

DESCRIPTION

UNDERWATER OXYGEN DISSOLVING APPARATUS AND UNDERWATER OXYGEN DISSOLVING METHOD USING THE SAME

TECHNICAL FIELD

[0001]

The present invention relates to an underwater oxygen dissolving apparatus and an underwater oxygen dissolving method using the same for improving water quality. The present invention more particularly relates to an underwater oxygen dissolving apparatus and an underwater oxygen dissolving method using the same where air is sucked into a vortex formed by gravity flow thus forming bubbles, and concentration of oxygen dissolved in water is increased by crushing the bubbles by an ultrasonic oscillator.

BACKGROUND ART

[0002]

Conventionally, for the purpose of improvement of water quality in a closed region such as a sewage disposal system, a lake, a pond and a dam, a technique of increasing concentration of oxygen dissolved in water has been utilized. The utilization of “bubbles” is known as a representative example of such a technique. This technique has an action of increasing an amount of oxygen moved to a liquid side from a gas side by increasing a contact area between a gas and a liquid. The technique is implemented in the form of, for example, a method where pressurized air is supplied to a porous aeration pipe, a method where a shear flow is formed by the rotation of an impeller or jetting of a gas and air is supplied to the shear flow or a method where microbubbles or nanobubbles are generated.

However, the above-mentioned techniques require, for example, a large compressor for compressing a gas or the like and hence, an apparatus used for the method becomes large-sized. As a result, there exists a drawback that an amount of power consumption and times and efforts for maintenance of the apparatus become enormous.

Particularly when the porous aeration pipe is utilized, small pores are clogged by fine particles or impurities in water thus giving rise to a drawback that efficiency for generating bubbles is lowered.

Further, when an impeller is used, there arise a drawback that power consumption for rotating the impeller at a high speed is increased and a drawback that the impeller is damaged or corrodes due to cavitation which occurs when the impeller is rotated at a high speed.

In view of the above, for the purpose of overcoming such drawbacks, recently,

there have been developed techniques relating to a bubble generating apparatus where an amount of power consumption can be suppressed and bubbles can be efficiently generated with a simple configuration, and several inventions have been already disclosed with respect to such techniques.

[0003]

Firstly, Patent Document 1 discloses the invention relating to a wastewater treatment apparatus capable of efficiently generating bubbles with a title “wastewater treatment apparatus”.

Hereinafter, the invention disclosed in Patent Document 1 is described. The invention relating to the wastewater treatment apparatus disclosed in Patent Document 1 is characterized by a suction-type aerator where a porous flowing waste water transfer pipe is exposed in atmosphere.

According to the wastewater treatment apparatus having such a technical feature, an average diameter of generated bubbles can be made fine to several 100 μm to several 10 μm . Accordingly, a contact area between wastewater and oxide gas bubbles can be increased to a value approximately 10 to 100 times as large as a contact area in a conventional method. Further, a stay time of bubbles can be increased to a value 10 to 100 times as long as a stay time in the conventional method. Accordingly, an amount of dissolved oxygen can be remarkably increased.

[0004]

Next, Patent Document 2 discloses the invention relating to a fine bubble generating apparatus having the simple structure with a title “fine bubble generating apparatus”.

The invention disclosed in Patent Document 2 is the fine bubble generating apparatus where a gas is introduced into a liquid and fine bubbles are generated in the liquid. The fine bubble generating apparatus includes: a liquid storing portion for storing a liquid; a liquid jetting nozzle arranged in the liquid stored in the liquid storing portion and having a liquid outlet portion; a gas suction nozzle arranged on an outer edge portion of the liquid outlet portion and having a gas outlet portion; and a flow rate controller for controlling a flow rate of a gas flowing out from the gas outlet portion. In such a fine bubble generating apparatus, the gas outlet portion is arranged in a flow passage of a liquid jetted from the liquid outlet portion, and a negative pressure generating portion is generated at a downstream end portion of the gas outlet portion thus enabling an automatic suction of the gas into the liquid.

According to the fine bubble generating apparatus having such a technical feature, by making use of a negative pressure generating phenomenon which occurs at a downstream end portion of an object arranged in the liquid flow passage, a gas is automatically sucked into a liquid and hence, the gas can be introduced into the liquid without providing a gas supply device such as a compressor or a compressed gas storing tank. That is, fine bubbles can be efficiently generated in a liquid with a simpler

apparatus structure.

[0005]

Next, Patent Document 3 discloses the invention relating to a wastewater treatment apparatus which performs biological treatment using an activated sludge generated in sewage, wastewater from a plant or the like with a title “Wastewater treatment apparatus”.

The invention disclosed in Patent Document 3 is characterized in that, in a wastewater treatment apparatus which uses an activated sludge, an ultrasonic generator is disposed in the inside of a reaction tank provided with an aerator, the ultrasonic generator includes an ultrasonic vibrator and an ultrasonic vibration element unit, and the ultrasonic vibrator is disposed in a bubble existing portion.

According to the wastewater treatment apparatus having such a technical feature, an effect of reducing an amount of generating sludge and the improvement of oxygen dissolving efficiency can be simultaneously achieved without providing a large facility installing space outside the reaction tank.

PRIOR ART DOCUMENTS

PATENT DOCUMENTS

[0007]

Patent Document 1: JP 5-64975 A

Patent Document 2: JP 2012-120988 A

Patent Document 3: JP 2007-111598 A

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0007]

However, in the invention disclosed in Patent Document 1, to generate bubbles having an extremely fine diameter, it is necessary to increase an amount of water which flows through the inside of the porous pipe simultaneously with the increase of a speed of the water flowing through the porous pipe. Further, when fine particles or the like are contained in water which flows through the inside of the porous pipe, at the time of generating bubbles having an average diameter of several 100 μm to several 10 μm , it is considered that the closure of fine holes occurs. Accordingly, there is a possibility that the invention disclosed in Patent Document 1 cannot sufficiently overcome the drawback that the apparatus becomes large-sized or the drawback that efficiency for generating bubbles is lowered.

