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(54) **GAS DISSOLVING APPARATUS AND METHOD**

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(57) **ABSTRACT**

A method and apparatus for dissolving a gas into a fluid which may contain at least one other dissolved gas. The apparatus includes an inlet tube for receipt of the fluid from a container containing the fluid. A gas inlet is operably connected to the inlet tube for the introduction of gas into the fluid. The mixture of gas and fluid is introduced into a gas transfer device via the inlet tube. The gas transfer device is positioned below the surface of the fluid in the container so that the gas transfer device is hydrostatically pressurized in order to increase the rate and concentration at which the gas is dissolved into the fluid. The gas and fluid mixture is allowed to flow downward through the gas transfer device such that bubbles of gas are dissolved in the fluid. The fluid having the gas dissolved therein enters an outlet means positioned within the gas transfer device. The fluid having the gas dissolved therein flows upward through the outlet means and is released from the gas transfer device while the bubbles of gas which are not dissolved in the fluid are retained in the gas transfer device.

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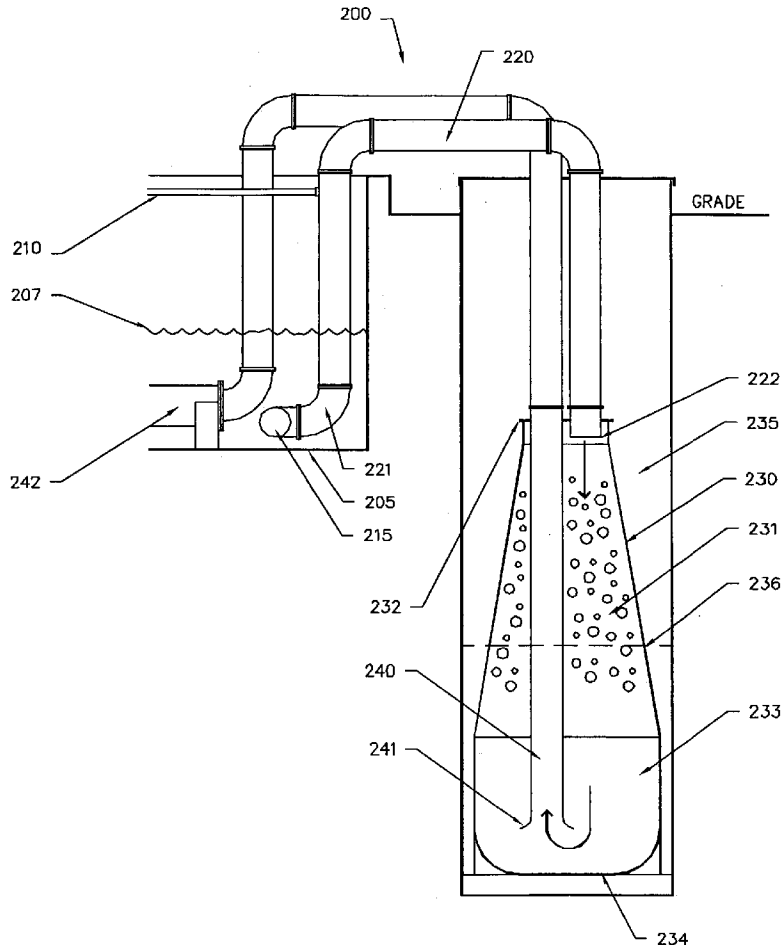
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(63) Continuation-in-part of application No. PCT/US01/30793, filed on Oct. 2, 2001.

Continuation of application No. 09/677,369, filed on Oct. 2, 2000, now Pat. No. 6,322,055.



