatic life species, age (*i.e.*, growth cycle), size, mass, or other characteristics, and/or from user input. The controller 116 may then retrieve a current ammonia concentration (at step 934), for example from an ammonia concentration sensor 128 in the culture tank 112, at an output of the biofilter 118, or some combination thereof. Following step 934, the controller 116 may compare the current ammonia concentration with the maximum ammonia concentration (at step 936).

[0060] If the current ammonia concentration is greater than the maximum ammonia concentration, as determined at step 936, the controller 116 may respond by increasing a current water flow rate in the aquaculture system 100 by increasing a speed of the variable speed pump 114 (at step 938). It is envisioned that the current water flow rate is increased for a time period sufficient to lower the current ammonia concentration to a value that is less than the maximum ammonia concentration as determined at step 932.

[0061] If the current ammonia concentration is less than the maximum ammonia concentration, as determined at step 936, the controller 116 may respond by decreasing the current water flow rate in the aquaculture system 100 by decreasing the speed of the variable speed pump 114 (at step 940).

[0062] Following the controller 116 adjustment of the current water flow rate in the aquaculture system 100 (*e.g.*, an increase in the current water flow rate at step 938 or a decrease in water flow rate at step 940), the controller 116 may wait for a predetermined time period (at step 942) and then revert back to step 934 to retrieve a new current ammonia concentration and repeat the above process.

[0063] FIG. 9B illustrates a second method 944 (*e.g.*, as executed by the controller 116) for controlling ammonia in the aquaculture system 100. As shown in FIG. 9B, the method 944 may include the step of retrieving a maximum ammonia concentration (at step 946). As previously discussed, the controller 116 may retrieve the maximum ammonia concentration from lookup tables, for example based on aquatic life species, age (*i.e.*, growth cycle), size, mass, or other characteristics, and/or from user input. The controller 116 may then retrieve a current ammonia concentration (at step 948), for example from the ammonia concentration sensor 128 in the culture tank 112, at an output of the biofilter 118, or some combination thereof. Following step 948, the controller 116 may compare the current ammonia concentration with the maximum ammonia concentration (at step 950).

[0064] If the current ammonia concentration is less than the maximum ammonia concentration, as determined at step 950, the controller 116 may respond by decreasing the current water flow rate in the aquaculture system 100 by decreasing the speed of the variable speed pump 114 (at step 952).

[0065] If the current ammonia concentration is greater than the maximum ammonia concentration, as determined at step 950, the controller 116 may determine an efficiency of the biofilter 118 (*e.g.*, the ammonia removal efficiency of the biofilter 118) at step 954. In one embodiment, the controller 116 may determine the efficiency of the biofilter 118 by comparing the current ammonia concentration in the aquaculture system 100 (at step 948) with a current ammonia concentration in the output of the biofilter 118 (at step 956). The controller 116 may then calculate whether the efficiency of the biofilter 118 is at or below about 100% (at step 956). It is envisioned that the biofilter 118 is functioning to actively remove substantially about 100% of the ammonia present within the aquaculture system 100 where the efficiency of the biofilter 118 is at substantially about 100%.

[0066] If the efficiency of the biofilter 118 is at substantially about 100%, as determined at step 956, the controller 116 may increase a current water flow rate in the aquaculture system 100 (*i.e.*, to the culture tank 112) by increasing a speed of the variable speed pump 114 (at step 958). It is envisioned that the current water flow rate is increased for a time period sufficient to lower the current ammonia concentration to a value that is less than the maximum ammonia concentration as determined at step 946.

[0067] Referring back to FIG. 1, should the efficiency of the biofilter 118 fall below about 100%, (*e.g.*, below about 99%, below about 95%, below about 90%, etc.) as determined at step 956, the controller 116 may increase the current water flow rate through a recycle loop 161 in the aquaculture system 100, by increasing the speed of the variable speed pump 114, opening the water control valve 126A to allow water flow through the recycle loop 161 (see FIG. 1) (at step 960), or some combination thereof. The recycle loop 161 may allow the biofilter 118 to continue removing ammonia from at least a portion of the water flow before the water is returned to the culture tank 112.

[0068] Following the controller 116 adjustment of the current water flow rate in the aquaculture system 100 (*e.g.*, an increase in the current water flow rate to culture tank 112 at step 958 or an increase in water flow rate through the recycle loop 161 at step 960), the controller 116 may wait for a predetermined time period (at step 962) and then revert back to step 948 to retrieve a new current ammonia concentration and repeat the above process.

[0069] In some embodiments, when the current ammonia concentration is less than the maximum ammonia concentration, as determined at step 950, the controller 116 may take a responsive action. The controller 116 may respond by decreasing the current water flow rate in the aquaculture system 100 by decreasing the speed of the variable speed pump 114 (at step 952) to the culture tank 112 for a time period.

[0070] In other embodiments, when the current ammonia concentration is less than the maximum ammonia concentration, as determined at step 950, the controller 116 may respond by decreasing or stopping the current water flow rate through the recycle loop 161. The water flow rate through the recycle loop 161 may be decreased or stopped for a time period sufficient to change the value of the current ammonia concentration within the aquaculture system 100.

[0071] In further embodiments, when the current ammonia concentration is less than the maximum ammonia concentration, as determined at step 950, the controller 116 may decrease the current water flow rate through the aquaculture system 100 by decreasing the speed of the variable speed pump 114 to the culture tank 112, as described above, and/or may also decrease or stop water flow through the recycle loop 161.

