



- (51) International Patent Classification:
B01F 5/04 (2006.01)
- (21) International Application Number:
PCT/US2014/028269
- (22) International Filing Date:
14 March 2014 (14.03.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/785,639 14 March 2013 (14.03.2013) US
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: CARBON DIOXIDE CONTROL SYSTEM FOR AQUACULTURE

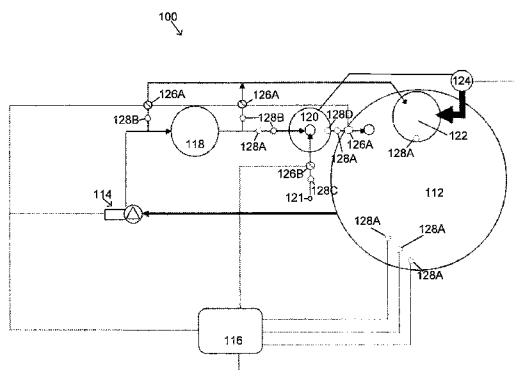


FIG. 1

(57) Abstract: Some embodiments provide a recirculating aquaculture system for aquatic life. The system includes a culture tank, a sensor configured to measure a carbon dioxide concentration in the culture tank, a variable speed pump configured to circulate water through the culture tank, and a controller in communication with the sensor and the variable speed pump. The controller is configured to retrieve a maximum carbon dioxide concentration in the culture tank, retrieve a current carbon dioxide concentration, and compare the current carbon dioxide concentration to the maximum carbon dioxide concentration. When the current carbon dioxide concentration is greater than the maximum carbon dioxide concentration, the controller is configured to automatically increase the current water flow rate or automatically increase the current air flow rate based on the current gas to liquid ratio in the system.



CARBON DIOXIDE CONTROL SYSTEM FOR AQUACULTURE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of United States Provisional Patent Application No. 61/785,639 filed on March 14, 2013, the entire contents of which is incorporated herein by reference.

BACKGROUND

[0001] 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.

[0002] 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.

[0003] 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.

[0004] 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

[0005] 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 carbon dioxide concentration and a maximum gas to liquid ratio in a degasser, retrieving a current carbon dioxide concentration, and comparing the current carbon dioxide concentration to the maximum carbon dioxide concentration. When the current carbon dioxide concentration is greater than the maximum carbon dioxide concentration, the method also includes determining a current gas to liquid ratio using a current water flow rate and a current air flow rate in the degasser, increasing the current water flow rate when the current gas to liquid ratio is greater than the maximum gas to liquid ratio, and increasing the current air flow rate when the current gas to liquid ratio is less than the maximum gas to liquid ratio.

[0006] Other embodiments provide a recirculating aquaculture system for aquatic life. The system includes a culture tank, a sensor configured to measure a current carbon dioxide concentration in the culture tank, a variable speed pump configured to circulate water through the culture tank, and a controller in communication with the sensor and the variable speed pump. The controller is configured to retrieve a maximum carbon dioxide concentration and a maximum gas to liquid ratio in the culture tank, retrieve the current carbon dioxide concentration, and compare the current carbon dioxide concentration to the maximum carbon dioxide concentration. When the current carbon dioxide concentration is greater than the maximum carbon dioxide concentration, the controller is configured to determine a current gas to liquid ratio using a current water flow rate and a current air flow rate, increase the current water flow rate when the current gas to liquid ratio is greater than the maximum gas to liquid ratio, and increase the current air flow rate when the current gas to liquid ratio is less than the maximum gas to liquid ratio.

[0007] Further embodiments provide a method for controlling carbon dioxide in an aquaculture system including a culture tank that houses aquatic life. The method includes measuring a current carbon dioxide concentration in a culture tank, retrieving a maximum carbon dioxide concentration and a maximum gas to liquid ratio, comparing the current carbon dioxide concentration with the maximum carbon dioxide concentration, and increasing at least one of the current water flow rate and the current air flow rate based on the comparison of the current carbon dioxide concentration with the maximum carbon dioxide concentration. The method also includes waiting a predetermined time period, then reverting back to measuring a current carbon dioxide concentration and repeating the method steps.

[0008] These and other aspects of the invention will become apparent in light of the following detailed description.

DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a schematic view of an aquaculture system according to one embodiment;

[0010] FIG. 2 is an isometric view of a culture tank for use in the system of FIG. 1;

[0011] FIG. 3 is an isometric view of a variable speed pump for use in the system of FIG. 1;

[0012] FIG. 4 is an exploded isometric view of the variable speed pump of FIG. 3;

[0013] FIG. 5 is a front elevational view of a controller for use with the variable speed pump of FIG. 3;

[0014] FIG. 6 is an isometric view of an external controller for use with the system of FIG. 1;

[0015] FIG. 7 is a front isometric view of an oxygen cone for use with the system of FIG. 1;

[0016] FIG. 8 is a schematic representation of a gas diffusing column or gas diffuser for use with the system of FIG. 1; and

[0017] FIG. 9 is a flow chart illustrating a method for controlling carbon dioxide in a recirculating aquaculture system.

DETAILED DESCRIPTION

[0018] 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.

[0019] 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.

[0020] 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 excess carbon dioxide from the culture tank, and maintaining a sustainable and healthy aquatic environment for the aquatic life.

[0021] 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.

[0022] 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.

[0023] 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.

[0024] 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.

[0025] 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.

[0026] 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.

[0027] 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).

[0028] As shown in FIG. 4, the motor 314 may include a coupling 458 used to connect to a controller 316. The controller 316 may be associated with the variable speed pump 114, or may be provided separately (*e.g.*, 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 controllers 116 and 316 are 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.

[0029] 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.

[0030] 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.

[0031] 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 other suitable chips or memory devices.

[0032] 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.

[0033] 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, 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.*, controller 116), or integrated into the variable speed pump 114 (*i.e.*, 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.

[0034] 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 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 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.

[0035] 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 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.

[0036] 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 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 system 100

[0037] 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 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 system 100, either as a standalone controller, or in conjunction with the on-board controller 316.

[0038] 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 (NO_2^-) and finally to nitrate (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.

[0039] 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^3 of water. However, by using pure oxygen (*e.g.*, supplied by the oxygen gas inlet 121) and high efficient gas transfer devices (*e.g.*, 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^3 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/m³ to about 120 kg/m³.