[0008]

Next, in the invention disclosed in Patent Document 2, a negative pressure generating portion is formed at the time of jetting a liquid from a liquid jetting nozzle, and fine bubbles (microbubbles) are formed by the negative pressure generating portion.

However, the liquid storing portion is filled with a liquid in a stationary state as an initial state and hence, to mix such a liquid and the formed microbubbles with each other, it is necessary to use a highly pressurized water having a large jetting speed from the liquid jetting nozzle, for example. Accordingly, in such a case, a highly pressurized water generating apparatus becomes necessary and hence, there arises a possibility of an occurrence of a drawback that the apparatus becomes large-sized or a drawback that an amount of power consumption is increased.

[0009]

Further, in the invention disclosed in Patent Document 3, although the ultrasonic generator is provided, a prior art is used as it is with respect to the aeration apparatus which generates fine bubbles. Accordingly, depending on water quality, there is a possibility that a drawback of lowering efficiency for generating fine bubbles cannot be overcome.

[0010]

The present invention has been made in view of the above-mentioned conventional circumstances, and it is an object of the present invention to provide an underwater oxygen dissolving apparatus and an underwater oxygen dissolving method using such an underwater dissolving apparatus where bubbles can be efficiently generated and the movement of oxygen contained in the bubbles into a fluid can be accelerated while suppressing an amount of power consumption due to the simplified configuration.

SOLUTIONS TO THE PROBLEMS

[0011]

In order to solve these objects, an underwater oxygen dissolving apparatus according to the first invention includes: a cylindrical tank where a falling hole is formed in a bottom portion of the cylindrical tank thus enabling a fluid filled into the cylindrical tank to form a vortex; a cylindrical descending pipe including: an inner pipe having an upper end which communicates with the falling hole and a side wall in which a plurality of suction holes are formed; and an outer pipe disposed around the inner pipe, forming a closed space between the outer pipe and the inner pipe, and provided with an air supply unit which supplies air into the closed space, the descending pipe being configured such that air is sucked into the fluid from a periphery of the vortex through the air supply unit and the plurality of suction holes when the fluid passes through the inner pipe so that bubbles are formed in the fluid; a box-type reservoir arranged vertically downward the descending pipe, the reservoir being configured such that the fluid in which the bubbles are formed falls into and is stored in the box-type reservoir; and an ultrasonic oscillator immersed in the fluid stored in the reservoir, the ultrasonic oscillator emitting the ultrasonic wave to the fluid stored in the reservoir thus crushing the bubbles.

[0012]

In the invention having such a configuration, for example, the cylindrical tank includes an upper opening portion, and a fluid is filled into the cylindrical tank from the upper opening portion by gravity falling. Since the falling hole is formed in the bottom portion of the cylindrical tank, the filled fluid flows into the falling hole while circulating above the falling hole thus forming a vortex. Air is taken into the fluid from an indented inner surface of the vortex.

[0013]

Next, the fluid which flows into the falling hole passes through the inner pipe which forms a descending pipe. In this case, air taken into the fluid from an inner surface of the vortex is separated from a distal end of the vortex and hence, bubbles are formed in the fluid. Further, the descending pipe is configured to introduce air into the inside of the inner pipe from the outer pipe through the air supply unit and the plurality of suction holes. On the other hand, a negative pressure in the vortex is gradually increased toward a center portion of the vortex in a radial direction of the vortex. Accordingly, when a fluid passes through the inner pipe downward, air is sucked into the inside of the vortex and hence, bubbles are further formed.

[0014]

The fluid in which the bubbles are formed passes through the inner tube and, thereafter, falls into the reservoir and is stored in the reservoir. At this stage of the operation, the bubbles move so as to spread in the inside of the reservoir.

[0015]

Subsequently, when ultrasonic waves emitted from an emitting surface of the ultrasonic oscillator are irradiated to the bubbles in the course of spreading in the reservoir, cavitation occurs. In the cavitation, when a sound pressure (amplitude) of the emitted ultrasonic waves is changed cyclically, the generation and the extinction of bubbles are repeated in a fluid. Accordingly, both the bubbles generated by the cavitation and the bubbles formed in a fluid which passes through the inner pipe are crushed and hence, oxygen is dissolved into the fluid stored in the reservoir.

[0016]

Next, the second invention is, in the first invention, characterized in that the ultrasonic oscillator is arranged with a long axis thereof extending along a horizontal direction, the reservoir is provided with a reflector on a wall surface thereof or in the inside thereof, the reflector forming a first reflected wave by reflecting a first ultrasonic wave emitted from a first emission surface of the ultrasonic oscillator (hereinafter referred to as "first incident wave"), and the reflector is arranged in a spaced-apart manner from the first emission surface such that the first incident wave and the first reflected wave are synthesized thus producing a first standing wave.

In the invention having such a configuration, the reflector is formed of the structure having a planar surface. The long axis of the ultrasonic oscillator is arranged along the horizontal direction and hence, the planar surface of the reflector is arranged

along a vertical direction orthogonal to the horizontal direction.

Further, a sound pressure of the ultrasonic waves takes a maximum value and a minimum value at “node” and “antinode” formed on the first standing wave. Accordingly, by arranging the descending pipe, the reflector and the ultrasonic oscillator in the horizontal direction such that the “node” and a position at which the fluid falls agree with each other, bubbles can be crushed most efficiently.