[0072] The predetermined time period at steps 942 and 962 may be a suitable time period to allow the aquaculture system 100 to reach steady state conditions reflecting any actions taken. For example, the predetermined time period may be based on a number of variables such as, but not limited to, a volume of the culture tank 112, a magnitude of action taken (*e.g.*, a longer time period for large water flow rate adjustments vs. a shorter time period for smaller water flow rate adjustments), energy optimization (*e.g.*, minimizing unnecessary process iterations and actions taken during on-peak hours), feeding or rest times of the aquatic life (*e.g.*, increasing process iterations and actions taken, by selecting a shorter time period during feeding times and decreasing process iterations and actions taken, by selecting a longer time period during rest times). In some embodiments, a lookup table of time periods may be stored by the controller 116, and the controller 116 may determine the appropriate time period based on one or more of the variables discussed above. In addition, water flow rate may be increased or decreased (*i.e.*, at steps 938, 940, 952, 958, or 960) over a time period to allow a gradual or incremental ramping of the speed of the variable speed pump 114. For example, the

controller 116 may determine that the current water flow rate should be increased by less than about 1%, about 1%, about 2%, about 3%, about 4%, about 5% or less than about 10% of the current water flow rate, and subsequently gradually ramp up the speed of the variable speed pump 114 until the increased current water flow rate is substantially reached.

[0073] In some embodiments, current water pressure in the aquaculture system 100 may be monitored and variably adjusted instead of current water flow. To maintain current water flow rates in the aquaculture system 100 (*i.e.*, in accordance with the water flow control algorithm described above) when the water pressure is increased, the controller 116 may also automatically increase the speed of the variable speed pump 114. In some embodiments, the controller 116 or a user may select to operate under a water pressure monitoring model or a water flow monitoring model based on the efficiency of the variable speed pump 114 and energy consumption of the aquaculture system 100.

[0074] In some embodiments, the controller 116 may monitor and/or store the ammonia concentration and the actions taken over time. For example, the controller 116 may monitor how long the current ammonia concentration stays above the maximum ammonia concentration. If the controller 116 fails to reduce the ammonia concentration below the maximum after a specific number of consecutive process iterations or after a predetermined time period, the controller 116 may initiate an alarm (*e.g.*, an audible and/or visual alarm) to alert an operator.

[0075] The controller 116 may also incorporate a maximum capacity of the biofilter 118 into the above-described methods. More specifically, the biofilter 118 may include a maximum use capacity per day (*i.e.*, water flow through the biofilter 118 per a 24-hour time period). For example, the controller 116 may adjust the water flow rate through the aquaculture system 100 (*i.e.*, by adjusting the speed of the variable speed pump 114) to stay under the maximum daily capacity of the biofilter 118. In one embodiment, where the biofilter 118 is at the maximum daily capacity and the controller 116 determines that an action to increase flow through the biofilter 118 is necessary, the controller 116 may initiate an alarm (*e.g.*, an audible and/or visual alarm) to alert an operator.

[0076] In one embodiment, the controller 116 may include one or more stored hierarchical lists of actions for execution. For example, the controller 116 may execute a second action from the one or more hierarchical lists should a number of process iterations of a first action fail to decrease the current ammonia concentration level below the maximum ammonia concentration value. The controller 116 may then execute a third action if the second action fails, and so on. In one embodiment, the list may include nitrification of ammonia (resulting in a reduced current ammonia concentration) through an increase in the water flow rate to the culture tank 112 as a first action and nitrification of ammonia through an increase in the water flow rate through the recycle loop 161 as a second action. In some embodiments, the controller 116 may include a number of hierarchical lists of actions based on the calculated difference between the current ammonia concentration and the maximum ammonia concentration. For example, if the current ammonia concentration is dangerously high as compared to the maximum ammonia concentration (*i.e.*, there is a large difference between the current ammonia concentration and the maximum ammonia concentration, at steps 936 and 950), the controller 116 may first increase the current water flow rate to the culture tank 112 by increasing the speed of the variable speed pump 114, increase the current water flow rate through the recycle loop 161, or a combination thereof based on the calculated difference ammonia concentration and the maximum ammonia concentration.

[0077] Suitable water treatment may include one or more of carbon dioxide removal, disinfection, biological filtration, nitrification, waste solids removal, aeration, oxygenation, fine and dissolved solids removal, other suitable water quality treatments known in the art, and any combination thereof using the components described above and/or additional components.

[0078] The aquaculture system 100 may include additional components. For example, in some embodiments, rotating drum filters may be used for high-volume solids removal and a radial flow settler may be used to capture settleable solids from the bottom drain of a dual drain system for solids removal. In some embodiments, the aquaculture system 100 of FIG. 1 may optionally include an ultraviolet (UV) sterilizer, an ozone generator, or any combination thereof. Disinfection may be accomplished by the ultraviolet (UV) sterilizer and/or the ozone generator. In some embodiments, the aquaculture system 100 of FIG. 1

may further include swirl separators, screen filters, bead filters, rotating drum filters, a double drain mechanism, or any combination thereof. Waste solids removal may be accomplished through sedimentation, using the swirl separators, the screen filters, the bead filters, the rotating drum filters, the double drain mechanism, or any combination thereof. In some embodiments, the aquaculture system 100 of FIG. 1 may include a protein skimmer, also referred to as a foam fractionator, which may be used to remove dissolved solids, including any fine particulates that mechanical filtration does not catch. These dissolved solids are usually proteins that have broken down from wastes, uneaten food, and dead fish.

[0079] Although the controller 116 is described throughout, the controllers 316 and/or 600 may perform one or more of the functions associated with the controller 116.

[0080] Although numerous embodiments have been provided with respect to various components of the system 100, it should be apparent that one or more components may be omitted and/or additional components may be added to the system 100. Additionally, other types of the culture tank 112, the variable speed pump 114, the controller 116, the biofilter 118, the oxygen cone 120, the oxygen gas inlet 121, the degasser 122, the air blower 124, the plurality of control valves 126, and the plurality of sensors 128 may be used as known in the art, consistent with the disclosure as set forth herein.