[0040] 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 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.

[0041] 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.

[0042] The aquaculture system 100 further includes the regenerative air blower (*e.g.*, 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 m³/min to about 36.1 m³/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 m³/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 air blower 124 may be provided with filtering baffles and materials that aid in the elimination of noise and vibration reduction.

[0043] 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, the subsegment 810 may be manufactured of plastic, 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.

[0044] 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 m³/min to about 0.57 m³/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 m³/min to about 0.57 m³/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 m³/min, and may be substantially packed with about 0.017 m³ 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 m³/min, about 0.20 m³/min, about 0.30 m³/min, about 0.40 m³/min, about 0.50 m³/min, about 0.60 m³/min, or about 0.70 m³/min and may be substantially packed with about 0.005 m³, about 0.010 m³, about 0.020 m³, or about 0.025 m³, of suitable packing medium 820.

[0045] 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 degasser 122 may serve two roles, depending upon the quality of incoming water. For example, if water is supersaturated with dissolved gases, 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.

[0046] 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.

[0047] 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 sensors, 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.

[0048] 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.

[0049] The water flow rate sensors 128B and 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 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, water flow rate sensors 128B and 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.

[0050] In another embodiment, the water flow rate sensors 128B and 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 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 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.

[0051] The oxygen gas pressure sensors 128C and 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 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 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.

[0052] The component parts having been described, operation of the aquaculture system 10 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.

[0053] 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.

[0054] FIG. 9 illustrates a method 900 (*e.g.*, as executed by the controller) for controlling carbon dioxide in the aquaculture system 100. As shown in FIG. 9, the method 900 may include the step of retrieving a maximum carbon dioxide concentration and a maximum G:L (at step 932). The controllers 116 and/or 316 may retrieve the maximum carbon dioxide concentration and the maximum G:L 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 controllers 116 and/or 316 may then retrieve a current carbon dioxide concentration (at step 934), for example from a carbon dioxide sensor 128 in the culture tank 112, in the degasser 122, or some combination thereof, and may compare the current carbon dioxide concentration with the maximum carbon dioxide concentration (at step 936).

[0055] If the carbon dioxide concentration is less than the maximum carbon dioxide concentration, as determined at step 936, the controllers 116 and/or 316 may “do nothing,” or maintain current operation of the system 100 (at step 938). If the carbon dioxide concentration is greater than the maximum carbon dioxide concentration, as determined at step 936, the controllers 116 and/or 316 may determine or retrieve the current water flow rate (at step 940), determine or retrieve the current air flow rate (at step 942), calculate the current G:L (at step 944), and compare the current G:L to the maximum G:L (at step 946). If the current G:L is greater than the maximum G:L, as determined at step 946, the controllers 116 and/or 316 may increase the current water flow rate by increasing the speed of the variable speed pump 114 to increase the water flow rate (at step 948) in response to a calculated current G:L ratio greater than the maximum G:L ratio. It is envisioned that the water flow rate may be increased for a time period sufficient to lower the current G:L ratio to a value that is less than the maximum G:L ratio value. Such an increase in water flow rate may result in lowering the value of the current carbon dioxide concentration within the system 100 to a value less than the maximum carbon dioxide concentration as determined at step 932.

[0056] If the current G:L is less than the maximum G:L, as determined at step 946, the controllers 116 and/or 316 may increase the current air flow rate (at step 950) for a time period sufficient to lower the carbon dioxide concentration within the system 100 to a value less than the maximum carbon dioxide concentration as determined at step 932.

After the controllers 116 and/or 316 executes a necessary action (*e.g.*, at step 938, 948, or 950), the controllers 116 and/or 316 may wait for a predetermined time period (at step 952) and then revert back to step 934 to retrieve a new current carbon dioxide concentration and repeat the above process. In some embodiments, rather than "do nothing" at step 938, the controllers 116 and/or 316 may instead decrease the water flow rate or the air flow rate in the system (*e.g.*, based on the current G:L, as described above). In some embodiments, a flow control algorithm may be used to operate the variable speed pump 114 to maintain the current water flow rate after the water flow rate has been increased.

[0057] The predetermined time period at step 952 may be a suitable time period to allow the system 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(s) 112, a magnitude of action taken (*e.g.*, a longer time period for larger flow increases vs. a smaller time period for smaller flow increases), 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 aquatic life rest times), etc. In some embodiments, the predetermined time period is based on a magnitude of speed of the variable speed pump used to adjust a water flow rate to an increased or decreased water flow rate as compared to the current water flow rate. In some embodiments, a lookup table of time periods may be stored by the controllers 116 and/or 316, and the controllers 116 and/or 316 may determine the appropriate time period based on one or more of the variables discussed above. In addition, water flow rate may be increased (*i.e.*, at step 948) over a time period to allow a gradual or incremental ramping of pump speed. For example, the controllers 116 and/or 316 may determine an increase amount of the current water flow rate to a water flow rate of greater than about 1%, greater than about 2%, greater than about 4%, greater than about 8%, greater than about 10%, greater than about 15%, or greater than about 20% of the current water flow rate, and gradually ramp up the speed of the variable speed pump 114 until the increase amount is reached.

[0058] In addition to stored predetermined time periods, the controller 116 may store lookup tables of maximum carbon dioxide concentrations and maximum G:L ratios. In some embodiments, the maximums may be input by a user (*e.g.*, through a user interface of the controller 116) and stored in the lookup tables. In other embodiments, the controller 116 may include pre-stored lookup tables. In yet other embodiments, the controller 116 may be in communication with a network and is capable of downloading lookup tables. The controller 116 may select the maximums from the lookup tables based on a number of factors, such as species, mass, size, age (*i.e.*, growth cycle) of aquatic life, or a combination thereof. For example, smaller fish may survive in higher carbon dioxide concentrations in comparison to larger fish. In one specific example, a maximum carbon dioxide concentration for tilapia less than about 250 grams in weight may be up to about 60 mg/L and a maximum carbon dioxide concentration for tilapia greater than about 250 grams in weight may be up to about 20 mg/L.