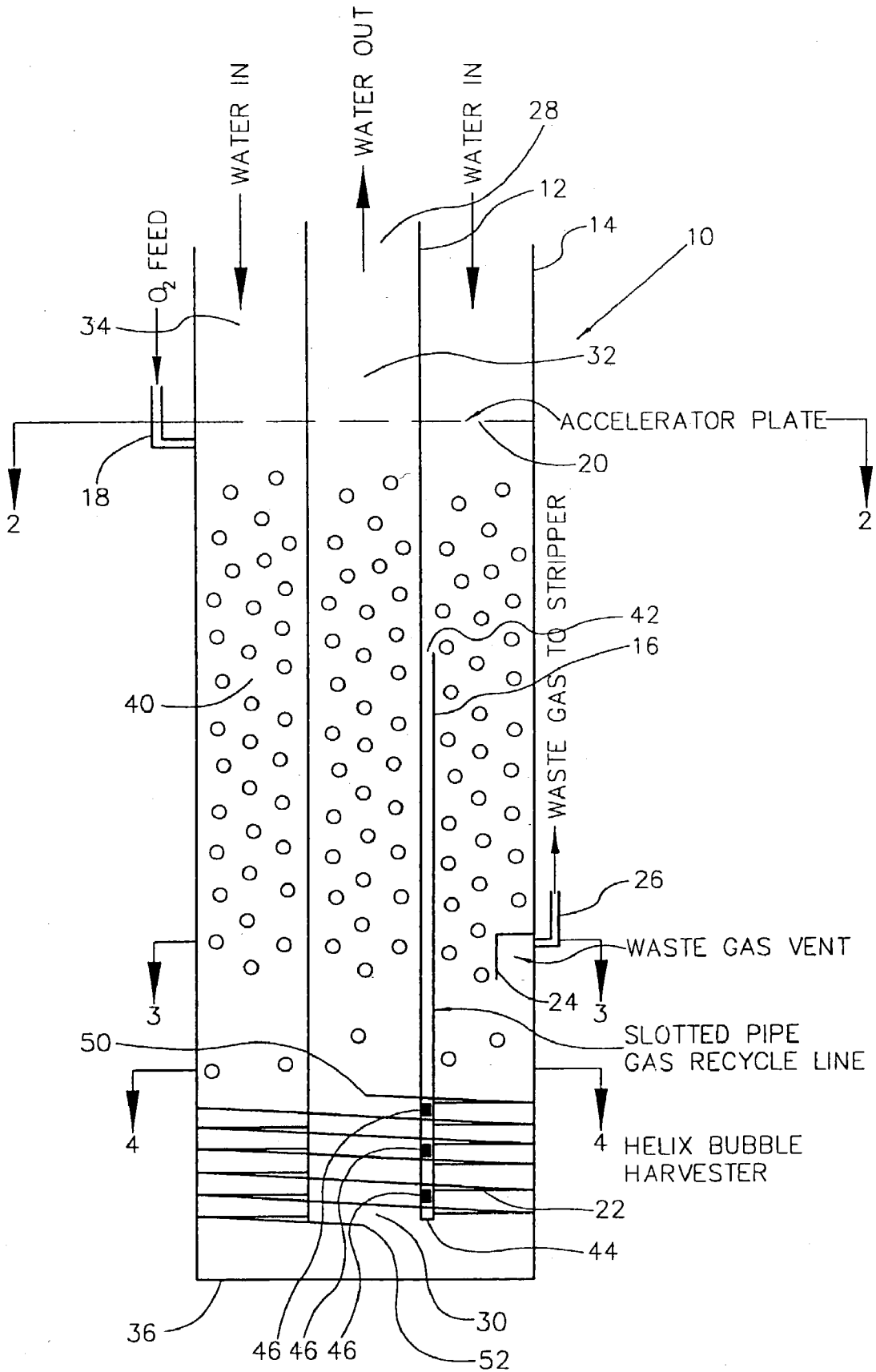


FIGURE 1

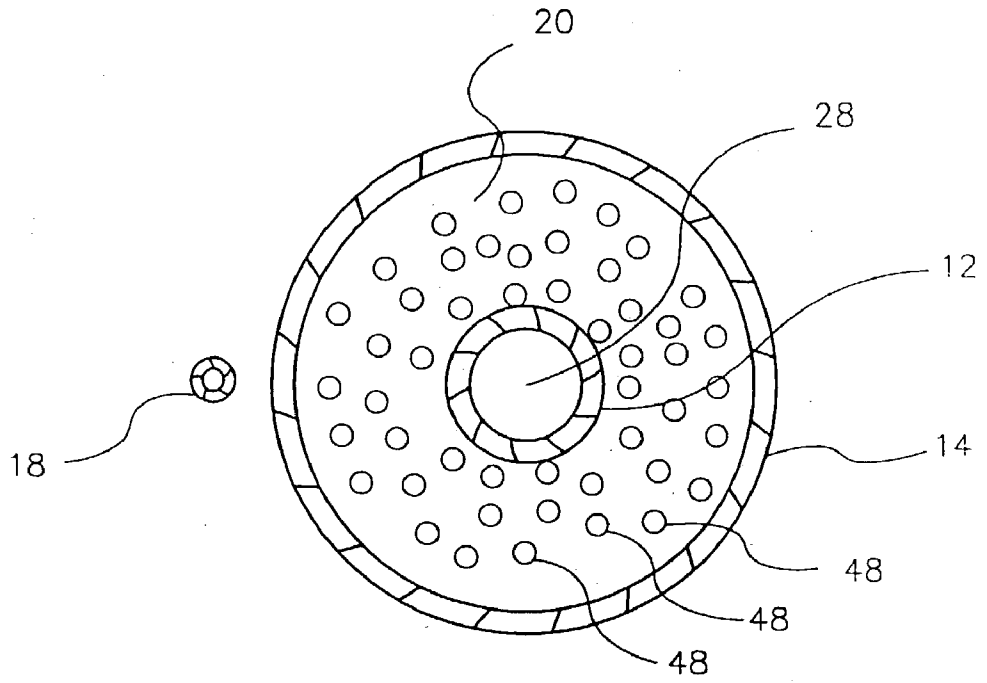


FIGURE 2

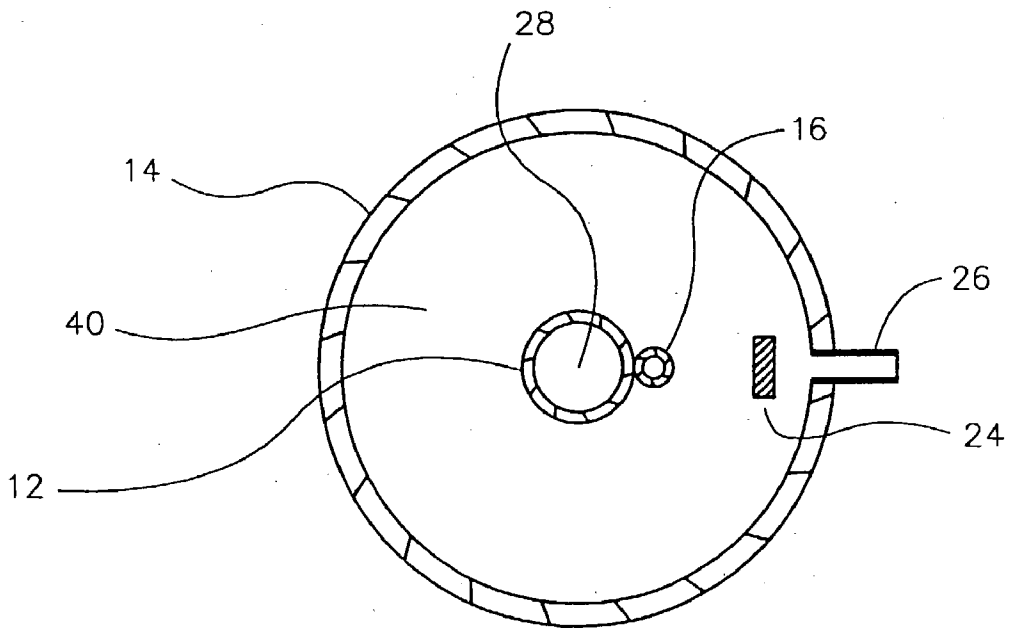


FIGURE 3

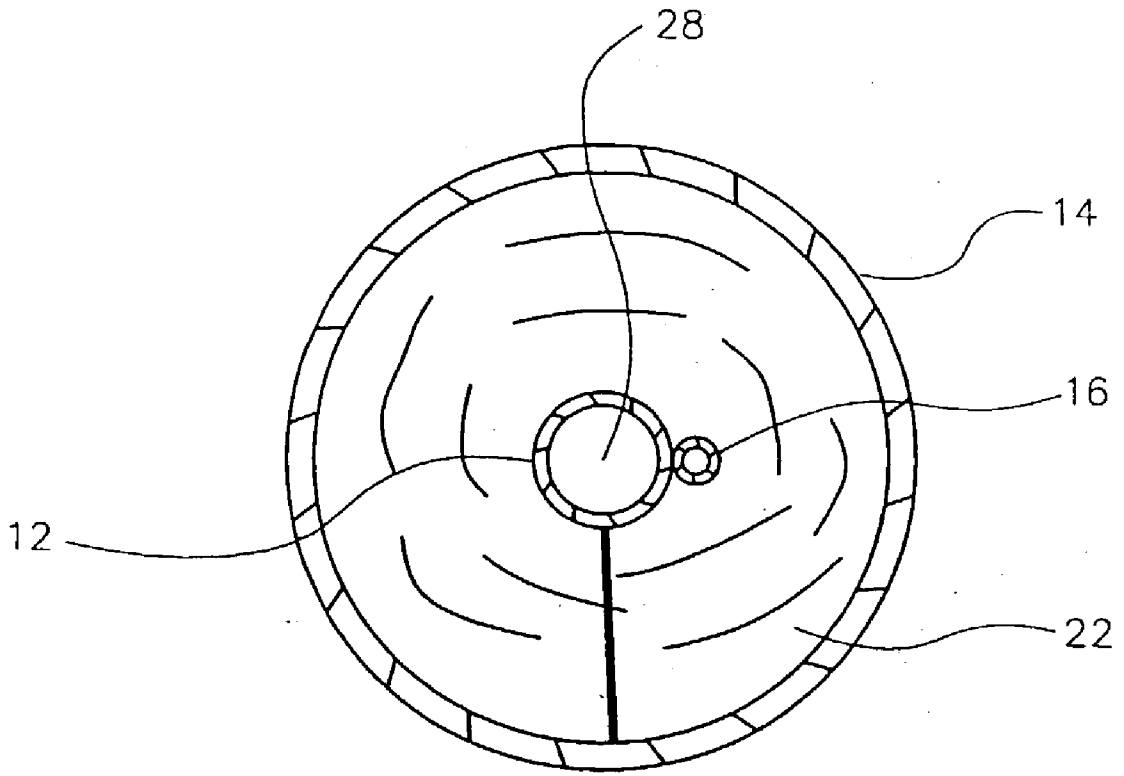


FIGURE 4

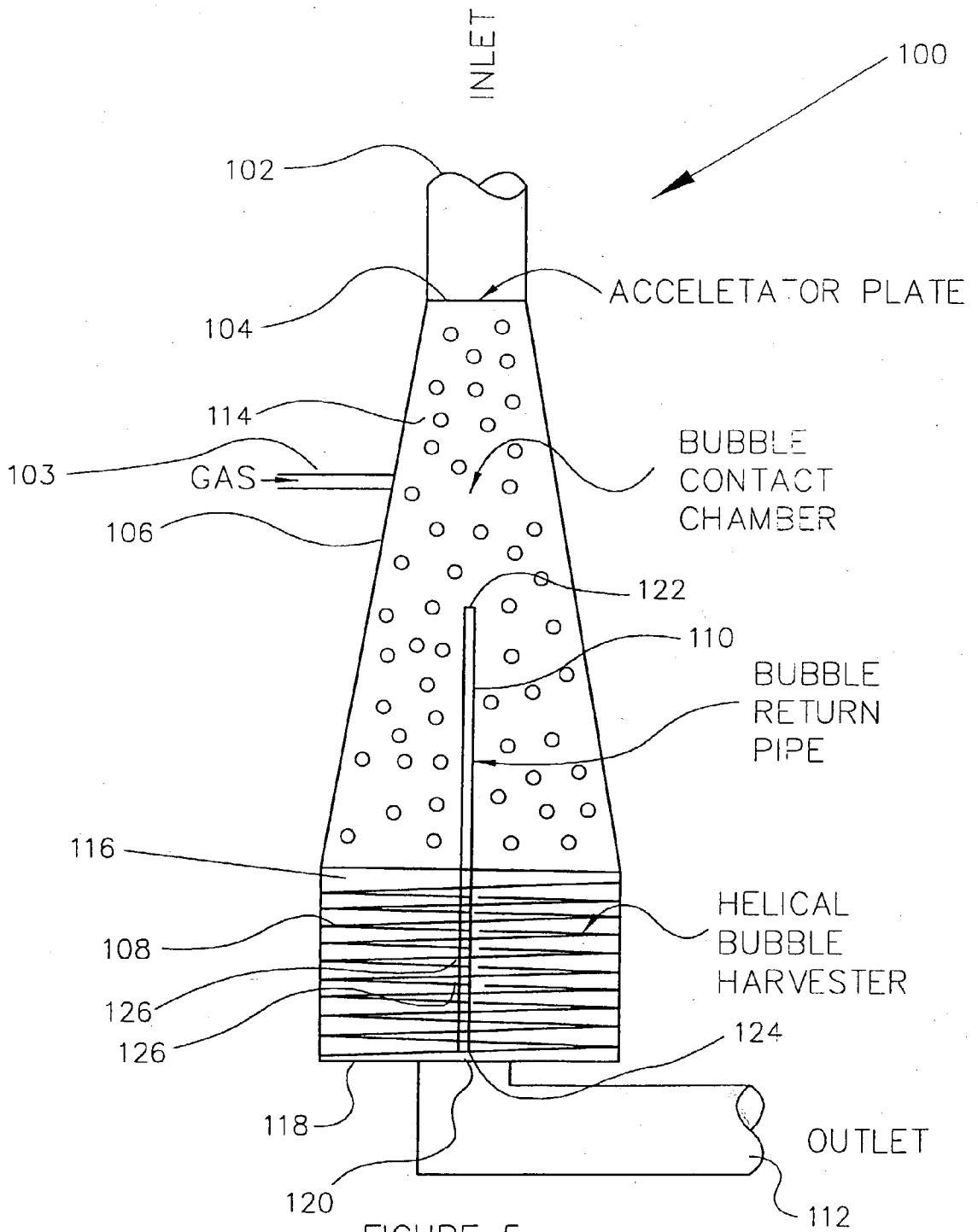


FIGURE 5

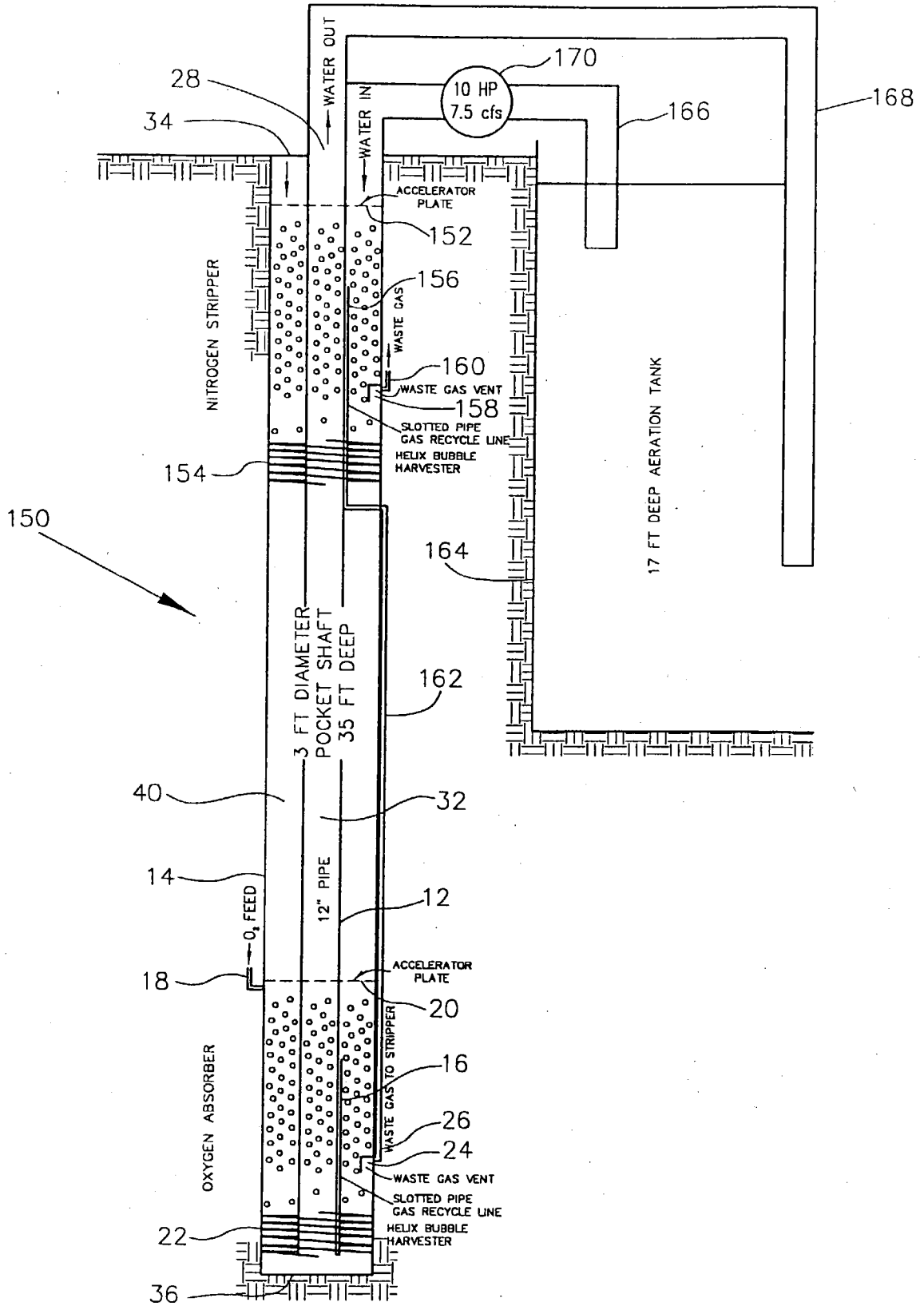


FIGURE 6

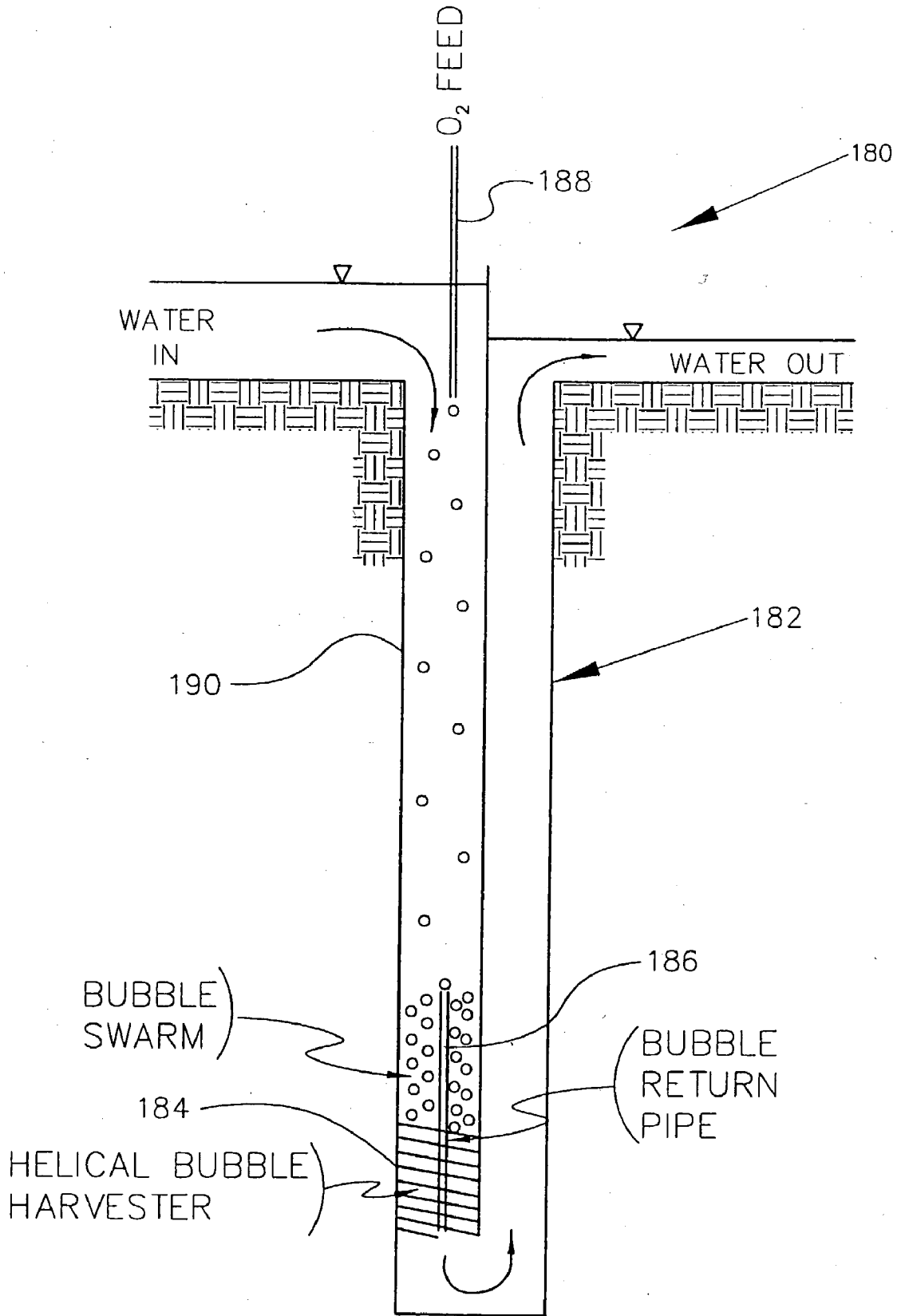


FIGURE 7

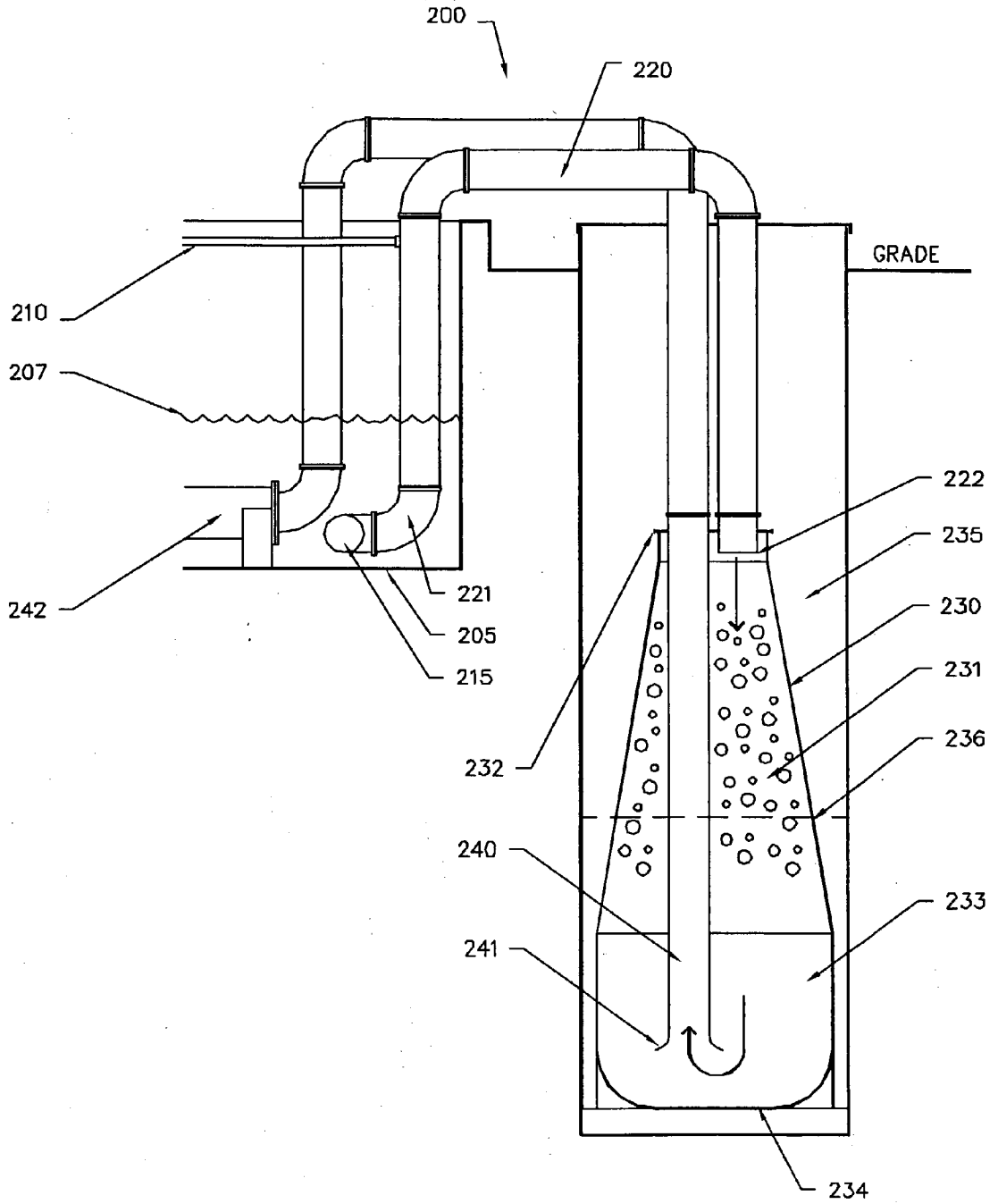


FIGURE 8

GAS DISSOLVING APPARATUS AND METHOD**RELATED PATENT APPLICATIONS**

[0001] This application is a continuation-in-part of International Application No. PCT/US01/30793, filed on Oct. 2, 2001, and assigned to the same assignee as the present invention. International Application No. PCT/US01/30793 was published in English, and is a continuation of U.S. Ser. No. 09/677,369, filed on Oct. 2, 2000, now U.S. Pat. No. 6,322,055, and assigned to the same assignee as the present invention.

BACKGROUND OF THE INVENTION

[0002] There are many instances when it is desirable to dissolve a gas, whether soluble or insoluble, into a fluid which may already contain other dissolved gases. For example, the macro and microbial organisms in all rivers, lakes, oceans, and all aerobic wastewater treatment processes are based on the presence of sufficient dissolved oxygen to sustain their life processes. Normally, in undisturbed bodies of water there is a rather low density of macro and micro organisms in the surface water and the limited natural absorption of oxygen from the air into the water is sufficient to maintain sufficient concentrations of dissolved oxygen in the water to sustain the life processes of that body of water. However, with increased population density and industrial activity, the associated organic water pollution causes a high microbial oxygen demand that natural oxygen aeration processes cannot begin to provide sufficient oxygen resources. Thus, artificial aeration mechanisms are required to enhance oxygen absorption.

[0003] Some specific examples of oxygenation applications are worthy of discussion. Odors at aerobic wastewater treatment facilities are associated with the inability to maintain sufficient levels of dissolved oxygen ("D.O."). In the absence of sufficient D.O., nitrates are reduced to N_2 gas. In the absence of both D.O. and nitrates, strongly reducing conditions develop and sulfates are reduced to H_2S , also known as "rotten egg gas." This process can occur in any aquatic system where the oxygen demand exceeds the D.O. supply. In addition, indoles, skatoles, and mercaptans are also generated. These volatile compounds all have an offensive odor even at very low concentrations.

[0004] The high organic pollution in municipal wastewater of sewer lift stations supports a corresponding high microbial population, which, in turn, requires a high rate of D.O. to meet the demand. If the demand is not met, H_2S formation readily occurs, as well as the formation of other compounds that have an offensive odor. Consequently, sewer force mains are a common source of odor nuisance for municipal public works.