[0017]

Further, the third invention is, in the first invention, characterized in that the ultrasonic oscillator is arranged with a second emission surface extending vertically upward, the reservoir includes a reflection surface which forms a second reflected wave by reflecting a second ultrasonic wave emitted from the second emission surface (hereinafter referred to as “second incident wave”), and the second emission surface is arranged in a spaced-apart manner from the reflection surface such that the second incident wave and the second reflected wave are synthesized thus producing a second standing wave.

In the invention having such a configuration, the reflection surface may be a water surface of a fluid stored in the reservoir, for example. This is because the second incident wave is reflected on the water surface thus forming a second standing wave. A height position of the reflection surface from the bottom portion of the reservoir is determined by adjusting a wave length of the ultrasonic waves and a water level of a fluid stored in the reservoir.

In the invention having the above-mentioned configuration, “node” and “antinode” are formed also in the second standing wave and hence, bubbles are crushed most efficiently when a fluid in which bubbles are contained reaches “node”.

[0018]

The fourth invention is, in any one of the first to third inventions, characterized in that the ultrasonic oscillator is housed in a housing provided with an opening portion on at least one end surface thereof.

In the invention having such a configuration, in addition to the manner of operation of any one of the first to third inventions, it is possible to prevent ultrasonic waves other than ultrasonic waves which propagate in a concentrated manner toward a front side of the ultrasonic oscillator from propagating in the fluid as spherical waves by the housing. That is, the ultrasonic waves whose propagation is suppressed are reflected on the housing and a water surface, and generates a water flow in the housing. This water flow gently spreads in the reservoir through the opening portion.

[0019]

The fifth invention is, in any one of the first to fourth inventions, characterized in that the ultrasonic oscillator includes a vibrator mounted on an emission surface thereof.

In the invention having such a configuration, when the vibrator resonates with a

frequency of ultrasonic waves emitted from the emitting surface of the ultrasonic oscillator, an amplitude of the ultrasonic waves is increased so that a pressure of the ultrasonic waves is increased. Accordingly, a large amount of bubbles can be surely crushed with small inputted energy.

[0020]

An underwater oxygen dissolving method according to the sixth invention is characterized by including: a vortex forming step where a falling hole is formed in a bottom portion of a cylindrical tank thus enabling a fluid filled into the cylindrical tank to form a vortex; a bubble forming step where, in a cylindrical descending pipe which includes: an inner pipe having an upper end which communicates with the falling hole and a side wall in which a plurality of suction holes are formed; and an outer pipe disposed around the inner pipe, forming a closed space between the outer pipe and the inner pipe, and provided with an air supply unit which supplies air into the closed space, air is sucked into the fluid from a periphery of the vortex through the air supply unit and the plurality of suction holes when the fluid passes through the inner pipe so that bubbles are formed in the fluid; a storing step where the fluid in which the bubbles are formed falls into and is stored in the reservoir; and a bubble crushing step where an ultrasonic wave is emitted from an ultrasonic oscillator immersed in the fluid stored in the reservoir toward the fluid which is stored in the reservoir and in which the bubbles are formed so that the bubbles are crushed.

The invention having such a configuration can acquire the manner of operation substantially equal to the manner of operation of the first invention.

EFFECTS OF THE INVENTION

[0021]

According to the first invention, due to the provision of the cylindrical tank and the descending pipe, a large amount of bubbles can be formed in the fluid by downward flow of the fluid by gravity. That is, a porous pipe, a compressor and the like in the prior art are unnecessary and hence, the simple configuration is realized thus preventing the apparatus from becoming large-sized. Accordingly, the apparatus can be manufactured at a low cost, and an amount of power consumption or the like can be suppressed.

Since the porous pipe is unnecessary, lowering of efficiency for generating bubbles caused by clogging of the fine holes can be prevented. Accordingly, the apparatus can efficiently generate bubbles.

Further, bubbles in a fluid stored in the reservoir can be crushed by the ultrasonic oscillator and hence, the movement of oxygen contained in the bubbles to the fluid can be accelerated. Further, the bubbles in the fluid stored in the reservoir includes bubbles generated by cavitation and the bubbles formed in the fluid which passes through the inner pipe and hence, due to the provision of the ultrasonic oscillator,

the cylindrical tank and the descending pipe, the oxygen dissolving efficiency can be increased.

[0022]

According to the second invention, in addition to the advantageous effect acquired by the first invention, bubbles can be crushed most efficiently by making “node” formed on the first standing wave agree with the position at which the fluid falls and hence, the concentration of oxygen dissolved into the fluid can be further increased.

[0023]

According to the third invention, an advantageous effect substantially equal to the advantageous effect acquired by the second invention can be acquired.

[0024]

According to the fourth invention, in addition to the advantageous effects acquired by the first to the third inventions, a water flow which is generated in the housing spreads in the inside of the reservoir through the opening portion and hence, a fluid stored in the reservoir is agitated whereby the concentration of dissolved oxygen in the inside of the reservoir can be made uniform.

[0025]

According to the fifth invention, in addition to the advantageous effects acquired by the first to the fourth inventions, an amount of power consumption of the ultrasonic oscillator can be reduced and, at the same time, the concentration of oxygen dissolved in the fluid can be increased.

[0026]

According to the sixth invention, an advantageous effect substantially equal to the advantageous effect acquired by the first invention can be acquired.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

FIG. 1 is a constitutional view of an underwater oxygen dissolving apparatus according to an embodiment 1.