[0081] It will be appreciated by those skilled in the art that while the invention has been described above in connection with particular embodiments and examples, the invention is not necessarily so limited, and that numerous other embodiments, examples, uses, modifications and departures from the embodiments, examples and uses are intended to be encompassed by the claims attached hereto. The entire disclosure of each patent and publication cited herein is incorporated by reference, as if each such patent or publication were individually incorporated by reference herein. Various features and advantages of the invention are set forth in the following claims.

## CLAIMS

1. A method of operating a pump in an aquaculture system, the aquaculture system including a culture tank that houses aquatic life, the method comprising:

retrieving a maximum ammonia concentration;

retrieving a current ammonia concentration;

comparing the current ammonia concentration with the maximum ammonia concentration; and

increasing a current water flow rate through the aquaculture system when the current ammonia concentration is greater than the maximum ammonia concentration by increasing a speed of a variable speed pump.

2. The method of claim 1 further comprising determining a current biofilter efficiency, increasing the current water flow rate through a biofilter in the aquaculture system via a recirculation loop when the current biofilter efficiency is below about 100 percent, and increasing the current water flow rate through a culture tank in the aquaculture system when the current biofilter efficiency is at about 100 percent.

3. The method of claim 1 further comprising decreasing the current water flow rate through the aquaculture system when the current ammonia concentration is less than the maximum ammonia concentration by decreasing the speed of the variable speed pump.

4. The method of claim 1 further comprising operating the variable speed pump according to a flow control algorithm to maintain the current water flow rate after the current water flow rate has been increased.

5. The method of claim 1 further comprising determining an increase amount of the current water flow rate based on at least one of time of day, feeding cycle of the aquatic life, and rest cycle of the aquatic life.

6. The method of claim 5, wherein the increase amount is 1 percent of the current water flow rate.

7. The method of claim 1, wherein increasing the current water flow rate includes gradually ramping up the speed of the variable speed pump.

8. A recirculating aquaculture system for aquatic life, the system including a culture tank and a biofilter in fluid communication with the culture tank, the system comprising:

a first sensor configured to measure a current ammonia concentration in the culture tank;

a variable speed pump configured to circulate water through the culture tank and the biofilter; and

a controller in communication with the first sensor and the variable speed pump, the controller configured to:

retrieve a maximum ammonia concentration,

retrieve the current ammonia concentration from the sensor,

compare the current ammonia concentration with the maximum ammonia concentration, and

control the variable speed pump to increase a current water flow rate through the system when the current ammonia concentration is greater than the maximum ammonia concentration.

9. The system of claim 8, wherein the controller is further configured to control the variable speed pump to decrease the current water flow rate through the system when the current ammonia concentration is less than the maximum ammonia concentration.

10. The system of claim 8 further comprising a recirculation loop that cycles fluid through the biofilter, wherein the controller is further configured to determine a current efficiency of the biofilter, increase the current water flow rate through the tank

when the current efficiency is at about 100 percent, and increase the current water flow rate through the recirculation loop when the current efficiency is below about 100 percent.

11. The system of claim 10 further comprising a fluid connection line between the biofilter and the culture tank, and a second sensor configured to measure an ammonia concentration in the fluid connection line, wherein the controller is configured to compare the ammonia concentration measured by the second sensor and the ammonia concentration measured by the first sensor to determine the current efficiency of the biofilter.

12. The system of claim 8, wherein the controller is further configured to determine a current capacity of the biofilter within a time period and to maintain the current capacity of the biofilter below a maximum capacity within the time period by optimizing a speed of the variable speed pump over the time period.

13. The system of claim 12, wherein the time period is 24 hours.

14. The system of claim 8, wherein the controller is configured to wait a predetermined time period and to retrieve a new current ammonia concentration after the predetermined time period.

15. A method of controlling ammonia in an aquaculture system, the aquaculture system including a culture tank that houses aquatic life, the method comprising:

retrieving a maximum ammonia concentration;

retrieving a current ammonia concentration;

comparing the current ammonia concentration with the maximum ammonia concentration;

when the current ammonia concentration is greater than the maximum ammonia concentration, determining an efficiency of a biofilter;

increasing a current water flow rate through the aquaculture system using a first mechanism when the efficiency of the biofilter is about 100 percent by increasing a speed of a pump; and

increasing the current water flow rate using a second mechanism when the efficiency of the biofilter is below about 100 percent.

16. The method of claim 15, wherein the first mechanism comprises increasing the current water flow rate by increasing the speed of the pump.

17. The method of claim 15, wherein the second mechanism comprises increasing the current water flow rate through a recycle loop by opening a valve allowing water flow through the recycle loop.

18. The method of claim 15, wherein a controller is configured to retrieve the maximum ammonia concentration from a look-up table based on at least one of species, age, mass, and size of the aquatic life.

19. The method of claim 18, wherein the controller is integrated into the pump.

20. The method of claim 18, wherein the controller is further configured to initiate an alarm when the current ammonia concentration is greater than the maximum ammonia concentration for greater than a predetermined time period.