[0005] Some industries (pharmaceutical, petroleum, and chemical, for example) create significant air pollution problems in the course of aerobically treating their wastewater by the use of conventional aeration systems. The wastewaters contain significant volatile organics/solvents which are readily biodegradable if they can be retained in the aqueous phase for a sufficient time. The use of conventional aeration systems has led to the requirement that the wastewater aeration basins must be covered to capture and incinerate the off gas in order to comply with air emission regulations. The need for a covered basin arises because conventional aera-

tion systems readily strip the organics/solvents from the aqueous phase, not allowing for a sufficient time to biodegrade in the liquid.

[0006] Aerobic activated sludge processes are dependent upon oxygen transfer and sludge settling and recycle in the secondary clarifiers. It is now possible to develop high concentrations of sludge concentrations within the reactors, such as with the use of aerobic fluidized beds and moving bed filters, to the point where oxygen transfer becomes the limiting factor. Specifically, high levels of D.O. are required without subjecting the sludge to high energy dissipation/turbulence conditions which could shear off the biofilms or hinder flocculent sedimentation in the secondary clarifiers.

[0007] Fish farming and shrimp production commonly occurs in large ponds. To maximize production, the ponds are operated at the edge of D.O. availability. Since a still pond absorbs very little oxygen, there exists a need for artificial aeration to sustain high levels of fish/shellfish production.

[0008] The desire to increase dissolved oxygen levels is also applicable to slow moving rivers (such as the Cuyahoga River flowing through Cleveland, Ohio, and the rivers in Bangkok and Taipei) and canals (such as the waterways of Chicago, Ill. and the canals of Amsterdam). Many industries must curtail production (to considerable economic detriment) due to insufficient D.O. in the rivers, streams, and canals to which they discharge their treated wastewaters. Odor and corrosion problems can also occur in the bottom layer of stratified lakes and reservoirs feeding hydroelectric power dams. The low D.O. levels also result in fish kills.

[0009] Systems for dissolving a gas into a fluid are not limited to dissolving oxygen in water. Other gas/fluid combinations include: hydrogenation of vegetable oils, coal liquification, yeast production, Vitamin C production, pharmaceutical and industrial aerobic bioprocesses, and other processes well known in the art.

[0010] Therefore, it is desired to provide an apparatus and method of dissolving a gas into a fluid possibly containing other dissolved gases that has application in at least the following situations:

- [0011] Slow moving rivers and canals
- [0012] Reservoirs
- [0013] Fish, shrimp shellfish, and/or mussel ponds
- [0014] Aerobic wastewater treatment systems
- [0015] Sewer lift stations
- [0016] Wastewater industries such as the pharmaceutical, petroleum, and chemical industries
- [0017] Aerated lagoons
- [0018] Hydrogenation of vegetable oils
- [0019] Coal liquification
- [0020] Yeast Production
- [0021] Vitamin C product
- [0022] Pharmaceutical and industrial aerobic bioprocesses
- [0023] Ozonation of water or other fluids

[0024] Dissolving xenon in fluids for injecting into the body

[0025] Supersaturating eye-wash liquids with super-saturated D.O.