FIG. 2(a) is a cross-sectional view of the underwater oxygen dissolving apparatus as viewed in a direction indicated by an arrowed line A-A in FIG. 1, and FIG. 2(b) is a cross-sectional view of the underwater oxygen dissolving apparatus as viewed in a direction indicated by an arrowed line B-B in FIG. 1.

FIG. 3 is a longitudinal cross-sectional view of a cylindrical tank and a descending pipe which form parts of the underwater oxygen dissolving apparatus according to the embodiment 1.

FIG. 4(a) and FIG. 4(b) show the results obtained by comparing a dissolved oxygen concentration and an amount of power consumption in the underwater oxygen dissolving apparatus according to the embodiment 1 and a dissolved oxygen concentration and an amount of power consumption in an underwater oxygen dissolving

apparatus of the prior art.

FIG. 5(a) is a constitutional view of an underwater oxygen dissolving apparatus according to a first modification of the embodiment 1, and FIG. 5(b) is an explanatory view for describing the manner of operation of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus.

FIG. 6 is a longitudinal cross-sectional view of a cylindrical tank and a descending pipe which form parts of an underwater oxygen dissolving apparatus according to a second modification of the embodiment 1.

FIG. 7 is a constitutional view of an underwater oxygen dissolving apparatus according to a third modification of the embodiment 1, and FIG. 7(b) is an explanatory view for describing the manner of operation of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus.

FIG. 8 is a side view of an ultrasonic oscillator which forms a part of an underwater oxygen dissolving apparatus according to a fourth modification of the embodiment 1 as viewed from above.

FIG. 9(a) is a constitutional view of an underwater oxygen dissolving apparatus according to an embodiment 2, and FIG. 9(b) is an explanatory view for describing the manner of operation of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus.

FIG. 10 is a side view of an ultrasonic oscillator which forms a part of an underwater oxygen dissolving apparatus according to a modification of the embodiment 2.

FIG. 11 is a view showing steps of an underwater oxygen dissolving method according to an embodiment 3.

EMBODIMENTS OF THE INVENTION

EMBODIMENT 1

[0028]

An underwater oxygen dissolving apparatus according to an embodiment 1 of a mode for carrying out the present invention is described in detail with reference to FIG. 1 to FIG. 8. FIG. 1 is a constitutional view of the underwater oxygen dissolving apparatus according to the embodiment 1.

As shown in FIG. 1, the underwater oxygen dissolving apparatus 1 according to this embodiment includes: a cylindrical tank 2 where a falling hole 2a is formed in a bottom portion 2b of the cylindrical tank 2 thus enabling a fluid 10 filled into the cylindrical tank 2 to form a vortex 11 (see FIG. 3); a cylindrical descending pipe 5 including: an inner pipe 3 having an upper end 3a which communicates with the falling hole 2a and a side wall 3b in which a plurality of suction holes 6 (see FIG. 3) are formed; and an outer pipe 4 disposed around the inner pipe 3, forming a closed space 13 between the outer pipe 4 and the inner pipe 3, and provided with an air supply unit 7 which

supplies air into the closed space 13, the descending pipe 5 being configured such that air is sucked into the fluid 10 from a periphery of the vortex 11 through the air supply unit 7 and the plurality of suction holes 6 when the fluid 10 passes through the inner pipe 3 so that bubbles 12 are formed in the fluid 10; a box-type reservoir 8 arranged vertically downward the descending pipe 5, the reservoir 8 being configured such that the fluid 10 in which the bubbles 12 are formed falls into and is stored in the box-type reservoir 8; and an ultrasonic oscillator 9 immersed in the fluid 10 stored in the reservoir 8, the ultrasonic oscillator 9 emitting an ultrasonic wave to the fluid 10 stored in the reservoir 8 thus crushing the bubbles 12 (indicated by star marks in the drawing, the same goes hereinafter).

In such a configuration, an upper opening portion 2d is formed on an end surface of the cylindrical tank 2 on a side opposite to the bottom portion 2b (an upper side in FIG. 1). The reservoir 8 includes side walls 8a, 8b respectively having a surface extending along a vertical direction V. The ultrasonic oscillator 9 is formed of an ultrasonic wave vibration element 9a and a horn 9b, and is disposed in a spaced-apart manner from the side wall 8b by a distance L with a long axis X thereof extending along a horizontal direction H in a state where the ultrasonic oscillator 9 is stored in a storage vessel 14 having a flange 14a. To be more specific, the ultrasonic oscillator 9 adopts a structure where the horn 9b and the flange 14a are fixed to each other so that the ultrasonic oscillator 9 is supported on the side wall 8a of the reservoir 8 by way of the flange 14a.

As the air supply unit 7, for example, an air supply amount adjusting valve is used so that an amount of air supplied into the closed space 13 can be freely adjusted.
[0029]

Next, the cylindrical tank and the descending pipe which form parts of the underwater oxygen dissolving apparatus according to the embodiment 1 are further described with reference to FIG. 2. FIG. 2(a) is a cross-sectional view of the underwater oxygen dissolving apparatus as viewed in a direction indicated by an arrowed line A-A in FIG. 1, and FIG. 2(b) is a cross-sectional view of the underwater oxygen dissolving apparatus as viewed in a direction indicated by an arrowed line B-B in FIG. 1. Constitutional elements shown in FIG. 2 are also given the same symbols used in FIG. 1, and the description of such elements is omitted.

As shown in FIG. 2(a), the cylindrical tank 2 which forms a part of the underwater oxygen dissolving apparatus 1 according to this embodiment includes: the bottom portion 2b; a side wall 2c which is formed on a peripheral edge of the bottom portion 2b; and the falling hole 2a which is formed at the approximately center of the bottom portion 2b. The position of the falling hole 2a is not limited to the approximately center of the bottom portion 2b and the falling hole 2a may be positioned at any place of the bottom portion 2b.