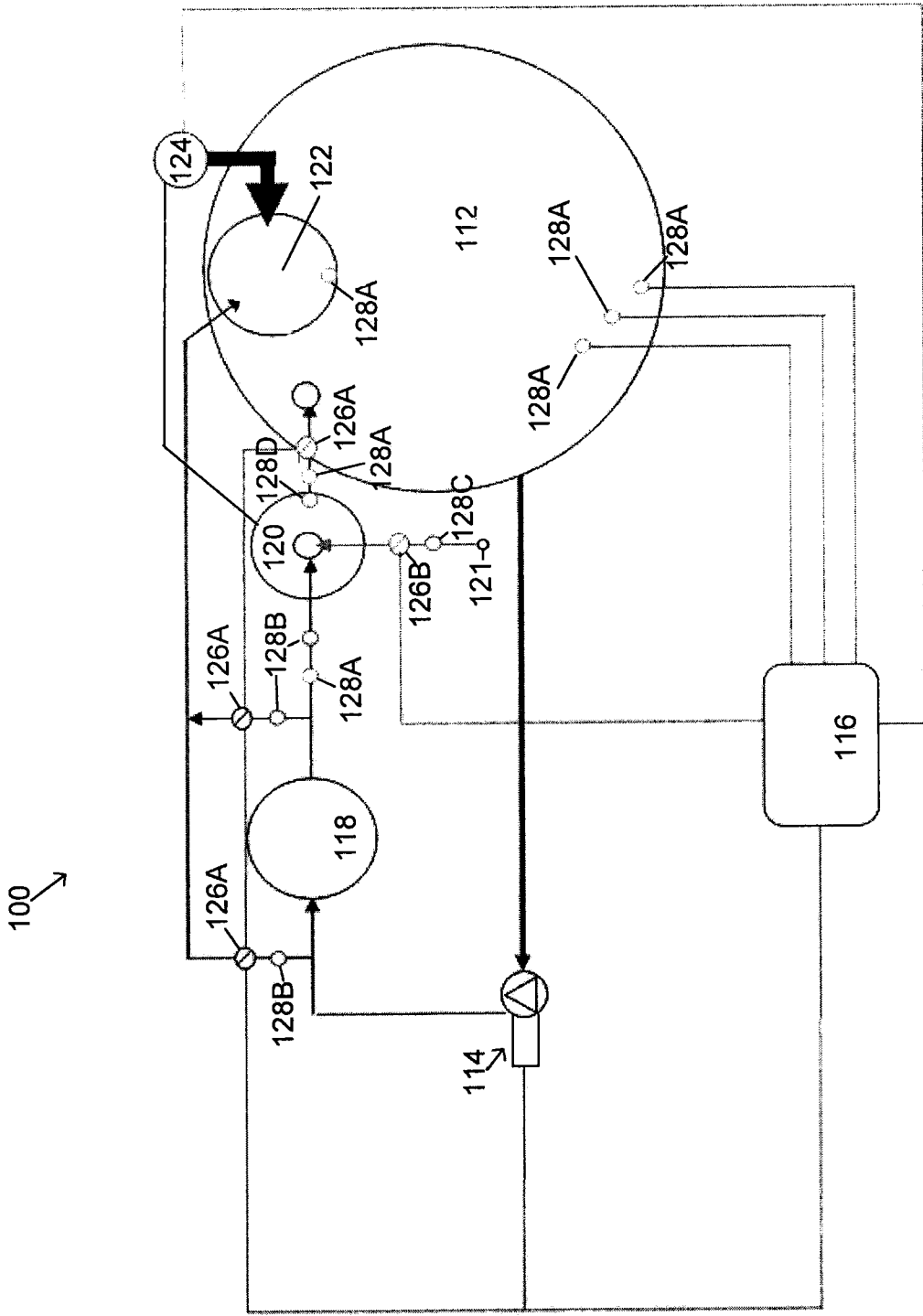


FIG. 1

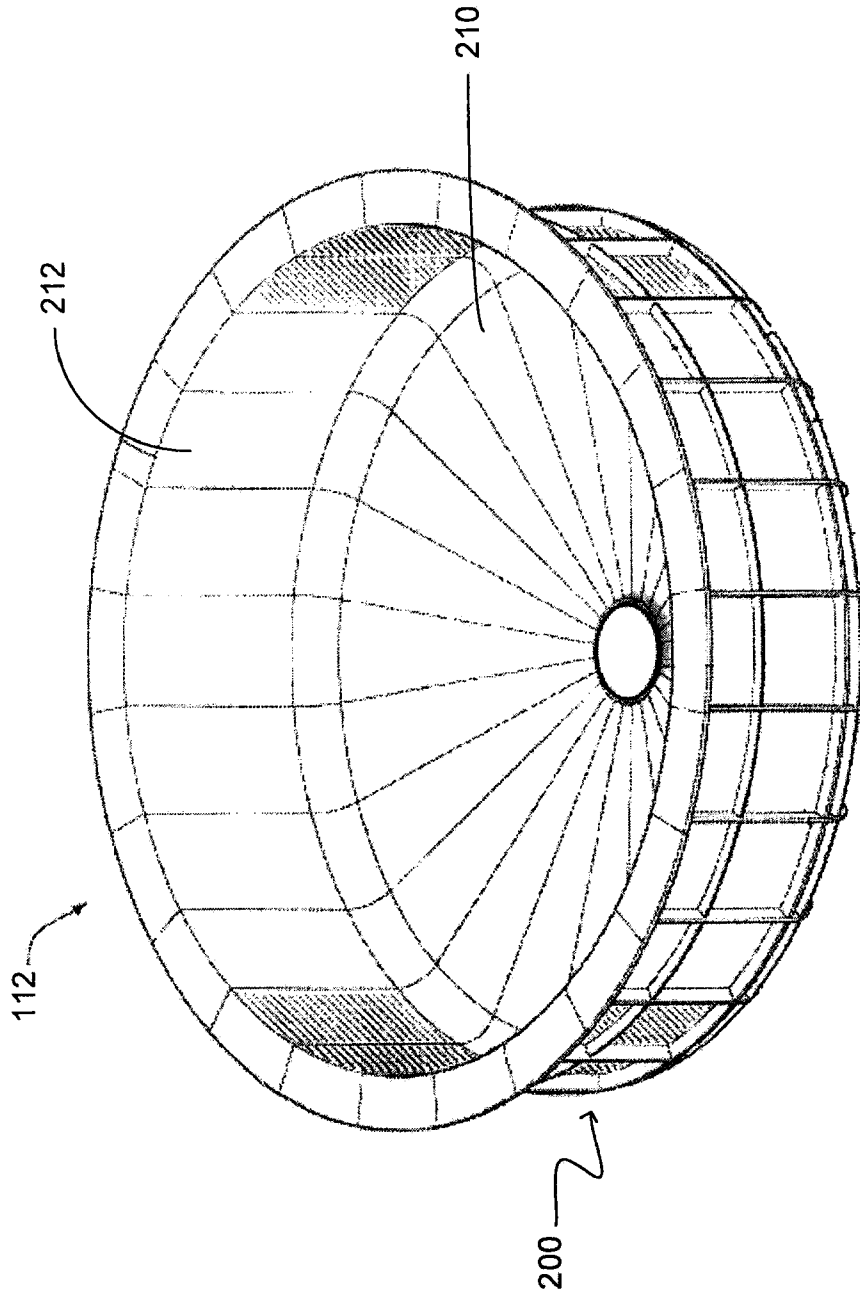


FIG. 2