[0026] Conventional aeration systems either bubble air through diffusers in the bottom of the aeration tank or splash the water in contact with the air. These systems typically absorb 1 to 2 lbs. of oxygen per kilowatt hour of energy consumed. Oxygen absorption efficiency is generally not an issue with these systems because air is free. These systems are most efficient when the D.O. in the water is near zero and are progressively inefficient as the water D.O. level approaches saturation, i.e., 9.2 ppm at 20° C. at sea level. Because the oxygen used in the aeration process is from the air and therefore at no cost, the costs of such systems emanates from capital costs and operating costs. The capital cost of a surface aerator capable of dissolving one ton per day of D.O. is about \$40,000. The cost of power for the aerator is \$70 to \$140/ton of D.O. If the capital costs are amortized at 8% for a 10 year life, the total cost is approximately \$87 to \$157/ton of D.O.

[0027] In addition to costs, there are other disadvantages or shortcomings of conventional aeration systems. These shortcomings include: (a) low achievable D.O. concentrations of only 1 to 3 ppm; (b) high off-gas production; (c) high air stripping of volatile organic contaminants; (d) high energy dissipation in the reactor; (e) floc shear; and (f) limited D.O. supply potential.

[0028] As an alternative to conventional systems using "free" air to increase D.O. levels, systems now exist which generate or store oxygen on-site and dissolve this generated or stored oxygen into the water. Some of these systems are as economical as conventional aeration systems. Some of these systems address some of the shortcomings of conventional aeration systems. However, these systems have their own shortcomings.

[0029] For example, when high purity oxygen is being transferred into water, issues arise as to handling of dissolved nitrogen ("D.N.") already in the water. D.N. is not utilized in an aqueous environment. Air is primarily comprised of 21% oxygen and 79% nitrogen gas. When water is in contact with air for prolonged periods, the water is saturated with D.N. At 20° C., the saturation concentration of D.N. in water is 16 mg/L. With conventional aeration systems, D.N. levels remain in a steady state. However, when high purity oxygen is introduced into the water, it results in a reduced D.N. partial pressure which strips the D.N. from the dissolved phase into the gas phase where it, in turn, reduces the percentage oxygen composition. The reduction in percentage oxygen composition reduces the partial pressure of oxygen in the gas phase, and the saturation concentration of oxygen, and ultimately the rate of oxygen transfer.

[0030] Thus, the presence of D.N. in the incoming water presents a trade-off situation. If high oxygen absorption efficiency is to be achieved, the increased nitrogen gas composition in the gas phase has to be accepted. This reduces the D.O. concentration which can be achieved in the discharge. Conversely, if high D.O. levels are to be achieved in the discharge, then the stripped nitrogen in the gas phase has to be wasted to reduce its percentage composition

carrying with it a commensurate ratio of oxygen gas and reducing the percentage oxygen absorption efficiency.

[0031] Therefore, it is desirable to develop an oxygenation system which manages the level of D.N. already present in the water, and which reduces the composition of N₂ of the gas phase to allow for higher potential D.O. saturation (total gas composition of N₂+O₂=100%). Further, effervescent loss of highly saturated D.O. in the discharge should be prevented if the D.N. is reduced. Of course, these principles are applicable to dissolving a gas into a fluid containing dissolved gases other than dissolving oxygen in water (containing dissolved nitrogen).

[0032] Another problem associated with prior art systems is the ability of the systems to provide a protracted period of contact (generally preferred to be greater than 100 seconds) of the bubbles of oxygen (air) with the water. Prolonged contact of the bubbles with the water helps to ensure a high oxygen absorption efficiency. Further, bubbles in the water should be controlled—the greater number of bubbles of oxygen, the greater the percentage oxygen absorption efficiency. Therefore, it is desired to provide an oxygenation system and method which fully utilizes the bubbles in the system and which prolongs the contact of those bubbles with the water to increase oxygen absorption efficiency of the apparatus.

[0033] With regard to the systems using oxygen rather than air, it is well known that high purity oxygen can be transported to the site in the form of liquid oxygen which is subsequently converted to gaseous oxygen for delivery to the oxygenator apparatus. Alternatively, on-site generation using cryogenic separation or pulsed swing adsorption produced O₂ is feasible for oxygen requirements of 0.5 to 40 tons or more per day. Costs of liquid oxygen transported to the site fluctuate with the vagaries of site-specific conditions and the number of regional suppliers in competition, among other factors. Thus, in some instances, the cost of transported liquid oxygen may be prohibitive.

[0034] In some situations, a very high level of D.O. must be achieved in the discharge to match the accumulative oxygen consumption demand in order to prevent anaerobic conditions from developing. Such situations include, but are not limited to those present in primary clarifiers, excessively polluted urban rivers, gravity and force main sewers, combined sewer overflow storage basins, sludge dewatering operations, and wastewater lagoons. As high purity oxygen contains 100% O₂ whereas air contains only 21% O₂, it would be expected that the rate of oxygenation would be five times as fast, and high purity oxygen would be utilized for such situations. However, as discussed above, in traditional oxygenation systems using high purity oxygen, there is a significant stripping of N₂ gas already dissolved in the water. Therefore, the full potential of using high purity oxygen instead of air to achieve high levels of D.O. has not been realized.

[0035] The gas transfer reactions in traditional oxygenation systems using high purity oxygen have occurred at near ambient pressure. Oxygen dissolution into water is enhanced by increased pressure in the oxygen/water contactor (bubble swarm). For example, at 1 atmosphere of pressure and at 20 degrees Celsius, the dissolved oxygen saturation concentration is 45 mg/L for water at sea level and in contact with high purity oxygen. At 2 atmospheres of

pressure at the same temperature, the dissolved oxygen concentration saturation increases to 90 mg/L.

[0036] However, the unit energy consumption is excessive if the water has to be pumped into the oxygen/water contactor to achieve pressurization because there is no practical way to recover this energy when the water leaves the contactor. However, if the oxygen/water contactor is placed below the ground surface and pressurized by a static head of water, the water can be moved into and out of it with negligible energy—only frictional losses. Yet, the oxygen transfer is significantly enhanced without associated energy consumption for pumping to maintain the pressure.

[0037] For oxygen generated using cryogenic systems, the oxygen can be produced in either the liquid or gaseous forms. If the oxygen is to be used at the same rate as it is produced, the gaseous state is preferred as it is less expensive to produce the gaseous form. However, if the generated oxygen is not used immediately, storage usually requires generation in the liquid state which significantly increases the costs associated with the generated oxygen, both as to production and due to the requirement for double-walled liquid oxygen storage tanks.

[0038] Another on-site production system is known as the pulsed swing absorption (PSA) process which utilizes pressure vessels filled with molecular sieves. A standard air compressor is used to feed the PSA device, and it generates oxygen with a 90% to 95% purity. The outlet pressure is related to the pressure of the air compressor which thus is the major cost factor in operating a PSA system. Therefore, it is desired to use the lowest possible PSA outlet pressure. In view of the available oxygen sources not based on “free” air, it is desirable to use PSA systems.

[0039] Overall, it is desirable to provide an apparatus and method for dissolving a gas into a fluid which: (a) has a low capital cost; (b) has a low operating cost (kwhr/ton of gas dissolved); (c) discharges high D.O. concentrations; and (d) has a high oxygen absorption efficiency. Ideally, the system should be capable of producing a discharge D.O. of at least 10 mg/L to 250 mg/L, or more, and have an oxygen absorption efficiency of at least 80%, all accomplished with reasonable capital costs and a low unit operating cost.

SUMMARY OF THE INVENTION

[0040] The present invention is an apparatus and method for dissolving a gas (whether soluble or insoluble) into a fluid which may or may not contain other dissolved gases. For example, the present invention may be used as an oxygenation system, i.e., dissolving oxygen into water (water contains dissolved nitrogen).

[0041] In one embodiment, the apparatus comprises an inlet, an outlet, a bubble contact chamber, an acceleration device, a helix-shaped bubble harvester, and a bubble return pipe. The inlet receives the fluid containing the extraneous dissolved gas and is located at the top of the apparatus. Near the inlet and at the top of the bubble contact chamber is located the acceleration device for acceleration of the fluid therethrough into the chamber. The acceleration design may comprise a horizontally oriented plate extending through the entire upper end of the chamber and having at least one aperture therein. The chamber is made of two portions. The upper portion has either a constant or a generally diverging

inside surface. The lower portion is substantially cylindrical in shape with a closed bottom end having at least one aperture therethrough. An inlet for introduction of the gas to be dissolved is connected to the chamber. The outlet is operatively connected to at least one aperture of the bottom end of the chamber. Residing in the bottom portion of the chamber is a helix-shaped bubble harvester. The bubble return pipe of the apparatus is vertically oriented and cylindrical in shape. The bubble return pipe has an open bottom end in the lower portion of the chamber, an open top end in the upper portion of the chamber, and at least one aperture located in the lower portion of the chamber proximate to the harvester.

[0042] During operation of this embodiment, fluid enters the inlet and flows through the acceleration device. The accelerated fluid provides turbulence to prevent the bubble swarm from collapsing and to keep the bubble size small. Without this turbulence, the bubble swarm will coalesce and collapse, greatly reducing the oxygen absorption rate. The harvester translates the fluid flow into a horizontal component which allows the bubbles to rise and attach to the underside of the helix-shaped harvester. The bubbles then flow upward by gravity and inward due to centrifugal force in the helix. The bubbles either flow into the bubble return pipe through at least one aperture in the tube and into the bubble chamber for recycling, or travel upward along the underside of the helix-shaped harvester until the bubbles rise upward toward the bubble swarm. Exiting out the outlet is a fluid containing a high concentration of dissolved gas and devoid of bubbles.

[0043] In another embodiment of the apparatus of the present invention, first and second vertical cylindrical tubes are concentrically oriented, with the first tube inside the second tube. The space inside the first tube is the first inner space and is the space through which fluid containing dissolved gas exits upward out of the apparatus. The second inner space is the space between the first and second tubes and is the space through which fluid and the dissolved gas enter the apparatus.

[0044] Two alternatives of this invention are disclosed. In one alternative, the combination of an acceleration device, an inlet, a helix-shaped bubble harvester, and a bubble return tube are placed near the bottom of the apparatus. This combination is referred to as the gas dissolver, and operates similarly to the previously described embodiment. Briefly, fluid flows through the acceleration device in the second inner space. The gas is introduced to the second inner space immediately below the acceleration device to result in bubbles and fluid flowing downward within the second inner space. At the harvester, bubbles are returned to the second inner space. The fluid having dissolved gas exits upward through the first inner space.

[0045] In a second alternative, the combination of an acceleration device, a harvester, and a bubble return tube are placed near the top of the apparatus. This combination is referred to as the dissolved gas stripper. The apparatus also includes a means for receiving waste gas from the oxygen gas absorber in the bottom of the apparatus, including a first vent located near the gas dissolver, waste gas tube, and a second vent located above the second harvester. Waste gas (gas from a gas dissolved in the fluid initially but later displaced by the dissolved gas) exits from the gas dissolved

through the first vent and the waste gas tube into the bubble tube of the dissolved gas stripper. At the dissolved gas stripper, waste gas exits the apparatus through the second vent.

[0046] The dissolved gas stripper function is enhanced by the low pressure in the bubble swarm at the top of the apparatus, while the oxygen absorber function is enhanced by the increased hydrostatic head at the bottom of the apparatus.