[0059] Referring again to FIG. 1, in some embodiments, the controller 116 may execute one or more different actions to increase air flow rate. A first action includes adding air into the water by increasing the air fed into the degasser 122 (*e.g.*, by turning on and/or increasing a speed of the blower 124). Other actions may include adding water into the air (*i.e.*, aeration) through bubble diffusion, paddle wheel aerators, aspirators, propeller aerators, diffused aeration by disk diffuser, etc. Another action may include adding oxygen through the oxygen cone 120 or an oxygen saturator (*e.g.*, by automatic control of the proportional control valve 126 at the oxygen cone 120). In some embodiments, these actions may be selected to minimize operating costs in the system. For example, the controller 116 may select to add oxygen only during off-peak times (*e.g.*, at night) to reduce oxygen costs. In an embodiment, the action includes increasing the air flow rate through degasser 122 by operating the air blower 124.

[0060] Furthermore, in some embodiments, water pressure in the system may be monitored and variably adjusted instead of water flow. For example, the controller 116 may adjust restricting valves 126 positioned at an output of oxygen saturators to increase pressure of the system when the current carbon dioxide concentration is above the maximum. To maintain water flow rates in the system (*i.e.*, in accordance with the flow control algorithm described above) when the pressure is increased, the controller 116 may

also automatically increase the speed of pump 114. In some embodiments, the controller 116 or a user may select to operate under a pressure monitoring model or a flow monitoring model based on pump efficiency and energy consumption.

[0061] In addition, in some embodiments, the controller 116 may execute other actions alone, or in conjunction with other actions described herein, to remove carbon dioxide. For example, in addition to the physical actions described above, the controller 116 may execute chemical actions by adding chemical binding agents to the culture tank(s) 112. The binding agents, such as sodium hydride (NaH) or calcium hydride (CaH₂), interact with the carbon dioxide to form bicarbonate. In one embodiment, the controller 116 may execute chemical actions only after a number of process iterations using physical actions fail to reduce the carbon dioxide concentration below the maximum. In another embodiment, the controller 116 may execute chemical actions prior to the physical actions to attempt to reduce the carbon dioxide concentration below the maximum.

[0062] In some embodiments, the controller 116 may monitor and/or store the carbon dioxide concentration and the actions taken over time. For example, the controller 116 may monitor how long the current carbon dioxide concentration stays above the maximum carbon dioxide concentration. If the controller 116 fails to reduce the carbon dioxide 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.

[0063] 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.

[0064] 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 other 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 further 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.

[0065] Although controller 116 is described throughout, the controllers 316 and/or 600 may perform one or more of the functions associated with controller 116.

[0066] 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.

[0067] 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 carbon dioxide concentration and a maximum gas to liquid ratio;

retrieving a current carbon dioxide concentration;

comparing the current carbon dioxide concentration with the maximum carbon dioxide concentration; and

when the current carbon dioxide concentration is greater than the maximum carbon dioxide concentration,

determining a current gas to liquid ratio using a current water flow rate and a current air flow rate,

increasing the current water flow rate when the current gas to liquid ratio is greater than the maximum gas to liquid ratio, and

increasing the current air flow rate when the current gas to liquid ratio is less than the maximum gas to liquid ratio.

2. The method of claim 1 further comprising providing a variable speed pump, and wherein increasing the current water flow rate includes increasing a speed of the variable speed pump.

3. The method of claim 2 further comprising using a flow control algorithm to operate the variable speed pump to maintain the current water flow rate after the water flow rate has been increased.

4. The method of claim 1 further comprising providing a degasser, and wherein increasing the air flow rate includes operating an air blower through the degasser.

5. A recirculating aquaculture system for aquatic life, the system comprising:
a culture tank;
a sensor configured to measure a carbon dioxide concentration in the culture tank;
a variable speed pump configured to circulate water through the culture tank; and
a controller in communication with the sensor and the variable speed pump, the controller configured to:

retrieve a maximum carbon dioxide concentration and a maximum gas to liquid ratio in the culture tank,

retrieve a current carbon dioxide concentration,

compare the current carbon dioxide concentration with the maximum carbon dioxide concentration, and

when the current carbon dioxide concentration is greater than the maximum carbon dioxide concentration,

determine a current gas to liquid ratio using a current water flow rate and a current air flow rate,

increase the current water flow rate when the current gas to liquid ratio is greater than the maximum gas to liquid ratio, and

increase the current air flow rate when the current gas to liquid ratio is less than the maximum gas to liquid ratio.

6. The system of claim 5, wherein the controller is configured to wait a predetermined time period after increasing one of the current water flow rate and the current air flow rate and to retrieve a new current carbon dioxide concentration after the predetermined time period.

7. The system of claim 6, wherein the predetermined time period is based on a volume of the culture tank.

8. The system of claim 5, wherein the controller includes a user interface and the controller is configured to retrieve the maximum carbon dioxide concentration and the maximum gas to liquid ratio based on user input.

9. The system of claim 5, wherein the controller is configured to retrieve the maximum carbon dioxide concentration from a look-up table based on at least one of species, age, mass, and size of the aquatic life.

10. The system of claim 5, wherein when the current carbon dioxide concentration is less than the maximum carbon dioxide concentration, the controller is configured to:

determine the current gas to liquid ratio using the current water flow rate and the current air flow rate;

decrease the current water flow rate when the current gas to liquid ratio is greater than the maximum gas to liquid ratio; and

decrease the current air flow rate when the current gas to liquid ratio is less than the maximum gas to liquid ratio.

11. The system of claim 5, wherein the controller is configured to add a chemical binding agent to the culture tank when the current carbon dioxide concentration is greater than the maximum carbon dioxide concentration.

12. The system of claim 5 further comprising a degassing tower and an air blower, wherein the controller is configured to increase the current air flow rate through the degassing tower by operating the air blower.

13. The system of claim 5, wherein the controller includes a variable frequency drive.

14. The system of claim 5, wherein the controller is integrated into the variable speed pump.

15. The system of claim 5, wherein the controller is further configured to initiate an alarm when the current carbon dioxide concentration is greater than the maximum carbon dioxide concentration for greater than a predetermined time period.

16. A method for controlling carbon dioxide in an aquaculture system, the aquaculture system including a culture tank that houses aquatic life, the method comprising:

measuring a current carbon dioxide concentration in a culture tank;

retrieving a maximum carbon dioxide concentration and a maximum gas to liquid ratio;

comparing the current carbon dioxide concentration with the maximum carbon dioxide concentration;

increasing at least one of the current water flow rate and the current air flow rate, based on the comparison of the current carbon dioxide concentration with the maximum carbon dioxide concentration; and

waiting a predetermined time period, then reverting back to measuring a current carbon dioxide concentration and repeating the method steps.