As shown in FIG. 2(b), in the descending pipe 5 which forms a part of the

underwater oxygen dissolving apparatus 1 according to this embodiment, the closed space 13 is formed between the inner pipe 3 and the outer pipe 4. The plurality of suction holes 6 are formed in the inner pipe 3 about the center C of the cylindrical tank 2 (see FIG. 2(a)) and the descending pipe 5 at intervals of 90 degrees. The plurality of suction holes 6 are not necessarily formed of micropores for generating microbubbles or nanobubbles. It is sufficient for the plurality of suction holes 6 to have a size where bubbles having a diameter of approximately 1 mm can be generated, for example. Further, the plurality of suction holes 6 are formed in the inner pipe 3 in plural stages at fixed intervals along a longitudinal direction of the inner pipe 3. The number of such stages is not particularly limited.

[0030]

Next, the manner of operation of the cylindrical tank and the descending pipe which form parts of the underwater oxygen dissolving apparatus according to the embodiment 1 is described in detail with reference to FIG. 3. FIG. 3 is a longitudinal cross-sectional view of the cylindrical tank and the descending pipe which form parts of the underwater oxygen dissolving apparatus according to the embodiment. Constitutional elements shown in FIG. 3 are also given the same symbols used in FIG. 1 and FIG. 2, and the description of such elements is omitted.

As shown in FIG. 3, when the fluid 10 is filled into the cylindrical tank 2 from the upper opening portion 2d of the cylindrical tank 2 by gravity falling, since the falling hole 2a is formed in the bottom portion 2b of the cylindrical tank 2, the filled fluid 10 starts to flow into the falling hole 2a while circulating above the falling hole 2a thus generating a downward flow 11a in the vicinity of the falling hole 2a. When the inflow of the fluid 10 into the falling hole 2a progresses, a recess 10a is formed on the center of the circulating fluid 10 so that a rotational flow 11b is formed and, then, a vortex 11 is formed by an interaction between the downward flow 11a and the rotational flow 11b. The vortex 11 formed due to filling of the fluid 10 into the cylindrical tank 2 in this manner is a so-called bathtub vortex which is formed by gravity flow of the fluid 10 from a high place to a low place. Air is taken into the fluid through the recess 10a.

[0031]

Next, the fluid 10 which flows into the falling hole 2a passes through the inner pipe 3 which forms the descending pipe 5. In this case, air taken into the fluid 10 from the recess 10a is separated from a distal end of the vortex 11 and hence, bubbles 12a are formed in the fluid 10.

The descending pipe 5 is configured to introduce air into the inside of the inner pipe 3 from the outer pipe 4 through the air supply unit 7 and the plurality of suction holes 6. A negative pressure in the vortex 11 is gradually increased toward a center portion of the vortex 11 in a radial direction of the vortex 11. Accordingly, when the fluid 10 passes through the inner pipe 3 downward, air is sucked into the inside of the vortex 11 due to the rotational flow 11b of the vortex 11 and the above-mentioned

negative pressure of the vortex 11 and hence, bubbles 12b are formed. To be more specific, the bubbles 12b having a diameter of approximately 1 (mm) are formed at a bottom portion of the vortex 11. The diameter of the bubbles 12b depends on an amount of air supplied by the air supply unit 7, a size of the plurality of suction holes 6 and the like. Further, due to the rotation of an inner surface of the vortex 11 and the generation of turbulence at a boundary between an air layer and a liquid layer on the inner surface of the vortex 11, oxygen in the air layer is dissolved in the vortex 11 in the liquid layer.

Further, the fluid 10 in which the bubbles 12a, 12b are formed passes through the inner pipe 3 and, thereafter, falls into and is stored in the reservoir 8 (see FIG. 1). The bubbles 12 shown in FIG. 1 are formed of bubbles 12a and bubbles 12b shown in FIG. 2. When the fluid 10 falls into the reservoir 8, the bubbles 12a, 12b move so as to spread in the inside of the reservoir 8. Further, turbulence is generated on a water surface 10b of the stored fluid 10 due to the falling of the fluid 10 so that oxygen is dissolved in the fluid 10 from air around the fluid 10.

[0032]

Subsequently, when ultrasonic waves emitted from the ultrasonic oscillator 9 (see FIG. 1) are irradiated to the fluid 10 stored in the reservoir 8, cavitation occurs. In the cavitation, when a sound pressure (amplitude) of the emitted ultrasonic waves is changed cyclically, the generation and the extinction of bubbles are repeated in the fluid 10. Accordingly, both bubbles (not shown in the drawing) generated by the cavitation and the bubbles 12a, 12b formed in the fluid 10 which passes through the inner pipe 3 are crushed. Accordingly, oxygen supplied from the bubbles generated by the cavitation and oxygen supplied from the bubbles 12a, 12b are dissolved into the fluid 10 stored in the reservoir 8. That is, a larger amount of oxygen is dissolved in the fluid 10 by an amount corresponding to an amount of oxygen supplied from the bubbles 12a, 12b.

The side wall 8b (see FIG. 1) of the reservoir 8 is arranged in a spaced-apart manner from the ultrasonic oscillator 9 by a distance L (see FIG. 1) such that a first incident wave emitted from the ultrasonic oscillator 9 and a first reflected wave reflected by the side wall 8b are synthesized thus producing a first standing wave. With such a configuration, by making the center C of the descending pipe 5 agree with “node” of a standing wave, crushing efficiency of the bubbles 12a, 12b and the like can be maximized. However, this does not mean that the bubbles 12a, 12b and the like cannot be crushed without the formation of a first standing wave, but means that crushing efficiency can be enhanced by forming a first standing wave. Accordingly, depending on a length of the distance L, even when a first standing wave is not formed, bubbles 12a, 12b and the like can be sufficiently crushed. Such an advantageous effect of maximizing crushing efficiency is described later.