[0047] In yet another embodiment of the apparatus of the present invention, the harvester and bubble return pipe are placed near the bottom of the inlet side of a U-tube oxygenator. The use of the harvester and return pipe results in more efficient transfer. Thus, this modified U-tube oxygenator need not be as deep as a conventional U-tube oxygenator.

[0048] In another embodiment, the apparatus of the present invention comprises a container having fluid therein, an inlet tube, a gas inlet, a gas transfer device, and an outlet tube. The fluid is pumped from the container into the inlet tube. The gas inlet is operably connected to the inlet tube so that gas is introduced into the fluid. The gas transfer device is positioned below the surface of the fluid in the container so that the gas transfer device is hydrostatically pressurized in order to increase the rate and concentration at which the gas is dissolved into the fluid. The mixture of fluid and gas is introduced into the gas transfer device through the inlet tube. This mixture flows downward through the gas transfer device such that bubbles of gas are dissolved into the fluid. The fluid having the gas dissolved therein enters an outlet tube positioned within the gas transfer device. The fluid having the gas dissolved therein flows upward through the outlet tube and is released from the gas transfer device, and is returned to the container from which the fluid was initially introduced into the inlet tube. The bubbles of gas that are not dissolved into the fluid are retained in the gas transfer device.

[0049] The apparatus and method of the present invention is inexpensive to produce, install, maintain, and operate when compared to many systems used for oxygenation, for example. The apparatus and method may be used to dissolve a gas into a fluid which may or may not contain other dissolved gases. It has application where oxygenation is required, such as in slow moving rivers and canals, reservoirs, fish/shellfish/mussel ponds, aerobic wastewater treatment systems, primary clarifiers, sewer lift stations, wastewater industrial applications, lagoons, and more. It is also not limited to oxygenation of water, but is applicable for other gas dissolving applications.

[0050] The present invention is also highly efficient in absorption of the gas into the fluid. When the embodiment including a stripper is used, this efficiency is further increased. The apparatus may be used for fluid applications as well as when hydrostatic pressure is available, such as at the beginning of sewer force mains, or when a gas transfer device is positioned below the surface of the fluid to be introduced into the gas transfer device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0051] FIG. 1 shows a side view of one embodiment of the apparatus of the present invention in which the outer tube member is translucent to illustrate the components of the apparatus;

[0052] FIG. 2 shows a cross-sectional view of the apparatus of FIG. 1 at line 2-2 of FIG. 1;

[0053] FIG. 3 shows a cross-sectioned view of the apparatus of FIG. 1 at line 3-3 of FIG. 1;

[0054] FIG. 4 shows a cross-sectioned view of the apparatus of FIG. 1 at line 4-4 of FIG. 1;

[0055] FIG. 5 shows a side view of a second embodiment of the apparatus of the present invention wherein the exterior of the apparatus is translucent to illustrate the components of the apparatus;

[0056] FIG. 6 shows a side view of a third embodiment of the apparatus of the present invention wherein the outer tube member is translucent to illustrate the components of the apparatus;

[0057] FIG. 7 shows a side view of a fourth embodiment of the apparatus of the present invention wherein the tube member is translucent to illustrate the components of the apparatus; and

[0058] FIG. 8 shows a side view of a fifth embodiment of the apparatus of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0059] Referring now to FIG. 1, there is shown a side view of one embodiment of the apparatus of the present invention in which the outer tube member is translucent to illustrate the components of the apparatus. In this embodiment, apparatus 10 is used to oxygenate water. Because water contains dissolved nitrogen which is displaced by the dissolved oxygen, apparatus 10 also permits for outgassing (stripping) of nitrogen gas.

[0060] Apparatus 10 includes first tube member 12, second tube member 14, third tube member 16, gas feed inlet 18, accelerator plate 20, bubble harvester 22, waste gas vent 24, and waste gas tube 26. Both the upper end 28 and the bottom end 30 of first tube 62 are open. The interior of first tube 12 between upper end 28 and bottom end 30 defines first inner space 32. First tube member 12 is oriented in a substantially vertical orientation and is comprised of a material impervious to the passage of fluid therethrough. If the fluid comprises water, for example, first tube 12 may be comprised of plastic or metal. The material of first tube 12 should also be resistant to corrosion caused by the fluid.

[0061] Apparatus 10 also includes second tube member 14 oriented in a substantially vertical orientation. Second tube member is of a diameter greater than the diameter of first tube member 12 and is oriented in a substantial concentric orientation relative to the first tube member 12. Second tube member 14 has open upper end 34 and closed bottom end 36. The space between the outside of first tube member 12 and the inside of second tube member 14 is second inner space 40. Second tube member 14 should also be impervious to the flow of the fluid therethrough and it is preferred that it be resistant to corrosion caused by the fluid. Second tube member 14 should also be made of a material impervious to the flow of any material on the outside of second tube member 14 and is preferred to be resistant to corrosion caused by such material. First and second tube members 12 and 14 may be comprised of a similar material, but this is not required.

[0062] Third tube member 16 has open upper end 42 and open bottom end 44, is cylindrical in shape, and also substantially vertically oriented within second inner space 40. Bottom end 44 is on the place formed by bottom end 30 of first tube member 12. Upper end 42 is within second inner space 40 above bubble harvester 22, waste gas vent 24 and waste gas tube 26, and below accelerator plate 20 and inlet 18. Third tube member 16 also includes at least one aperture or slot 46 proximate harvester 22. Third tube member 16 should be comprised of a material impervious to the flow of fluid or the waste gas therethrough. Thus, third tube member 16 may be comprised of the same material as first tube member 12 and/or second tube member 14, but this is not required.

[0063] In the embodiment of FIG. 1, third tube member 16 is shown to lie against first tube member 12 (see also FIGS. 3 and 4). It is required that third tube member reside within second inner space 40, as explained in greater detail below. It is not required that third tube member 16 be in contact with first tube member 12 as shown; however, as will be explained hereinafter, it is advantageous to place third tube member 16 closer to the central longitudinal axis of first tube member 12 and of apparatus 10 and, more specifically, close to the central axis of helix-shaped harvester 22.

[0064] Returning now to FIG. 1, apparatus 10 also includes inlet 18, serving as an inlet means for introduction of the gas (in this illustration oxygen) to be dissolved into the fluid housed in second inner space 40. The gas may be pumped into inlet 18 by means well known in the art for introduction of the gas into second inner space 40 through second tube member 14.

[0065] Apparatus 10 further comprises accelerator plate 20. Accelerator plate 20 serves as a means to accelerate the flow of fluid therethrough. As shown in FIG. 2, a cross-sectional view along line 2-2 of FIG. 1, in this embodiment, accelerator plate 20 comprises a donut-shaped plate substantially extending horizontally and substantially filling second inner space 40. Accelerator plate 20 also includes at least one aperture 48 for the flow of fluid therethrough.

[0066] Accelerator plate 20 is only one alternative that may be used in the present invention. Again, the primary object of accelerator plate 20 is to accelerate the flow of fluid beneath accelerator plate 20 when compared to the flow of fluid above accelerator plate 20. Thus, the acceleration means used to accomplish this objective must reside within the second inner space 40, need not extend across the entire second inner space 40, and, overall, may be an accelerator of the type well known in the art. For example, a suitable acceleration means may be a small mixer which, like accelerator plate 20, prevents or inhibits the bubbles from coalescing and collapsing.

[0067] As shown in FIG. 1 and in FIG. 3 (a cross-sectional view along line 3-3 of FIG. 1), apparatus 10 also includes waste gas vent 24 and waste gas tube 26. Both waste gas vent 24 and waste gas tube 26 are positioned below upper end 42 of third tube member 16 and above bubble harvester 22. In this embodiment, waste gas vent 24 simply comprises a trap to trap rising waste gas. Waste gas tube 26 extends through second tube member 14 below the upper lip of waste gas vent 24 to capture waste gas and allow it to travel through waste gas tube 26.

[0068] Returning to FIG. 1, apparatus 10 further includes bubble harvester 22. As shown in FIG. 4, a cross-sectional

view of line 4-4 of FIG. 1, harvester 22 is positioned within second inner space 40 and substantially extends from the outside of first tube member 12 to the inside of second tube member 14 while accommodating third tube member 16 therethrough. Returning to FIG. 1, harvester 22 is helix-shaped and includes upper end 50 and bottom end 52. Bottom end 52 of harvester 22 is positioned above bottom end 36 of second tube member 14 and below bottom end 30 of first tube member 12. The upper end 50 of harvester 22 is below accelerator plate 20, inlet 18, waste gas vent 24, and waste gas tube 26.

[0069] Based on the above description, the operation of the embodiment of FIG. 1 is now described. Fluid (in this example, water) is allowed to flow downward within second inner space 40 toward accelerator plate 20. Gas (in this example, oxygen) is introduced into second inner space 40 at inlet 18. Acceleration plate 20 causes an increase in velocity in the fluid and bubbles below accelerator plate 20 when compared to the flow of fluid above accelerator plate 20. The faster flowing fluid is caused by the restriction of cross-sectional area in second inner space 40 and results in the creation of downward moving jets of fluid. The downward moving fluid jets assist in maintaining a dynamic swarm of bubbles of the gas within second inner space 40. Without the jets, the bubble swarm would coalesce and/or collapse, drastically reducing the gas bubble surface area per unit volume of liquid within second inner space 40.

[0070] The bubbles continue to flow downward toward helix-shaped bubble harvester 22. Harvester 22 acts similar to a parallel plate separator in that the fluid flow is converted into a horizontal component, which results in the bubbles rising to the underside of harvester 22 above. This process removes bubbles from the fluid flow and causes the bubbles to rise upward in the opposite direction of the fluid flow along the underside of harvester 22. The centrifugal force imparted by helix-shaped harvester 22 also forces bubbles toward the center of second inner space 40. Some bubbles may be, during this process, in sufficient contact with the fluid to become dissolved in the fluid. If bubbles are not so dissolved, they enter slots 46 of third tube member 16. These fugitive bubbles of gas are thus collected in the zone of harvester 22 of apparatus 10 and conveyed by gravity up third tube member 16 and into the bubble swarm of second inner space 40.

[0071] Because less than all of the bubbles are absorbed into the fluid, bubbles are continually wasted from apparatus 10. Excess bubbles leave apparatus 10 by being trapped by waste gas vent 24 and exit apparatus 10 by waste gas tube 26. The fluid containing dissolved gas exits apparatus 10 by flowing upward through first tube member 12.

[0072] It will be appreciated by those of skill in the art that the gas dissolving apparatus of the present invention is comprised of few parts and of no moving parts, other than might be recognized or desired to introduce gas through inlet 18 and/or fluid through second inner space 40 (see FIG. 6, for example). Thus, the apparatus is cost effective, both as to capital costs and costs of operation. The apparatus does not require significant maintenance. The apparatus allows large particles to freely pass through the system. Yet, it is quite capable of resulting in high nonsoluble gas absorption efficiency.

[0073] Referring now to FIG. 5, there is shown a side view of a second embodiment of the apparatus wherein the

exterior of the apparatus is translucent to illustrate the components of the apparatus. In this embodiment, apparatus 100 includes inlet 102, dissolved gas feed 103, accelerator plate 104, bubble contact chamber 106, bubble harvester 108, bubble return tube member 110, and outlet 112. Inlet 102 serves as a means for receipt of the fluid with or without a gas therethrough. Dissolved gas feed 103 serves as a means for introduction of the gas to the fluid housed in chamber 106. Accelerator plate 104, similar to accelerator plate 20 of FIG. 1, serves to accelerate the flow of fluids and bubbles in chamber 106 when compared to the fluid flow in inlet 102.