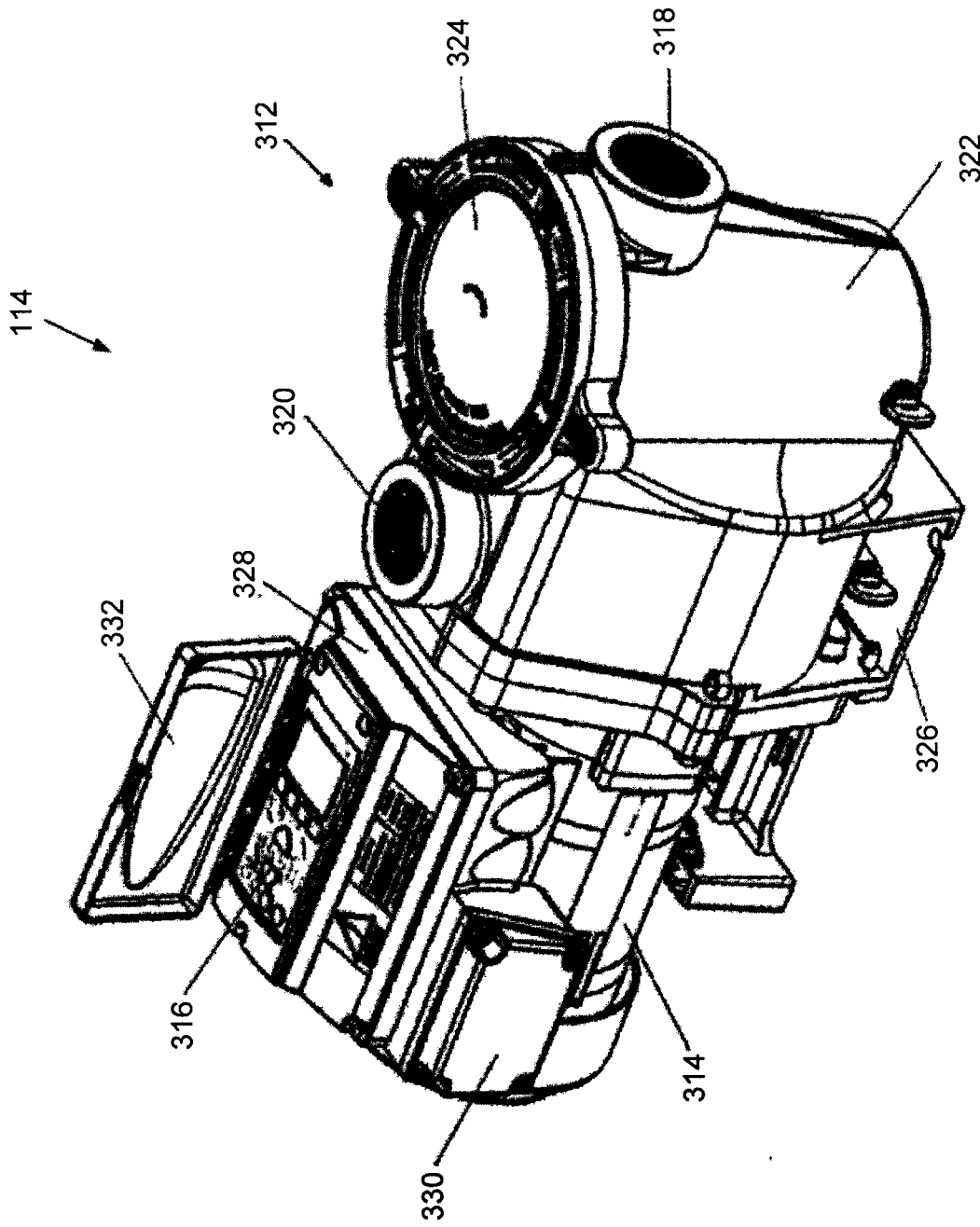


Fig. 3



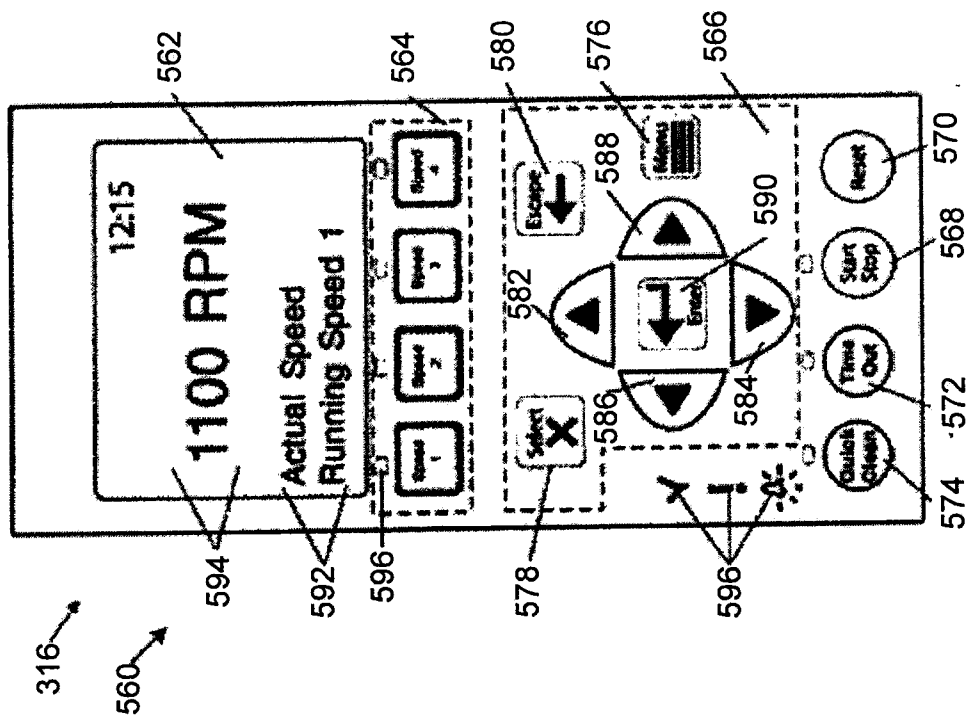


Fig. 5

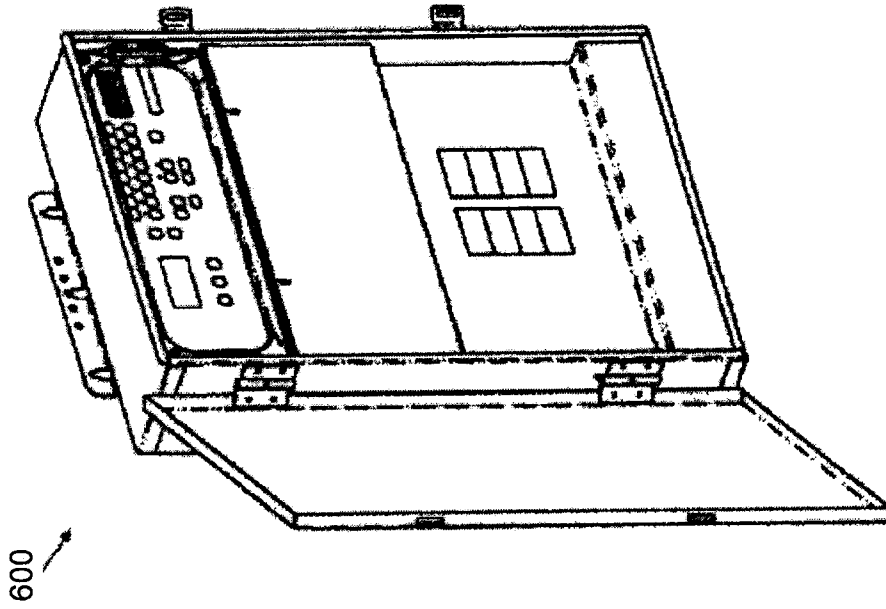