[0033]

Next, an experimental result which is obtained by comparing an effect of the

underwater oxygen dissolving apparatus according to the embodiment 1 and an effect of the underwater oxygen dissolving apparatus of a prior art is described in detail with reference to FIG. 4. FIG. 4(a) and FIG. 4(b) show the results obtained by comparing a dissolved oxygen concentration and an amount of power consumption in the underwater oxygen dissolving apparatus according to the embodiment 1 and a dissolved oxygen concentration and an amount of power consumption in the underwater oxygen dissolving apparatus of the prior art.

FIG. 4(a) is a graph where an increased amount of oxygen dissolved in water (increased amount Δ of dissolved oxygen) is plotted, wherein an elapsed time (min) is taken on an axis of abscissa, and an increased amount of dissolved oxygen (mg/L) is taken on an axis of ordinate. In the graph, white and black circular marks indicate a result of the underwater oxygen dissolving apparatus 1 according to the embodiment 1, square marks indicate a result of the aeration apparatus according to the prior art (hereinafter referred to as “apparatus α ”), and white circular marks indicate a result of a conventional apparatus obtained by combining the aeration and the irradiation of an ultrasonic wave (hereinafter referred to as “apparatus β ”). An amount of water used in the respective experiments is 4 L.

In FIG. 4(a), to pay attentions to an increased amount Δ of dissolved oxygen (mg/L) at an elapsed time of 30 (min), an increased amount Δ of dissolved oxygen (mg/L) of the underwater oxygen dissolving apparatus 1 according to the embodiment 1 is 2.4 times as large as an increased amount Δ of dissolved oxygen (mg/L) of the apparatus α , ($\cong 5.3/2.2$) and is 1.4 times as large as an increased amount Δ of dissolved oxygen (mg/L) of the apparatus β ($\cong 3.0/2.2$).

Further, an elapsed time (min) necessary for obtaining an increased amount Δ of dissolved oxygen of 2.2 (mg/L) which is the increased amount Δ of dissolved oxygen of the apparatus α at an elapsed time of 30 (min) is approximately 16.4 (min) in the apparatus β , and is approximately 3.1 (min) in the underwater oxygen dissolving apparatus 1 according to the embodiment 1. That is, an elapsed time in the underwater oxygen dissolving apparatus 1 according to the embodiment 1 is shortened to 1/10 of an elapsed time in the apparatus α ($\cong 3.1/30$), and is shortened to 1/5 of an elapsed time in the apparatus β ($\cong 3.1/16.4$).

[0034]

FIG. 4(b) is a Table showing an elapsed time (min) necessary for obtaining an increased amount Δ of dissolved oxygen of 2.2 (mg/L), an amount of power consumption (Wh), and a power consumption amount ratio with respect to the underwater oxygen dissolving apparatus 1 according to the embodiment 1, the apparatus α and the apparatus β .

As can be understood from the power consumption amount ratio shown in FIG. 4(b), an amount of power consumption of the underwater oxygen dissolving apparatus 1 according to the embodiment 1 is reduced to approximately 0.26 times of an amount of

power consumption of the apparatus α .

In this manner, the underwater oxygen dissolving apparatus 1 according to the embodiment 1 eventually has exhibited outstanding superiority over the prior art with respect to the increase of an amount Δ of dissolved oxygen and the reduction of an amount of power consumption.

[0035]

As has been described above, according to the underwater oxygen dissolving apparatus 1 of this embodiment, with the use of the cylindrical tank 2 and the descending pipe 5, a large amount of bubbles 12a, 12b can be formed in the inside of the fluid 10 by downward flow of the fluid 10 by gravity. That is, a compressor or an aeration pipe which is required in the prior art, or an active component such as an impeller is unnecessary for forming bubbles. By adjusting an amount of air supplied by the air supply unit 7 and by changing a size of the plurality of suction holes 6, an amount of air supplied to the closed space 13 can be freely adjusted and hence, a size of bubbles 12b can be increased and decreased. Further, by increasing a speed of the fluid 10 filled into the cylindrical tank 2 or by increasing the number of the plurality of suction holes 6, the number of bubbles 12a, 12b can be increased. The plurality of suction holes 6 are not formed of micropores used for generating microbubbles or the like so that there is no possibility that efficiency for generating bubbles 12b is lowered due to the clogging of the plurality of suction holes 6 by fine particles or impurities in the fluid 10.

Further, according to the underwater oxygen dissolving apparatus 1, bubbles generated by the cavitation and bubbles 12a, 12b are crushed by the ultrasonic oscillator 9 and hence, a larger amount of oxygen can be dissolved into the fluid 10. Oxygen moved into the fluid 10 decomposes harmful substances or bacteria contained in the fluid 10 so that water can be purified.

In this manner, according to the underwater oxygen dissolving apparatus 1, as shown in FIG. 4, oxygen dissolving efficiency can be remarkably enhanced and, at the same time, an amount of power consumption can be significantly reduced compared with the prior art with a simple configuration. The underwater oxygen dissolving apparatus 1 can be easily installed, and an amount of dissolved oxygen in water is increased and hence, a biodegradation action on contaminant by aerobic microorganisms is accelerated or the like whereby the underwater oxygen dissolving apparatus 1 can largely contribute to improve water quality in water environment.