17. The method of claim 16, further comprising providing a variable speed pump, and wherein the predetermined time period is based on a magnitude of speed of the variable speed pump used to increase the current water flow rate.

18. The method of claim 16, further comprising providing a variable speed pump, and wherein increasing the current water flow rate comprises incrementally ramping up the speed of the variable speed pump.

19. The method of claim 16, wherein the predetermined time period is based on a volume of the culture tank.

20. The method of claim 16 further comprising providing an oxygen cone including a proportional control valve, and wherein the current air flow rate is increased by controlling the proportional control valve of the oxygen cone.

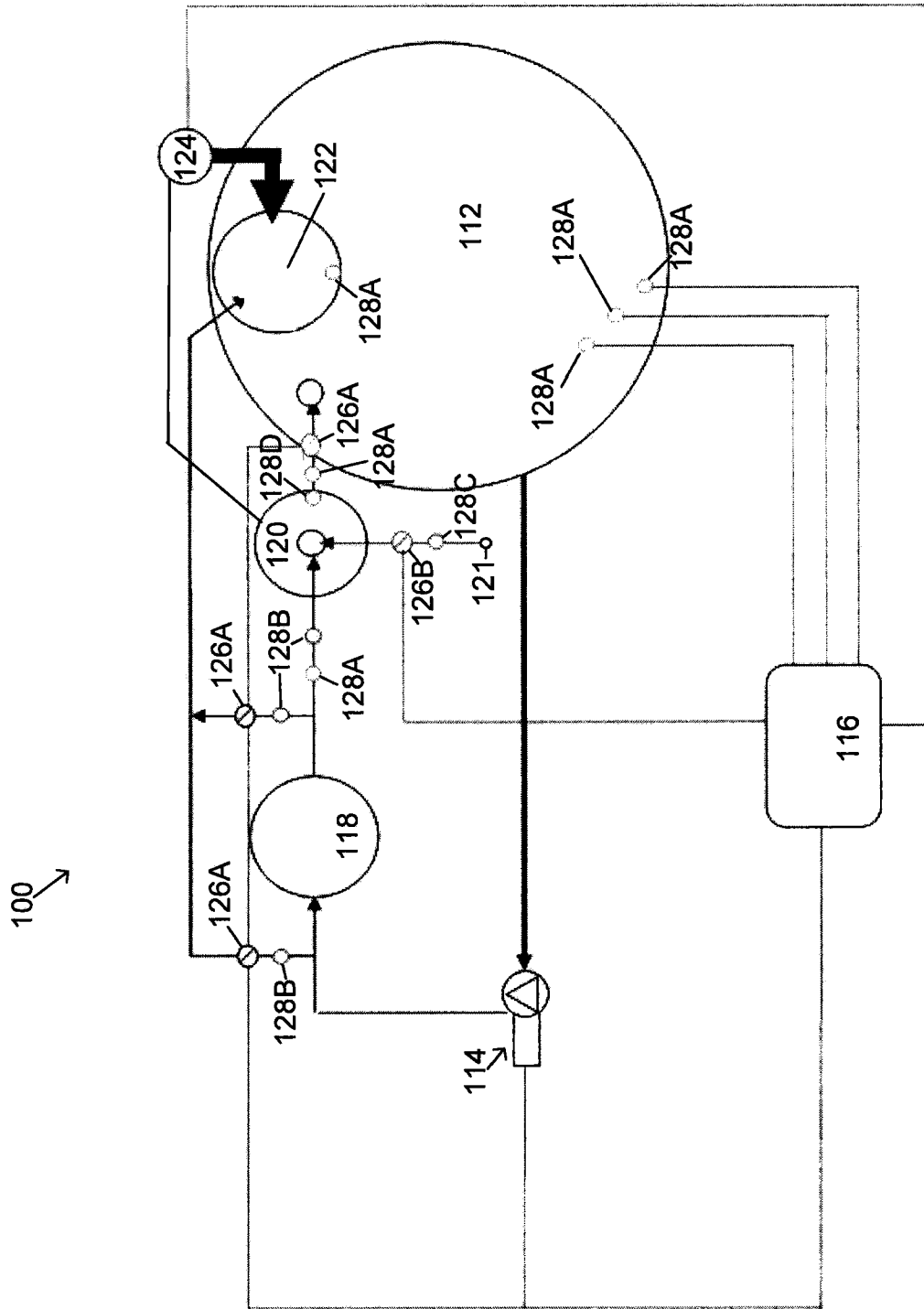


FIG. 1

2/8

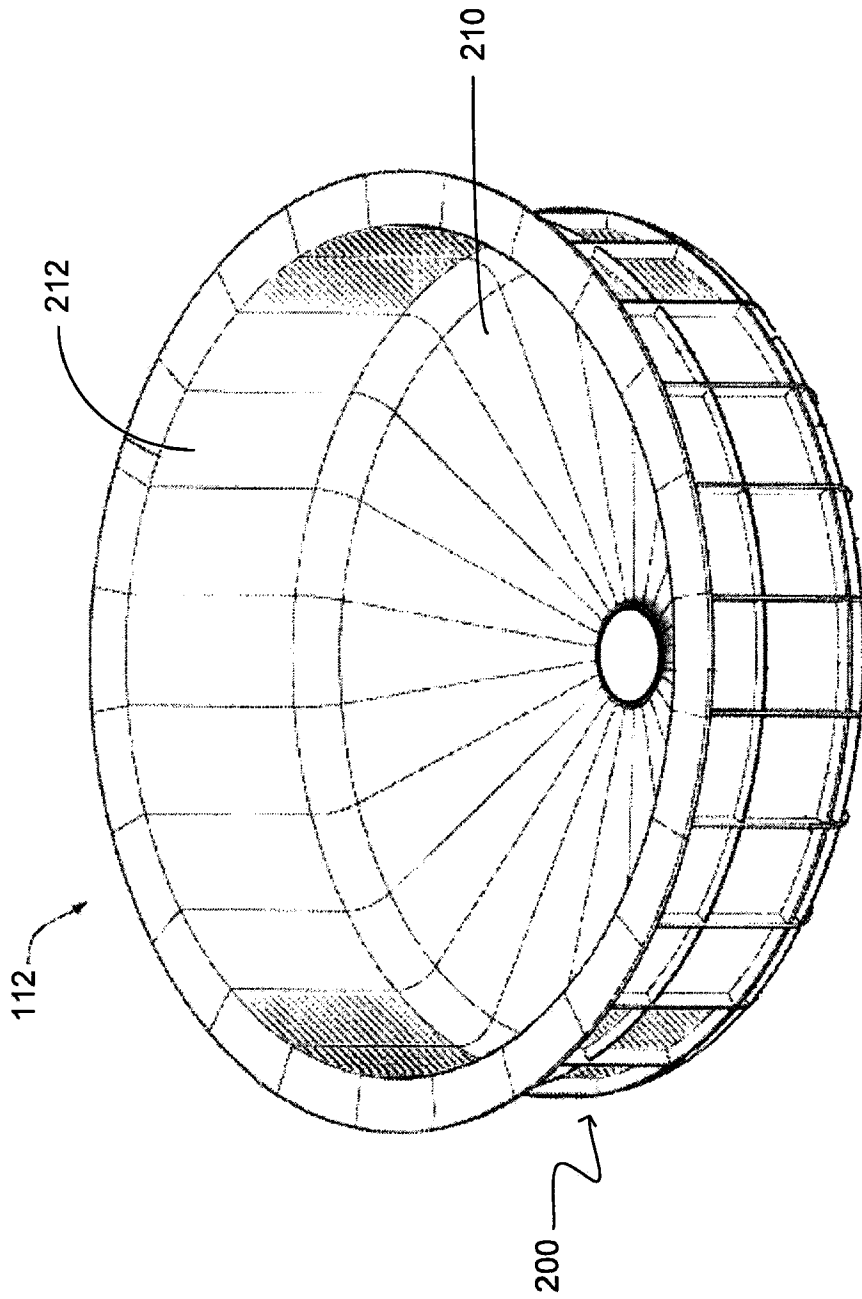


FIG. 2

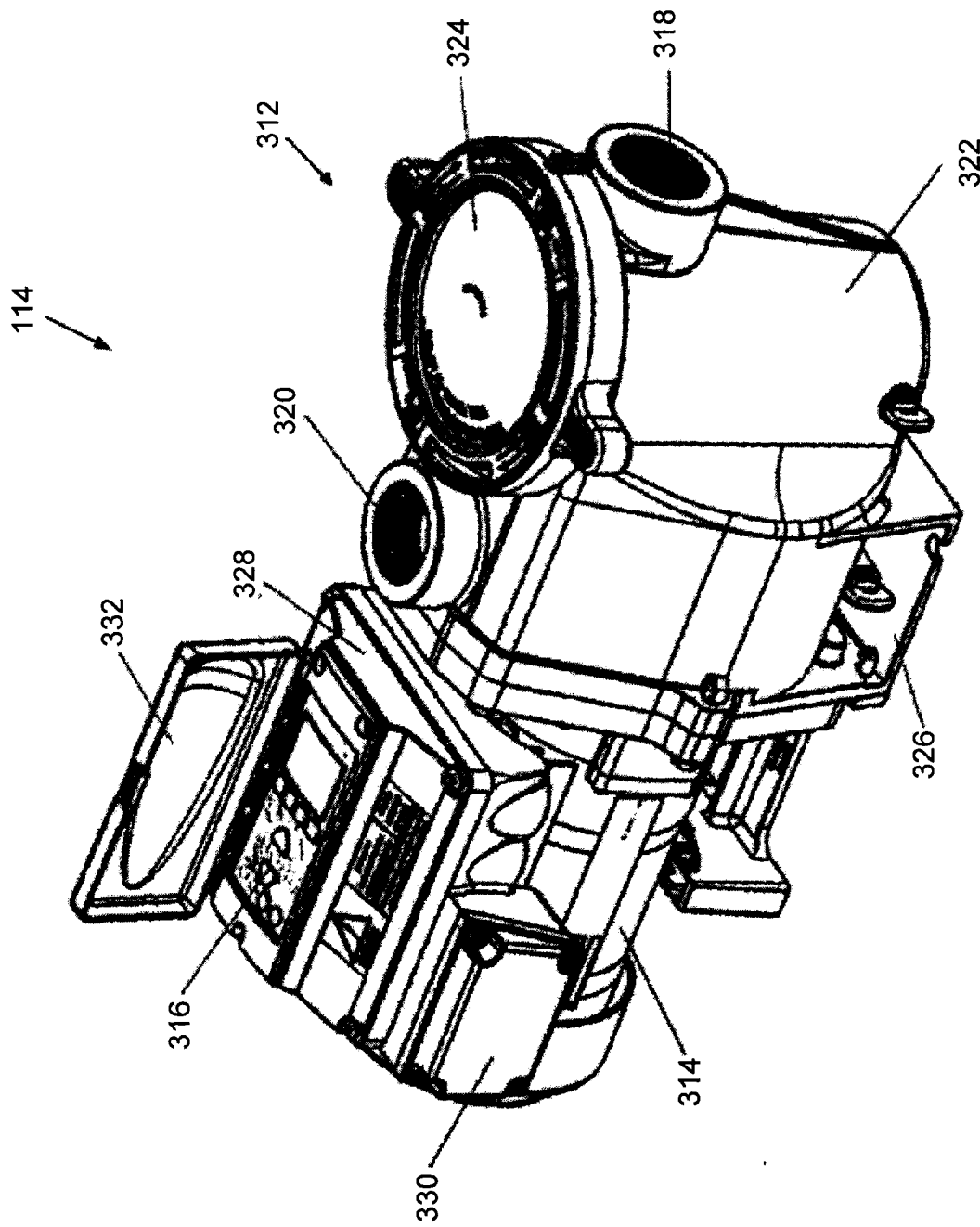


Fig. 3

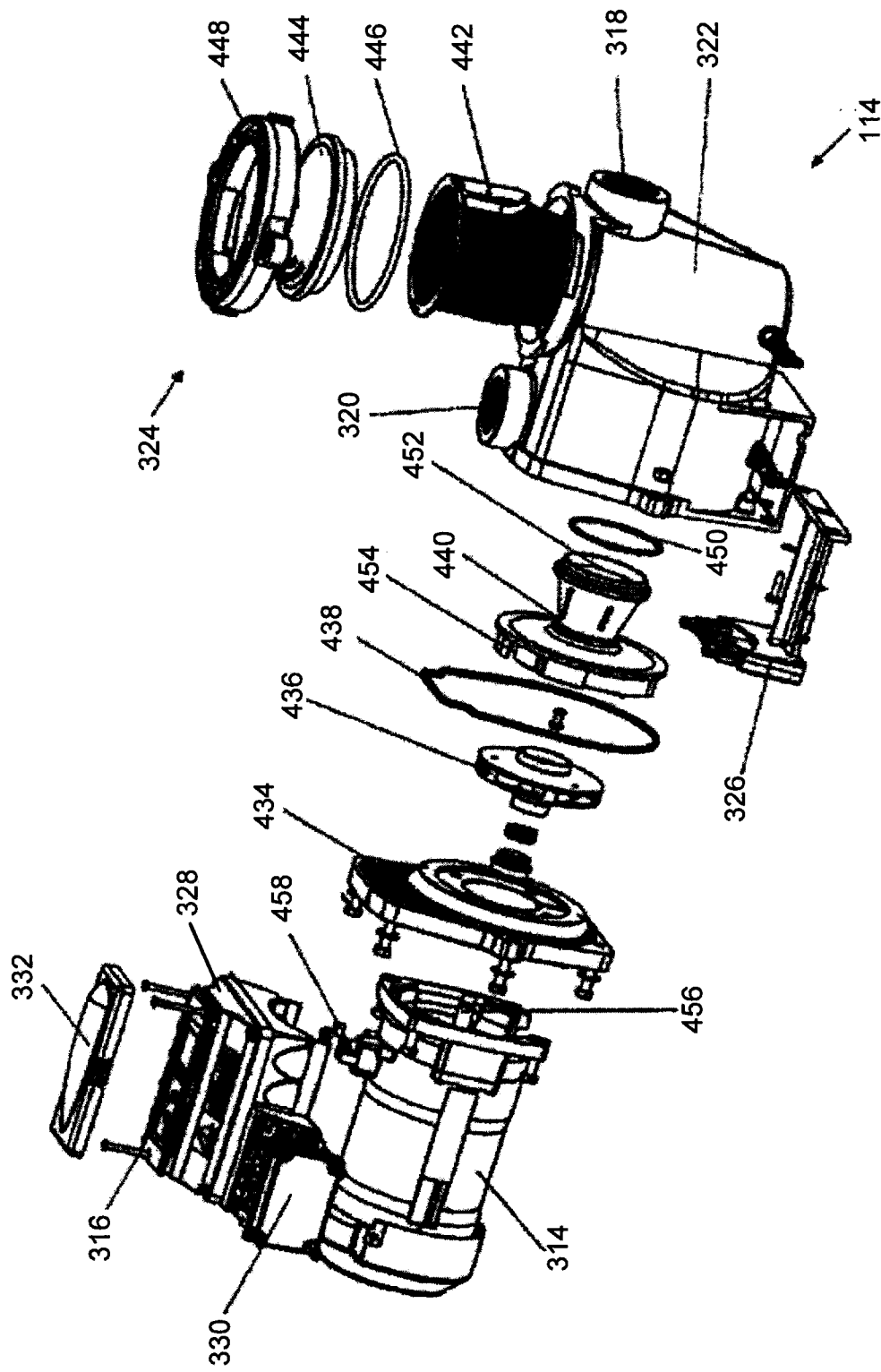


Fig. 4

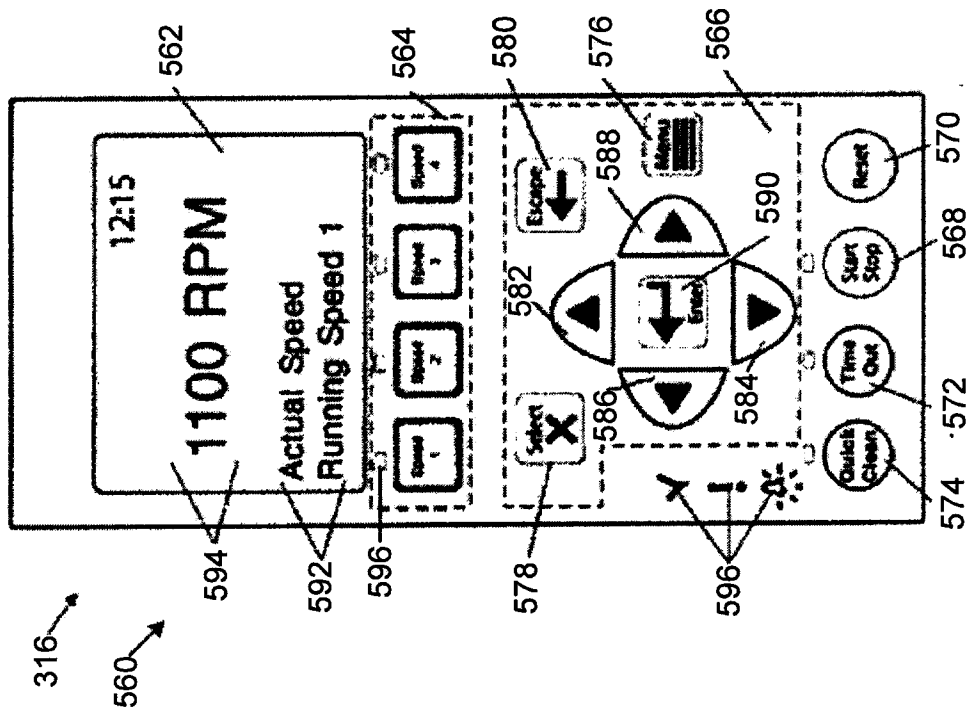


Fig. 5

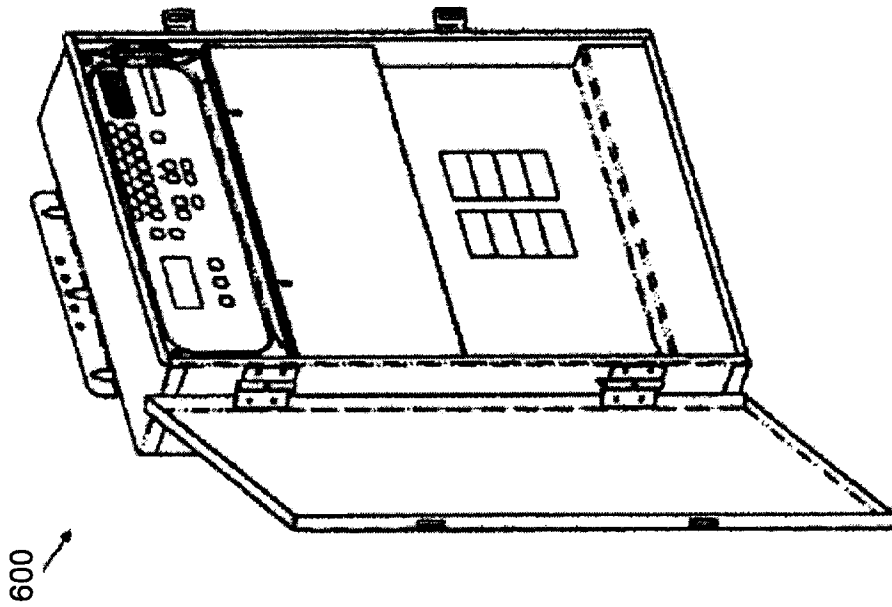


Fig. 6