Fig. 6

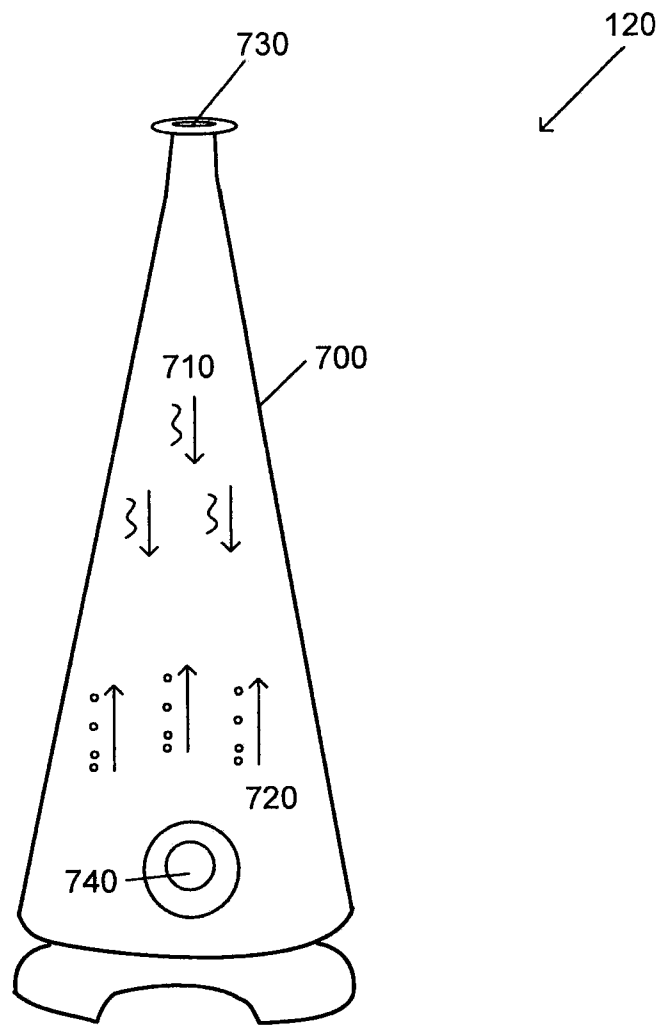


Fig. 7

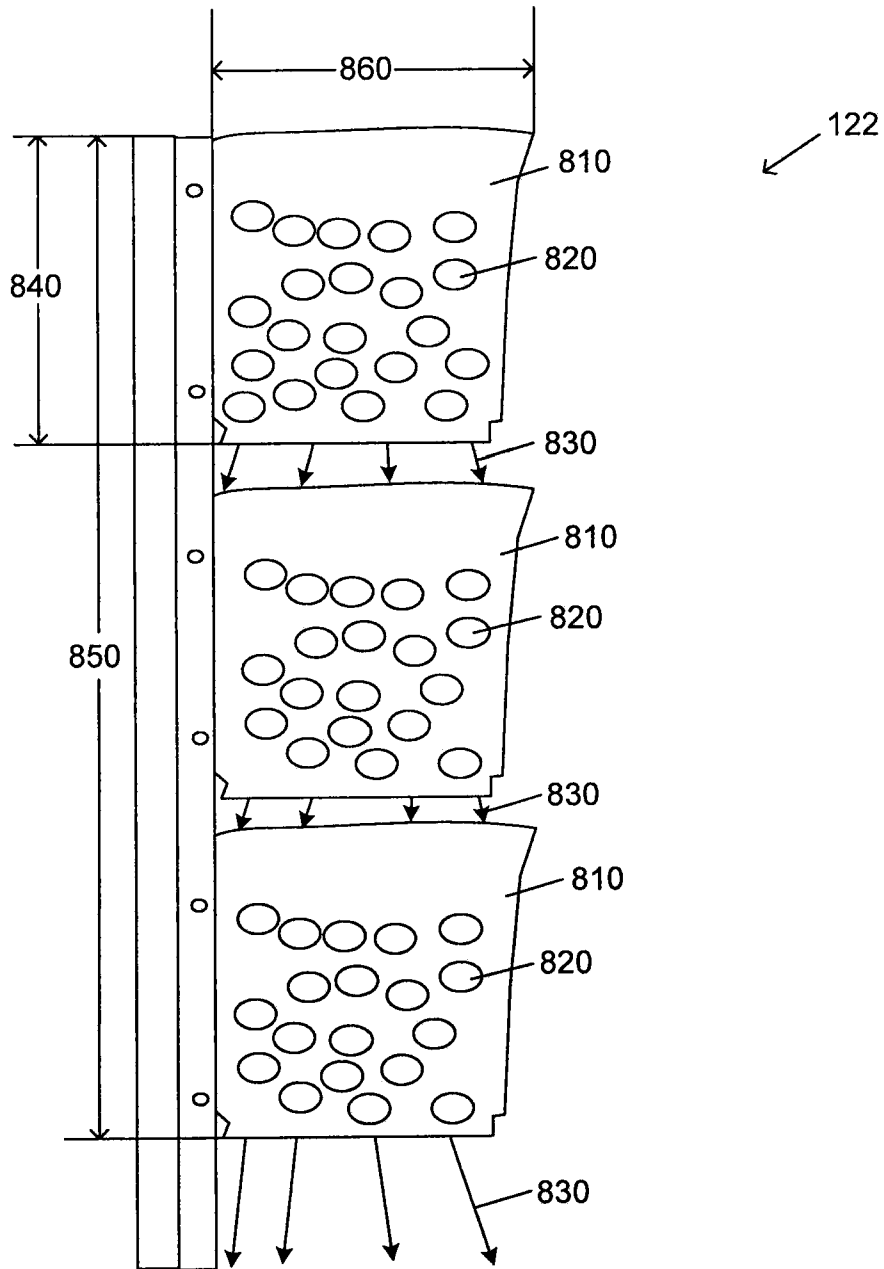