[0074] Bubble chamber 106 is comprised of first portion 114 and second portion 116. As illustrated, first portion 114 has a diverging interior surface. Second portion 116 is substantially cylindrical and includes a bottom surface 118 having at least one aperture 120 therethrough. Aperture 120 is operatively connected to outlet 112.

[0075] Within second portion 116 of chamber 106 is harvester 108. Like harvester 22 of FIG. 1, harvester 108 is helical and, except for the accommodation of bubble return tube member 110, substantially extends across the interior of second portion 116 of chamber 106.

[0076] Bubble return tube member 110 is substantially vertical and proximate to the center axis of chamber 106. Tube member 110, like third tube member 16 of FIG. 1, has open upper end 122, open bottom end 124, and at least one aperture 126. Apertures 126 are located proximate harvester 108 and are below the upper end of harvester 108.

[0077] As will be appreciated by those of skill in the art, the embodiment of FIG. 5 will operate in the presence of hydrostatic pressure, such as in a pump discharge. In such a configuration, there also is no need to accommodate outgassing of initially dissolved gases displaced by the absorption of the gas. Therefore, the embodiment of FIG. 3 does not contain any special components for handling waste gas.

[0078] Considering the operation of the apparatus of FIG. 5, fluid is introduced to apparatus via inlet 102 and gas is introduced via gas inlet 103. Increased jet velocity of the fluid is achieved by passage of the fluid through accelerator plate 104 in the manner described in association with accelerator plate 20 of FIG. 1. The expanded cross-section of first portion 114 of chamber 106 reduces the downward velocity of the fluid to less than or equal to that of the buoyant velocity of the bubbles of gas in the bubble swarm in chamber 106. This reduction in fluid velocity allows retention of a very high concentration of bubbles in the swarm housed in chamber 106. The configuration of chamber 106 therefore enhances gas absorption. Maintenance of prolonged bubble residence times in the bubble swarm is helpful in this regard.

[0079] As fluid and bubbles reach harvester 108 in second portion 116 of chamber 106, harvester 108 translates the fluid flow into a horizontal component which permits the bubbles to rise and attach to the underside of harvester 108, thereby removing them from the fluid flow. The bubbles then flow upward by gravity and inward due to centrifugal force in helix-shaped harvester 108. Some bubbles may, during this process, be in sufficient contact with the fluid to become dissolved in the fluid. If the bubbles do not become dissolved, the bubbles enter apertures 126 of bubble return tube

member 110 and flow upward out upper end 122 of tube member 110 into chamber 106. Thus, apparatus 100 returns fugitive bubbles to enhance efficiency by prolonging their residence times. Fluid having gas dissolved therein exits chamber 106 through aperture 120 of bottom surface 118 of chamber 106 into outlet 112.

[0080] It will be appreciated by those of skill in the art that several mechanisms contribute to the gas absorption efficiency of the apparatus of FIG. 5. The shape of chamber 106 assists in keeping bubbles in contact with the fluid for an extended period of time to enhance absorption. To dissolve oxygen in water, for example, it is desired to force contact of the bubbles with the water for as much as 100 seconds to ensure absorption. Also, the continuation of harvester 108 and bubble return tube member 110 recycle fugitive (unabsorbed) bubbles back into chamber 106. This also increases absorption efficiency.

[0081] It will also be appreciated that the exact shapes of chamber 106 need not be as illustrated in FIG. 5. For example, various angles and lengths of first portion 114 of chamber are possible. Also, second portion 116 need not be cylindrical in shape. Also, the chamber could be of unitary conical shape, unitary cylindrical shape, or any other shape reasonably able to promote the flow of fluid and the bubble swarm as described herein.

[0082] Referring now to FIG. 6, there is shown a side view of a third embodiment of the apparatus of the present invention wherein the outer tube member is translucent to illustrate the components of the apparatus. In this embodiment, apparatus 150, like apparatus 10 of FIG. 1, includes first tube member 12, second tube member 14, third tube member 16, inlet means 18, accelerator plane 20, first helix-shaped bubble harvester 22, first waste gas vent 24, and first waste gas outlet 26. This embodiment further includes second accelerator plate 152, second helix-shaped bubble harvester 154, fourth tube member 156, second waste gas vent 158, and second waste gas outlet 160. The apparatus further includes fifth tube member 162 connecting first gas tube outlet 26 to the open bottom end of fourth tube member 156.

[0083] As will become apparent with the description of apparatus 150 below, the lower portion of apparatus 150 is primarily responsible for absorption of the gas, and the upper portion is primarily responsible for stripping an initially dissolved gas which is replaced with the absorbed gas. If used to oxygenate water, the lower portion is the oxygen absorption and the upper portion is the nitrogen stripper.

[0084] In the embodiment of FIG. 6, apparatus 150 is buried in an excavated shaft, bottom end 36 of second tube member 14 is approximately 10 feet or more below the surface of the earth. First tube member 12 is about 12 inches in diameter and second tube member 14 is about 36 inches in diameter. These dimensions are illustrative, not a necessity, and not to be limiting in any respect.

[0085] Also nearby is tank 164 having the fluid therein. Tank outlet means 166 extends into the fluid residing in tank 164 and is operatively connected to upper end 34 of second tube member 14. Tank inlet means 168 extends into the fluid residing in tank 164 and is operatively connected to upper end 28 of first tube member 12. To initiate and/or maintain flow of fluid from tank 164 through tank outlet means 166 into apparatus 150, pump means 170 is shown.

[0086] Now, turning to the operation of apparatus **150**, fluid is pumped from tank **164** through tank outlet means **166** into upper end **34** of second tube member **14**. In one embodiment, the velocity of fluid entering upper end **34** of tube member **14** is approximately 0.5 ft/sec to 2.0 ft/sec. The fluid passes through second accelerator plate **152**. Second accelerator plate **152** restricts the cross-sectional area for fluid flow and includes apertures (see **FIG. 2**) to cause the fluid to accelerate into downward jets. In one embodiment, the downward jets of fluid move at approximately 6 ft/sec to 12 ft/sec. The increased velocity jets maintain a dynamic bubble swarm in the upper portion of apparatus **150**. The rise velocity of the bubbles in this upper portion (only about 0.5 ft/sec to 1 ft/sec in one embodiment) is low enough so that most of the bubbles accumulate and remain in the dynamic bubble swarm. The gas fed into the upper portion originates from first waste gas vent through first waste gas tube **26** as described below. As the gas bubbles accumulate in second inner space **40** in this upper portion of apparatus **150**, they are crowded downward and are eventually lost as the bubble swarm is pushed below second waste gas vent **158** to enter second waste gas tube **160**.

[0087] At the upper portion of apparatus **150**, as fluid flows downward through the bubble swarm the gas (introduced at inlet means **18** originally) is dissolved into the fluid and a gas already dissolved in the fluid is stripped out of the fluid into the gas phase. Fugitive bubbles which get inadvertently dragged out of the bubble swarm must be efficiently captured and returned to the bubble swarm. This is accomplished with second helix-shaped bubble harvester **154** and fourth tube member **156** in a manner as previously described in association with comparable components shown in **FIGS. 1 and 5**.

[0088] Fluid, devoid of fugitive bubbles, continues downward from the bottom of second harvester **154** toward first accelerator plate **20**. In one embodiment, the velocity of the fluid in this area is about 0.5 ft/sec to 2.0 ft/sec. The operation of the device is, at this point, as described in association with apparatus **10** of **FIG. 1**. Because less than all of the gas is absorbed in the lower portion of apparatus **150**, some bubbles are continually wasted from the system through waste gas vent **24** into first waste gas tube **26**, through fifth tube member **162** into fourth tube member **156**. These bubbles are then processed as described above for eventual exit from the system via second waste gas vent **158** and second waste gas tube **160**. Of course, fluid containing dissolved gas and devoid of bubbles exits the bottom of first harvester **22** and flows upward through first tube member **12**, through tank inlet means **168**, into tank **164**.

[0089] It will be appreciated by those of skill in the art that the embodiment of **FIG. 6** reduces the extraneous gas (gas initially dissolved in the fluid) in the system to enhance absorption of the gas. The extraneous gas is reduced before the gas dissolver. It will also be appreciated that, although shown as installed in an excavation, the apparatus of **FIG. 6** need not be so installed. Instead, apparatus **150** may be placed in a tube or directly into the fluid.

[0090] Referring now to **FIG. 7**, there is shown a fourth embodiment of the present invention wherein U-tube member **190** of the apparatus is translucent to illustrate the components of the apparatus. U-tube member **190** has an inlet side and an outlet side. In this embodiment, apparatus

180 comprises a conventional U-tube oxygenator **182**, a helical bubble harvester **184**, and a bubble return pipe (tube member) **186**. Harvester **184** is similar to the bubble harvesters of **FIGS. 1, 5, and 6** and bubble return pipe **186** is similar to those of **FIGS. 1, 5, and 6**.

[0091] Fluid enters apparatus **180** on the inlet side of U-tube member **190**. U-tube oxygenator **182** includes inlet **188** for introduction of the gas (such as oxygen) to be dissolved into the fluid (such as water) housed in U-tube member **190**. In one alternative embodiment of the present invention, inlet **188** is vertically oriented and extends through the inlet side of U-tube member **190**. In this embodiment, harvester **184** is placed proximate the bottom of the inlet side of the U-tube member **190**.

[0092] During operation of apparatus **180**, harvester **184** and bubble return pipe **186** serve the same functionality as described in association with the embodiments of **FIGS. 1, 5, and 6**. Specifically, as bubble move down the inlet side of the U-tube member **190**, undissolved (fugitive) bubbles flow upward against the underside of harvester **184**. During this process, some bubbles may be in sufficient contact with the fluid to become dissolved in the fluid. If the bubbles are not so dissolved, they then flow into the apertures of bubble return pipe **186** to be returned to the bubble swarm above harvester **184**. Exiting out the outlet side of U-shaped tube member **190** is the fluid containing a high concentration of dissolved gas and devoid of bubbles.

[0093] With regard to the embodiment of **FIG. 7**, it will be appreciated by those of skill in the art that use of harvester **184** to capture bubbles results in a more efficient transfer of gas into the fluid. As a result, the U-tube apparatus does not have to be as deep as a conventional U-tube apparatus to achieve the same absorption levels and dissolved oxygen concentrations.

[0094] It will be appreciated by those of skill in the art that the present invention solves several shortcomings of the prior art and can be used to dissolve soluble and insoluble gases. The apparatus manages the dissolved gases initially present in the fluid and stripped by the dissolved gas. The apparatus provides a high bubble area per volume of fluid to result in a high reduction in dissolved gas deficit. Fugitive bubbles are effectively separated and recycled to increase the percentage absorption efficiency of the gas. Hydrostatic pressurization rather than mechanical pressurization is used for dissolving the gas, thereby reducing operational costs. Also, gas is fed into a pressurized fluid chamber without the necessity of equal pressure from a PSA generator or other oxygen source.

[0095] It will also be appreciated that the harvester and bubble return pipe of the present invention may be used in any container containing fluid, and need not be vertically oriented as illustrated in **FIGS. 1, 5, 6, and 7**. Instead, the harvester/bubble return pipe may be used to capture bubbles from any fluid flowing in a pipe or conduit (or other container). Further, the harvester/bubble return pipe combination is useful whether or not any gas is to be dissolved into the fluid.

[0096] It will be further appreciated that the use of the harvester/bubble return pipe combination can reduce the cross-section and/or depth of bubble contactor of any apparatus in which it is used. Such reductions result in a lower cost of the apparatus and any cost of excavation of the apparatus, if applicable.