[0036]

Next, an underwater oxygen dissolving apparatus according to a first modification of the embodiment 1 is described with reference to FIG. 5. FIG. 5(a) is a constitutional view of the underwater oxygen dissolving apparatus according to the first modification of the embodiment 1, and FIG. 5(b) is an explanatory view for describing the manner of operation of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus. Constitutional elements shown in FIG. 5 are also given

the same symbols used FIG. 1 to FIG. 3 and hence, the description of such elements is omitted.

As shown in FIG. 5(a), in the underwater oxygen dissolving apparatus 1a according to the first modification of the embodiment 1, an ultrasonic oscillator 9 is arranged with a long axis X thereof extending along a horizontal direction H, and a reservoir 8 (see FIG. 1) is provided with a reflector 16 in the inside thereof which forms a first reflected wave by reflecting a first incident wave emitted from a first emission surface 15 of the ultrasonic oscillator 9. The first emission surface 15 is a distal end surface of a horn 9b.

As shown in FIG. 5(b), the reflector 16 is arranged in a spaced-apart manner from the first emission surface 15 by a distance L_1 such that a first incident wave and a first reflected wave are synthesized thus producing a first standing wave 17. The reflector 16 is formed of a rigid wall having a planar surface, and is fixed to the reservoir 8 (see FIG. 1) by means of a support member not shown in the drawing. Further, the ultrasonic oscillator 9 is arranged with a long axis X thereof extending along a horizontal direction H so that the reflector 16 is arranged with the planar surface thereof extending along a vertical direction V.

Other configurations of the underwater oxygen dissolving apparatus 1a are substantially equal to the corresponding configurations of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0037]

In the underwater oxygen dissolving apparatus 1a having such a configuration, a first standing wave 17 is formed where a node 17a where an amplitude assumes zero and an antinode 17b where the amplitude assumes a maximum value are repeated for every $\lambda_1/4$ (λ_1 being a wavelength of an ultrasonic wave emitted from the ultrasonic oscillator 9 when the ultrasonic wave emitted from the ultrasonic oscillator 9 propagates in the fluid 10 stored in the reservoir 8). A sound pressure of an ultrasonic wave takes a maximum value and a minimum value at the node 17a and the antinode 17b and hence, by arranging the descending pipe 5, the reflector 16 and the ultrasonic oscillator 9 in the horizontal direction H such that the node 17a and a position on which the fluid 10 falls from the descending pipe 5 agree with each other, bubbles 12a, 12b and the like can be crushed most efficiently. With respect to a depth direction (vertical direction V) of the fluid 10 stored in the reservoir 8, a height position of the ultrasonic oscillator 9 is not particularly limited provided that the ultrasonic oscillator 9 is disposed within a range from a maximum depth which the falling fluid 10 can reach to a water surface 10b.

The manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1a other than the above-mentioned manner of operation and advantageous effects are substantially equal to the manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0038]

An underwater oxygen dissolving apparatus according to a second modification of the embodiment 1 is described with reference to FIG. 6. FIG. 6 is a longitudinal cross-sectional view of a cylindrical tank and a descending pipe which form parts of the underwater oxygen dissolving apparatus according to the second modification of the embodiment 1. Constitutional elements shown in FIG. 6 are given the same symbols used in FIG. 1 to FIG. 5, and the description of such elements is omitted.

As shown in FIG. 6, in the underwater oxygen dissolving apparatus 1b according to the second modification of the embodiment 1, an annular projection 18 is circumferentially formed on a falling hole 2a of a cylindrical tank 2 of the underwater oxygen dissolving apparatus 1. The projection 18 has an approximately triangular shape in cross section, and is formed on the falling hole 2a so as to project toward the center C.

The manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1b other than the following manner of operation and advantageous effects are substantially equal to the manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0039]

In the underwater oxygen dissolving apparatus 1b having such a configuration, a diameter of the falling hole 2a is narrowed due to the formation of the projection 18 and hence, a small vortex 11c is generated directly below the projection 18. Due to such a small vortex 11c, some bubbles 12c out of bubbles 12a are agitated and are extinguished so that oxygen contained in the bubbles 12c is dissolved in the fluid 10 when the bubbles 12a are extinguished. Accordingly, the underwater oxygen dissolving apparatus 1b can enhance an oxygen dissolving efficiency compared with the underwater oxygen dissolving apparatus 1.

The manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1b other than the above-mentioned manner of operation and advantageous effects are substantially equal to the manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0040]

Next, an underwater oxygen dissolving apparatus according to a third modification of the embodiment 1 is described with reference to FIG. 7. FIG. 7 is a constitutional view of an underwater oxygen dissolving apparatus according to a third modification of the embodiment 1, and FIG. 7(b) is an explanatory view for describing the manner of operation of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus. Constitutional elements shown in FIG. 7 are also given the same symbols used in FIG. 1 to FIG. 6, and the description of such elements is omitted.

As shown in FIG. 7(a), the underwater oxygen dissolving apparatus 1c according to the third modification of the embodiment 1 is formed by additionally providing a cylindrical tank 2, a descending pipe 5 and the like to the underwater oxygen dissolving apparatus 1 according to the embodiment 1, and includes an ultrasonic oscillator 19 in place of the ultrasonic oscillator 9. The ultrasonic oscillator 19 includes a horn 19a having a larger length than the horn 9b of the ultrasonic oscillator 9. However, structure of the ultrasonic oscillator 19 is substantially equal to the structure of the ultrasonic oscillator 9 except for that the ultrasonic oscillator 19 includes the horn 19a.