Fig. 8

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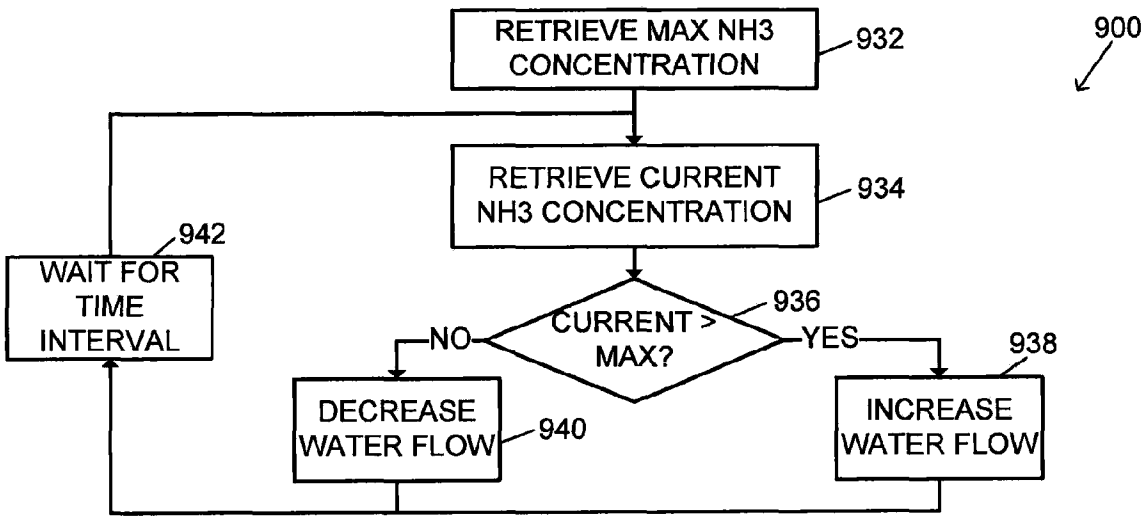