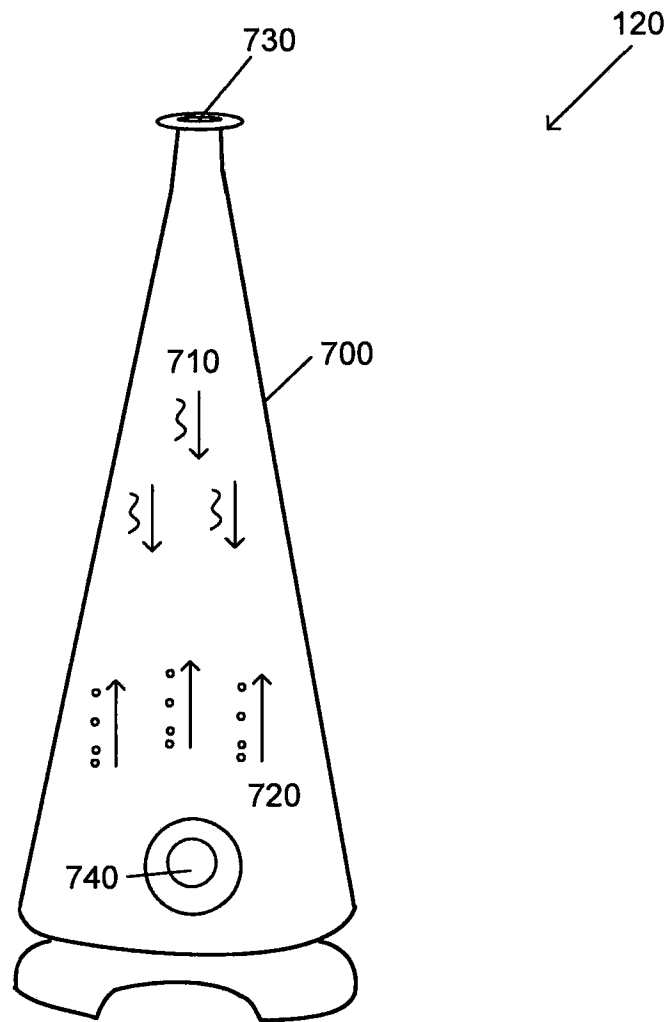


Fig. 7

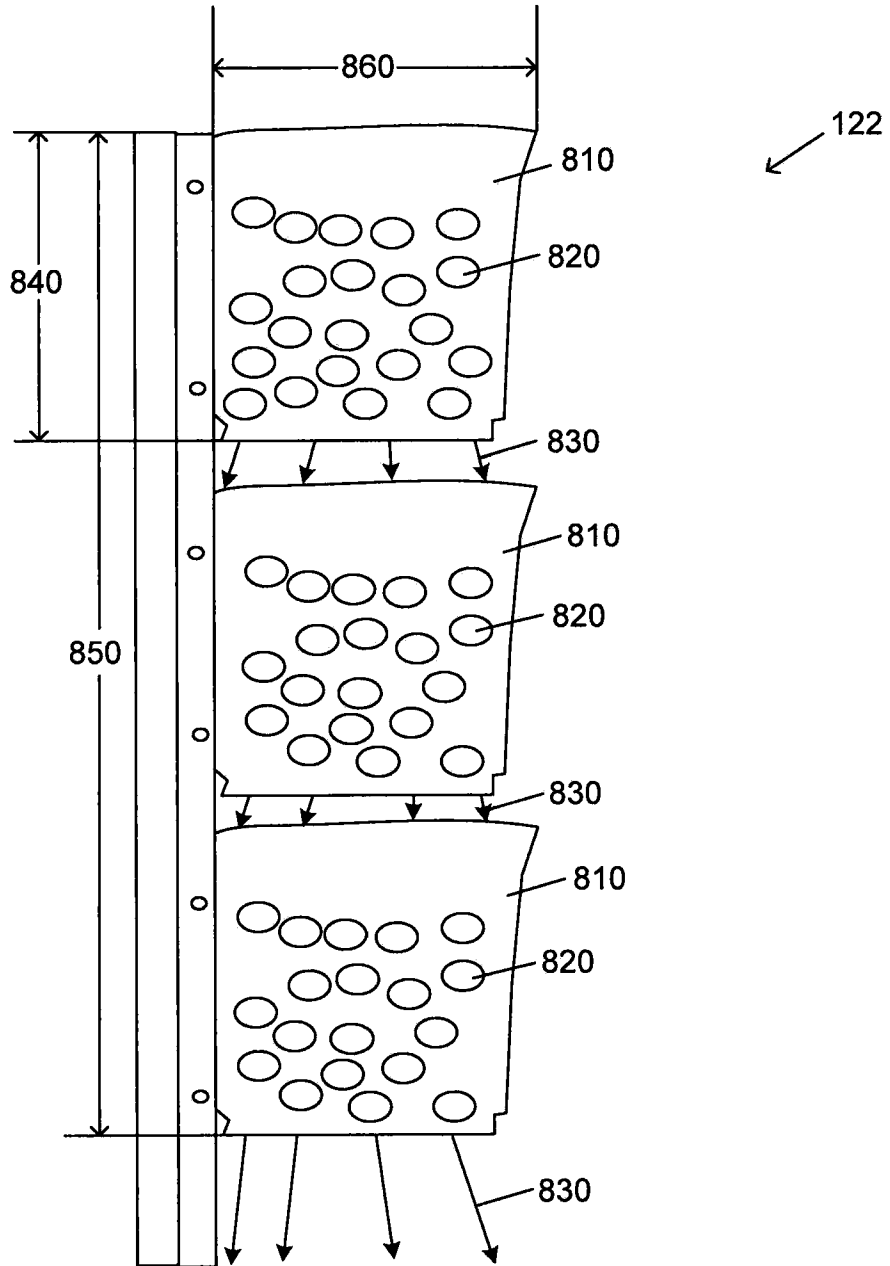


Fig. 8

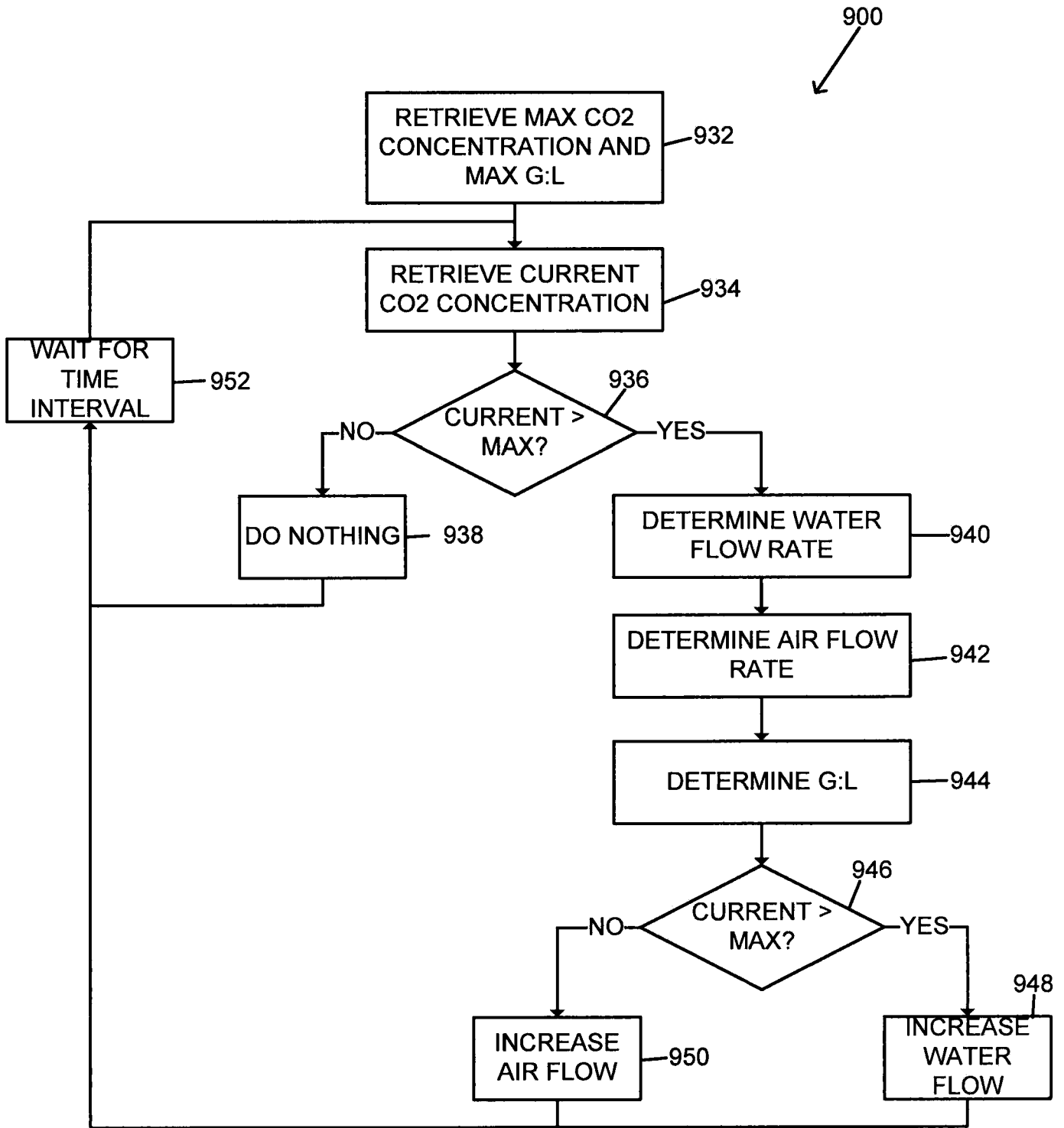


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/028269

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B01F 5/04 (2014.01)

USPC - 119/215

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) - B01F 5/04 (2014.01)

USPC - 119/215

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B01J 10/00 (2014.06)

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

PatBase, 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.
X — Y	SUMMERFELT et al. Oxygenation and carbon dioxide control in water reuse systems. Aquacultural Engineering 22(1-2): 87-108, 2000. [retrieved on 30 June 2014]. Retrieved from the Internet. <URL: http://photonics.inescporto.pt/outputs/fct2009/summerfelt-st_2000.pdf > entire document	1, 4 ----- 2, 3, 5-20
Y	US 7,845,913 B2 (STILES JR et al) 07 December 2010 (07.12.2010) entire document	2, 3, 5-20
A	US 2008/0041773 A1 (MORSE) 21 February 2008 (21.02.2008) entire document	1-20
A	US 7,854,597 B2 (STILES JR et al) 21 December 2010 (21.12.2010) entire document	1-20
A	US 6,499,431 B1 (LIN et al) 31 December 2002 (31.12.2002) entire document	1-20
A	US 6,117,313 A (GOLDMAN et al) 12 September 2000 (13.09.2000) entire document	1-20

 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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

30 June 2014

Date of mailing of the international search report

24 JUL 2014

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, Virginia 22313-1450

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