[0097] Referring now to FIG. 8, there is shown a side view of a fifth embodiment of the apparatus of the present invention. In this embodiment, apparatus 200 utilizes high purity oxygen in order to achieve high concentrations of dissolved oxygen in water. However, it will be appreciated by those of skill in the art that apparatus 200 may also be utilized to dissolve other types of gases into other types of fluids.

[0098] Apparatus 200 includes container 205, gas feed 210, inlet tube 220, gas transfer device 230, and outlet tube 240. Container 205 contains water. In the embodiment shown in FIG. 8, container 205 comprises a tank. In this embodiment, the tank is impervious to the passage of water therethrough. The material of the tank is resistant to corrosion caused by the water. For example, the tank may be comprised of plastic or metal. It will be recognized by those of skill in the art that in other embodiments of the present invention container 205 may comprise a natural container, such as, for example, a lagoon, or a sewage pool.

[0099] In the embodiment of the present invention shown in FIG. 8, gas transfer device 230 comprises an upper end 232, and a closed bottom end 234. In this embodiment, upper end 232 is closed. However, in other embodiments of the invention upper end 232 may be open. In the embodiment shown in FIG. 8, gas transfer device 230 further comprises a first portion 231 and a second portion 233. As illustrated, first portion 231 has a diverging interior surface. Second portion 233 is substantially cylindrical. In an alternative embodiment, the gas transfer device simply has a diverging interior surface and is generally conical in shape. As explained in more detail below, other embodiments of a gas transfer device may be utilized in apparatus 200.

[0100] Inlet tube 220 and outlet tube 240 may be of any size and shape provided that each of inlet tube 220 and outlet tube 240 permit for appropriate transfer of volume of fluid at desired flow rates. Further, inlet tube 220 and outlet tube 240 are comprised of a material impervious to the passage of fluid therethrough. It is also desired that the material of inlet tube 220 and outlet tube 240 be resistant to corrosion caused by the fluid. If the fluid comprises water, for example, inlet tube 220 and outlet tube 240 may be comprised of plastic or metal. Inlet tube 220 and outlet tube 240 may be comprised of a similar material, but this is not required.

[0101] A first end 221 of inlet tube 220 is positioned within container 205, and is adapted for the receipt of the fluid from container 205 to which the high purity oxygen will be introduced. In the embodiment shown in FIG. 8, the water from container 205 is pumped into first end 221 of inlet tube 220 via a pump 215 of a type well know in the art. A second end 222 of inlet tube 220 is adapted for the introduction of the mixture of the fluid and the high purity oxygen into gas transfer device 230 through upper end 232, as discussed below. In the embodiment shown in FIG. 8, second end 222 extends through upper end 232.

[0102] A first open end 241 of outlet tube 240 is positioned within the second portion 233 of gas transfer device 230. Outlet tube 240 extends through upper end 232. A second end 242 of outlet tube 240 is positioned outside of gas transfer device 230, and is adapted for the release of oxygenated water outside of gas transfer device 230. In the embodiment shown in FIG. 8, second end 242 is positioned within container 205.

[0103] Gas transfer device 230 is positioned below fluid surface 207 in order to create increased hydrostatic pressure in gas transfer device 230. In the embodiment of the present invention shown in FIG. 8, a midpoint of longitudinal axis 236 of gas transfer device 230 is positioned about 10 feet below fluid surface 207 in order to create the increased hydrostatic pressure in gas transfer device 230. However, the gas transfer device may be positioned less than 10 feet below fluid surface 207. In addition, gas transfer device 230 may be positioned as much as 100 feet or more below fluid surface 207.

[0104] The only requirement for this fifth embodiment of the present invention is that gas transfer device 230 be positioned below fluid surface 207 in order to create increased hydrostatic pressure in the gas transfer device 230, which in turn increases the concentration of dissolved oxygen in the oxygenated water released from gas transfer device 230. In the embodiment of the present invention shown in FIG. 8, gas transfer device 230 is positioned underground in an underground structure 235. In this embodiment, underground structure 235 comprises an excavated caisson; however, the gas transfer device may be positioned underground in a variety of different manners. In this embodiment, gas transfer device 230 is positioned underground as fluid surface 207 is below ground level.

[0105] Gas transfer device 230 need not be positioned underground. Instead, gas transfer device 230 simply must be positioned below fluid surface 207. For example, in one embodiment of the present invention container 205 may be positioned 30 feet above ground level. Thus, in this embodiment, gas transfer device 230 need not be positioned underground in order for gas transfer device 230 to be positioned below fluid surface 207.

[0106] Apparatus 200 further comprises gas feed 210 operably connected to inlet tube 220 for the introduction of gas (in this illustration high purity oxygen) into the water contained within inlet tube 220. The gas will subsequently be dissolved into the water, as explained below. Gas feed 210 is operably connected to inlet tube 220 between first end 221 and second end 222. In an alternative embodiment, gas feed 210 may introduce the gas directly into gas transfer device 230. The gas may be pumped into gas feed 210 by means well know in the art. The flow rates of the water introduced into gas transfer device 230 may range from less than 1 gallon of water per minute to over 200 million gallons of water per day.

[0107] Based on the above description, the operation of the embodiment of FIG. 8 is now described. Fluid (in this example, water) is pumped via pump 215 from container 205 into inlet tube 220 through first end 221, and the water flows from the first end 221 of inlet tube 220 toward the second end 222 of inlet tube 220. Gas (in this example, high purity oxygen) is introduced into the water contained within inlet tube 220 at gas feed 210. In one embodiment, the velocity of the water and high purity oxygen mixture introduced into gas transfer device 230 through upper end 232 is approximately 10 feet per second. This high inlet velocity provides turbulence which continually shears the larger bubbles of oxygen gas and maintains a bubble swarm with an exceptionally high gas surface/water volume ratio. Since the bubbles tend to coalesce under lower turbulence which exists at the second portion 233 of gas transfer device 230,

the bubbles are sheared into smaller bubbles at the first portion **231** of gas transfer device **230** by the vigorous turbulence of the water and high purity oxygen mixture introduced into gas transfer device **230** via inlet tube **220**. Thus, the bubble swarm is prevented from collapsing and greatly reducing the oxygen absorption rate.

[0108] As the cross section of gas transfer device **230** increases as the water and oxygen bubble mixture moves toward the second portion **233** of gas transfer device **230**, the downward velocity of the water becomes less than the buoyant upward velocity of the bubbles. Therefore, most of the bubbles are retained within gas transfer device **230**, while the oxygenated water passes through the first end **241** of outlet tube **240**. The oxygenated water flows toward the second end **242** of outlet tube **240** and is released outside gas transfer device **230** via second end **242**. As gas transfer device **230** is hydrostatically pressurized due to its placement below the fluid surface **207**, a high level of oxygen is dissolved into the water, while simultaneously minimizing the problems caused by stripping the dissolved N_2 from the water into the high purity oxygen phase.

[0109] Instead of hydrostatically pressurizing gas transfer device **230**, the pressure can be increased in gas transfer device **230** by pumping the fluid and gas mixture into the gas transfer device against a throttling valve of a type well known in the art as the mixture is introduced into gas transfer device **230**. However, placing gas transfer device **230** below fluid surface **207** achieves the necessary pressurization in a much more energy efficient manner. If gas transfer device **230** is positioned at the same level as fluid surface **207**, the unit energy consumption for pressurizing gas transfer device **230** for the purpose of dissolving oxygen is approximately 700 kilowatt-hours per ton of dissolved oxygen. The cost associated with such energy consumption is approximately \$220,000. However, the energy consumption decreases to approximately 350 kilowatt-hours per ton of dissolved oxygen if midpoint **236** of gas transfer device **230** is positioned 20 feet below fluid surface **207**. The cost associated with such energy consumption is approximately \$120,000. The reason for this dramatic decrease in energy consumption is that the requirements for pumping the fluid into gas transfer device **230** do not change significantly; however, the concentration of dissolved oxygen in the oxygenated water released from gas transfer device **230** increases from 15 mg/L to 30 mg/L. The concentration of dissolved oxygen in the oxygenated water released from gas transfer device **230** increases as the depth at which gas transfer device **230** is placed below fluid surface **207** increases.

[0110] In one embodiment of the present invention, if midpoint **236** of gas transfer device **230** is positioned 60 feet below fluid surface **207**, the oxygenated water released from the gas transfer device contains a concentration of 90 mg/L of dissolved oxygen. In the same embodiment of the present invention, if midpoint **236** of gas transfer device **230** is positioned 100 feet below fluid surface **207**, the oxygenated water released from gas transfer device **230** contains a concentration of over 120 mg/L of dissolved oxygen.

[0111] Water that contains more than air saturated concentrations of dissolved oxygen is referred to as "superoxygenated" water. However, if the discharged water contains over 120 mg/L of dissolved oxygen, some of the dissolved

oxygen may spontaneously effervesce. Such effervescence can be minimized, if not eliminated, if second end **242** is positioned within container **205** and if the superoxygenated water is released from second end **242** back into container **205**, or if the superoxygenated water is released into some other bulk volume of water that contains low concentrations of dissolved oxygen. Further, the low turbulence depressurization of the oxygenated water as it flows through outlet tube **240** also enhances the retention of the dissolved oxygen in the discharge. In an alternative embodiment of the present invention, the oxygenated water released from second end **242** of outlet tube **240** is subsequently introduced into the apparatuses shown in FIGS. 1, 5, 6, or 7 so that additional amounts of oxygen may be dissolved in the water through the operation of these apparatuses as described above.

[0112] It will be appreciated by those of skill in the art that apparatus **200** may comprise other gas transfer devices besides gas transfer device **230** as long as the gas bubbles are not swept out of the gas transfer device with the water passing through the gas transfer device, but remain in, or are captured and recycled to the gas transfer device. In other words, the bubble movement must be uncoupled from the water movement. This can be accomplished in two ways. The first way is if the vertical downward flow of water through the gas transfer device can be reduced to less than the vertical upward buoyant velocity of the gas bubbles, such as through the use of gas transfer device **230**. A second example of a gas transfer device wherein the vertical downward flow of water is reduced to less than the vertical upward buoyant velocity of bubbles is a cylindrical gas transfer device with an accelerator plate at the top of the gas transfer device which provides the energy necessary to maintain the bubble swarm so that it does not collapse. However, at the same time, the downward movement of the water within the cylindrical gas transfer device is less than the buoyant velocity of the bubbles so that the bubbles are trapped indefinitely within the gas transfer device. Such a gas transfer device is the second embodiment of the present invention shown in FIG.

[0113] The second way to ensure that the bubble movement is uncoupled from the water movement is if the bubbles can be harvested from the water flow through a helix or parallel plate separator or a centrifugal force, and returned to the gas transfer device. In such gas transfer devices, the downward water velocities are higher than the buoyant velocity of the bubbles, causing the bubbles to move in the direction of the water. However, this bubble and water mixture is then passed through a helix or parallel plate separator or centrifugal force to separate the bubbles and return them to the water flow. An example of this type of gas transfer device is the fourth embodiment of the present invention shown in FIG. 7.

[0114] It will be appreciated by those of skill in the art that by pressurizing the gas transfer device shown in FIG. 8, high levels of a gas are dissolved into a fluid, and the fluid retains such high levels of the gas while minimizing the stripping of dissolved N_2 in the fluid introduced into the gas transfer device. The apparatus does not consume much energy as pressurization occurs hydrostatically by the placement of gas transfer device **230** below fluid surface **207**. The embodiment of the present invention is particularly useful when a high level of dissolved oxygen must be achieved in the discharge to match the accumulative oxygen consump-

tion demand and prevent noxious end products, such as H₂S. Such anaerobic environments include, but are not limited to primary clarifiers, excessively polluted urban rivers, gravity and force main sewers, combined sewer overflow storage basins, sludge dewatering operations, and wastewater lagoons.