FIG. 9A

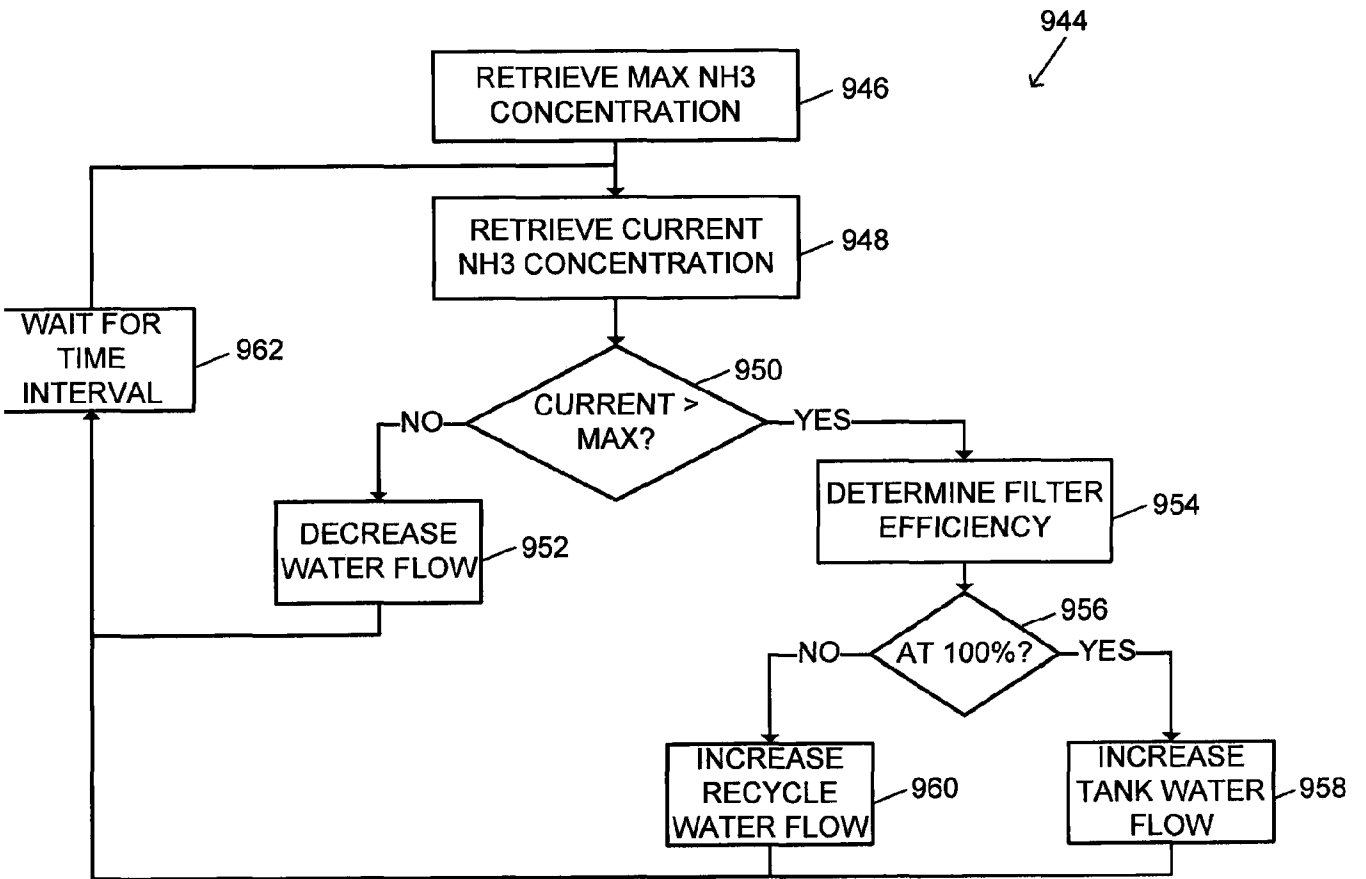


FIG. 9B

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US2014/030511

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(8) - A01K 63/04 (2014.01)

USPC - 119/227

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - A01K 61/00, 61/02; 63/00, 63/04; C02F 101/00, 101/10, 101/16 (2014.01)

USPC - 119/200, 204, 215, 226, 227, 245, 259

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

CPC - A01K 61/00, 61/02; 63/00, 63/04, 63/045 (2014.06)

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

Orbit, Google Patents, Google Scholar

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,030,450 A (HOULT) 21 June 1977 (21.06.1977) entire document	1, 3, 4, 7-9, 12-14
Y	US 2008/0041773 A1 (MORSE) 21 February 2008 (21.02.2008) entire document	1, 3, 4, 7-9, 12-14
Y	US 4,664,680 A (WEBER) 12 May 1987 (12.05.1987) entire document	3, 9
Y	US 2012/0063921 A1 (STILES, JR et al) 15 March 2012 (15.03.2012) entire document	4
Y	US 6,192,833 B1 (BRUNE et al) 27 February 2001 (27.02.2001) entire document	7
Y	US 2006/0237044 A1 (FERGUSON et al) 26 October 2006 (26.10.2006) entire document	12, 13
Y	US 6,123,846 A (KIKUCHI) 26 September 2000 (26.09.2000) entire document	14.

Further documents are listed in the continuation of Box C.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

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