[0115] It will also be appreciated that the apparatus of the present invention has use in a myriad of other applications. In oxygenation of water for example, the present invention may be used for slowly moving rivers and canals, lagoons, reservoirs, fish/shellfish/mussel/shrimp ponds, wastewater treatment systems, sewer lift stations, and wastewater processing for various industries; including but not limited to the pharmaceutical, petroleum, food and chemical industries. The present invention is also useful for dissolving hydrogen into vegetable oil, hydrogen into coal liquifaction fluids, or for pharmaceutical and industry aerobic bioprocesses, such as yeast production and Vitamin C production. The present invention also has application for ozonation of water or other fluids.

[0116] The foregoing is offered primarily for purposes of illustrating the apparatus and method of the present invention. It will be readily apparent to those of skill in the art that the materials, dimensions, operating procedures and conditions, and other parameters of the gas dissolving apparatus and method may be further modified or substantiated in various ways without departing from the spirit and scope of the invention.

I claim:

1. An apparatus for dissolving a gas into a fluid, the apparatus comprising:

a container having fluid therein, the fluid having a surface;

a gas transfer device, the gas transfer device having an upper end and a closed bottom end, the gas transfer device positioned below the surface of the fluid in the container;

a fluid inlet means, the fluid inlet means having a first end for receipt of the fluid from the container, and a second end for the introduction of the fluid into the gas transfer device;

a gas inlet means, the gas inlet means operably connected to the fluid inlet means between the first end of the fluid inlet means and the second end of the fluid inlet means for introduction of the gas into the fluid before it is introduced into the gas transfer device; and

an outlet means, the outlet means having a first end positioned within the gas transfer device for receipt of the fluid having the gas dissolved therein, and a second end positioned outside of the gas transfer device for release of the fluid having the gas dissolved therein from the gas transfer device.

2. The apparatus of claim 1 wherein the fluid comprises water.

3. The apparatus of claim 1 wherein the gas comprises oxygen.

4. The apparatus of claim 1 wherein the fluid comprises water and the gas comprises oxygen.

5. The apparatus of claim 1 wherein the gas transfer device has a generally diverging inside surface.

6. The apparatus of claim 1 further comprising an acceleration plate positioned within the gas transfer device for acceleration of the fluid and gas mixture therethrough, and wherein the gas transfer device is substantially cylindrical in shape.

7. The apparatus of claim 1 further comprising a helix-shaped bubble harvester positioned within the gas transfer device.

8. The apparatus of claim 1 wherein the gas transfer device is positioned underground.

9. The apparatus of claim 8 wherein the gas transfer device is positioned in an excavated caisson.

10. The apparatus of claim 1 wherein the second end of the outlet means is positioned within the container for the release of the fluid having the gas dissolved therein into the container.

11. The apparatus of claim 1 wherein a midpoint of a longitudinal axis of the gas transfer device is positioned at least about ten feet below the surface of the fluid in the container.

12. The apparatus of claim 1 further comprising a pumping means operably connected to the first end of the fluid inlet means for pumping the fluid from the container into the fluid inlet means.

13. An apparatus for dissolving a gas into fluid, the apparatus comprising:

a container having fluid therein, the fluid having a surface;

a gas transfer device, the gas transfer device having an upper end and a closed bottom end, the gas transfer device positioned below the surface of the fluid in the container;

a fluid inlet means, the fluid inlet means having a first end for receipt of the fluid from the container, and a second end for the introduction of the fluid into the gas transfer device;

a gas inlet means, the gas inlet means for introduction of the gas into the gas transfer device; and

an outlet means, the outlet means having a first end positioned within the gas transfer device for receipt of the fluid having the gas dissolved therein, and a second end positioned outside of the gas transfer device for release of the fluid having the gas dissolved therein from the gas transfer device.

14. A method for dissolving a gas into a fluid, the method comprising the steps of:

providing a container having the fluid therein, the fluid having a surface;

providing a gas transfer device, the gas transfer device having an upper end and a closed bottom end, the gas transfer device positioned below the surface of fluid in the container;

providing a fluid inlet means, the fluid inlet means having a first end for receipt of the fluid and a second end for the introduction of the fluid into the gas transfer device;

providing a gas inlet means, the gas inlet means operably connected to the fluid inlet means between the first end of the fluid inlet means and the second end of the fluid inlet means for introduction of the gas into the fluid before it is introduced into the gas transfer device;

- providing an outlet means, the outlet means having a first end positioned within the gas transfer device for receipt of the fluid having the gas dissolved therein, and a second end positioned outside of the gas transfer device for release of the fluid having the gas dissolved therein from the gas transfer device;
- allowing the fluid to flow from the container into the first end of the fluid inlet means;
- allowing the fluid to flow through the fluid inlet means;
- introducing the gas into the fluid through the gas inlet means before it is introduced into the gas transfer device;
- introducing the fluid and gas mixture into the gas transfer device through the upper end of the gas transfer device via the second end of the fluid inlet means;
- allowing the fluid and gas mixture to flow downward through the gas transfer device such that bubbles of gas are dissolved into the fluid;
- allowing the fluid having the gas dissolved therein to enter the first end of the outlet means and flow toward the second end of the outlet means;
- releasing the fluid having the gas dissolved therein from the gas transfer device via the second end of the outlet means; and
- retaining the bubbles of gas which are not dissolved into the fluid in the gas transfer device.
- 15.** The method of claim 14 wherein the fluid comprises water such that the method results in dissolving the gas into the water.
- 16.** The method of claim 14 wherein the gas comprises oxygen such that the method results in dissolving the oxygen into the fluid.
- 17.** The method of claim 14 wherein the fluid comprises water and the gas comprises oxygen such that the method results in dissolving the oxygen into the water.
- 18.** The method of claim 14 wherein the gas transfer has a generally diverging inside surface.
- 19.** The method of claim 14 further comprising the steps of:
- positioning the second end of the outlet means within the container; and
 - releasing the fluid having the gas dissolved therein into the container.
- 20.** The method of claim 14 further comprising the step of positioning the gas transfer device underground.
- 21.** The method of claim 20 further comprising the step of positioning the gas transfer device in an excavated caisson.
- 22.** The method of claim 14 further comprising the step of positioning a midpoint of a longitudinal axis of the gas transfer device at least about ten feet below the surface of the fluid in the container.
- 23.** The method of claim 14 further comprising the steps of:
- providing a pumping means operably connected to the first end of the fluid inlet means; and
 - pumping the fluid from the container into the first end of the inlet means.
- 24.** The method of dissolving a gas into a fluid, the method comprising the steps of:
- providing a container having fluid therein, the fluid having a surface;
 - providing a gas transfer device, the gas transfer device having an upper end and a closed bottom end, the gas transfer device positioned below the surface of the fluid in the container, the gas transfer device being substantially cylindrical in shape;
 - providing a fluid inlet means, the fluid inlet means having a first end for receipt of the fluid and a second end for the introduction of the fluid into the gas transfer device;
 - providing a gas inlet means, the gas inlet means operably connected to the fluid inlet means between the first end of the fluid inlet means and the second end of the fluid inlet means for introduction of the gas into the fluid before it is introduced into the gas transfer device;
 - providing an acceleration plate positioned within the gas transfer device for acceleration of the fluid and gas mixture therethrough;
 - providing an outlet means, the outlet means having a first end positioned within the gas transfer device for receipt of the fluid having the gas dissolved therein, and a second end positioned outside of the gas transfer device for release of the fluid having the gas dissolved therein from the gas transfer device;
 - allowing the fluid to flow from the container to the first end of the fluid inlet means;
 - allowing the fluid to flow through the fluid inlet means;
 - introducing the gas into the fluid through the gas inlet means before it is introduced into the gas transfer device;
 - introducing the fluid and gas mixture into the gas transfer device through the upper end of the gas transfer device via the second end of the fluid inlet means;
 - allowing the fluid and gas mixture to flow downward through the acceleration means and the gas transfer device such that bubbles of gas are dissolved into the fluid;
 - allowing the fluid having the gas dissolved therein to enter the first end of the outlet means and flow toward the second end of the outlet means;
 - releasing the fluid having the gas dissolved into the fluid therein from the gas transfer device via the second end of the outlet means; and
 - retaining the bubbles of gas which are not dissolved into the fluid in the gas transfer device.
- 25.** A method of dissolving a gas into a fluid, the method comprising the steps of:
- providing a container having fluid therein, the fluid having a surface;
 - providing a gas transfer device, the gas transfer device having an upper end and a closed bottom end, the gas transfer device positioned below the surface of the fluid in the container;

- providing a fluid inlet means, the fluid inlet means having a first end for receipt of the fluid and a second end for the introduction of the fluid into the gas transfer device;
- providing a gas inlet means, the gas inlet means operably connected to the fluid inlet means between the first end of the fluid inlet means and the second end of the fluid inlet means for introduction of the gas into the fluid before it is introduced into the gas transfer device;
- providing a helix-shaped bubble harvester positioned within the gas transfer device;
- providing an outlet means, the outlet means having a first end positioned within the gas transfer device for receipt of the fluid having the gas dissolved therein, and a second end positioned outside of the gas transfer device for release of fluid having the gas dissolved therein from the gas transfer device;
- allowing the fluid to flow from the container into the first end of the fluid inlet means;
- allowing the fluid to flow through the fluid inlet means;
- introducing the gas into the fluid through the gas inlet means before it is introduced into the gas transfer device;
- introducing the fluid and gas mixture into the gas transfer device through the upper end of the gas transfer device via the fluid inlet means;
- allowing the fluid and gas mixture to flow downward through the gas transfer device such that bubbles of gas travel downward to the helix-shaped bubble harvester where the bubbles are kept in contact with the fluid for dissolving at least a portion of the gas into the fluid;
- allowing the fluid having the gas dissolved therein to enter the first end of the outlet means and flow toward the second end of the outlet means;
- releasing the fluid having the gas dissolved therein from the gas transfer device via the second end of the outlet means; and
- retaining the bubbles of gas which are not dissolved into the fluid in the gas transfer device.
26. A method for dissolving a gas into a fluid, the apparatus comprising:
- providing a container having fluid therein, the fluid having a surface;
- providing a gas transfer device, the gas transfer device having an upper end and a closed bottom end, the gas transfer device positioned below the surface of the fluid in the container;
- providing a fluid inlet means, the fluid inlet means having a first end for receipt of the fluid from the container, and a second end for the introduction of the fluid into the gas transfer device;
- providing a gas inlet means, the gas inlet means for introduction of the gas into the gas transfer device;
- providing an outlet means, the outlet means having a first end positioned within the gas transfer device for receipt of the fluid having the gas dissolved therein, and a second end positioned outside of the gas transfer device for release of the fluid having the gas dissolved therein from the gas transfer device;
- allowing the fluid to flow from the container into the first end of the fluid inlet means;
- allowing the fluid to flow through the fluid inlet means;
- introducing the fluid into the gas transfer device via the second end of the fluid inlet means;
- introducing the gas into the gas transfer device via the gas inlet means;
- allowing the fluid and gas mixture to flow downward through the gas transfer device such that bubbles of gas are dissolved into the fluid;
- allowing the fluid having the gas dissolved therein to enter the first end of the outlet means and flow toward the second end of the outlet means;
- releasing the fluid having the gas dissolved therein from the gas transfer device via the second end of the outlet means; and
- retaining the bubbles of gas which are not dissolved into the fluid in the gas transfer device.

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