As shown in FIG. 7(b), a reflector 16 is arranged in a spaced-apart manner from a first emission surface 15 (a distal end surface of the horn 19a) by a distance L_2 such that a first standing wave 17 having at least two nodes 17a is formed. The cylindrical tank 2, the descending pipe 5 and the like are disposed directly above two nodes 17a. λ_1 is a wavelength of an ultrasonic wave emitted from the ultrasonic oscillator 9 when the ultrasonic wave emitted from the ultrasonic oscillator 9 propagates in the fluid 10 stored in the reservoir 8, and λ_2 is a wavelength of the ultrasonic wave when the ultrasonic wave propagates in the horn 19a.

Other configurations of the underwater oxygen dissolving apparatus 1c are substantially equal to the corresponding configurations of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0041]

In the underwater oxygen dissolving apparatus 1c having such a configuration, the cylindrical tank 2, the descending pipe 5 and the like are additionally provided and, at the same time, the cylindrical tank 2, the descending pipe 5 and the like are disposed directly above two nodes 17a. Accordingly, compared with the underwater oxygen dissolving apparatus 1 according to the embodiment 1, an amount of fluid 10 filled into the cylindrical tank 2 is increased, and a generation amount of bubbles 12 is also increased. As a result, according to the underwater oxygen dissolving apparatus 1c, it is possible to increase the concentration of oxygen dissolved in a fluid per unit time.

The manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1b other than the above-mentioned manner of operation and advantageous effects are substantially equal to the manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0042]

Next, an underwater oxygen dissolving apparatus according to a fourth modification of the embodiment 1 is described with reference to FIG. 8. FIG. 8 is a side view of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus according to the fourth modification of the embodiment 1 as viewed from above. Constitutional elements shown in FIG. 8 are also given the same symbols

used in FIG. 1 to FIG. 7, and the description of such elements is omitted.

As shown in FIG. 8, in the underwater oxygen dissolving apparatus 1d according to the fourth modification of the embodiment 1, an ultrasonic oscillator 9 arranged with a long axis X thereof extending along a horizontal direction H is housed in a housing 20 provided with an opening portion 20a on one end surface of the housing 20. The housing 20 is formed of a box body having closed surfaces except for the opening portion 20a, and is fixed to the reservoir 8 (see FIG. 1) by means of a support member not shown in the drawing.

Other configurations of the underwater oxygen dissolving apparatus 1d are substantially equal to the corresponding configurations of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0043]

In the underwater oxygen dissolving apparatus 1d having such a configuration, it is possible to prevent ultrasonic waves other than ultrasonic waves which propagate in a concentrated manner toward a front side of the ultrasonic oscillator 9 from propagating in the fluid 10 as spherical waves (see FIG. 1). That is, the ultrasonic waves which propagate toward the front side of the ultrasonic oscillator 9 generate a water flow 21a which advances linearly in the housing 20 and, at the same time, crush bubbles 12a, 12b (see FIG. 3) or the like so that oxygen is dissolved into the fluid 10 due to such crushing of bubbles 12a, 12b.

On the other hand, ultrasonic waves whose propagation is suppressed propagate as spherical waves and, thereafter, are reflected on the housing 20 and the water surface 10b (disposed on a viewer's side in the drawing), and generate a water flow 21b in the housing 20. Next, a water flow 21b and a water flow (not shown in the drawing) which is formed due to the reflection of a water flow 21a on the housing 20 or the like merge with each other thus forming a water flow 21c, and the water flow 21c gently spreads in the reservoir 8 through the opening portion 20a. Accordingly, it is possible to prevent the fluid 10 containing dissolved oxygen formed substantially solely by ultrasonic waves which propagate to the front side of the ultrasonic oscillator from staying in an area around the ultrasonic oscillator 9.

As a result, according to the underwater oxygen dissolving apparatus 1d, the water flow 21c which is generated in the housing 20 spreads in the inside of the reservoir 8 through the opening portion 20a and hence, the fluid 10 stored in the reservoir 8 is agitated whereby the concentration of dissolved oxygen in the inside of the reservoir 8 can be made uniform.

The manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1d other than the above-mentioned manner of operation and advantageous effects are substantially equal to the manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

Embodiment 2

[0044]

An underwater oxygen dissolving apparatus according to an embodiment 2 of the mode for carrying out the present invention is described in detail with reference to FIG. 9 and FIG. 10. FIG. 9(a) is a constitutional view of the underwater oxygen dissolving apparatus according to the embodiment 2, and FIG. 9(b) is an explanatory view for describing the manner of operation of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus. Constitutional elements shown in FIG. 9 are also given the same symbols used in FIG. 1 to FIG. 8, and the description of such elements is omitted.

As shown in FIG. 9(a), an underwater oxygen dissolving apparatus 22 of the embodiment 2 includes ultrasonic oscillators 23 in place of the ultrasonic oscillator 9 of the underwater oxygen dissolving apparatus 1 according to the embodiment 1. The ultrasonic oscillator 23 is formed of an ultrasonic wave vibration element 23a and a horn 23b, and is arranged with a second emission surface 24 (a distal end surface of the horn 23a) extending vertically upward. The reservoir 8 includes a reflection surface which forms a second reflected wave by reflecting a second incident wave emitted from the second emission surface 24. The reflection surface is formed of a water surface 10b.

Further, as shown in FIG. 9(b), the second emission surface 24 is arranged in a spaced-apart manner from the water surface 10b by a distance L_3 such that a second incident wave and a second reflected wave are synthesized thus producing a second standing wave 25. In the same manner as the first standing wave 17, the second standing wave 25 is formed where a node 25a and an antinode 25b are repeated for every $\lambda_1/4$ (λ_1 being a wavelength of an ultrasonic wave emitted from the ultrasonic oscillator 9 when the ultrasonic wave emitted from the ultrasonic oscillator 9 propagates in the fluid 10 stored in the reservoir 8). In the same manner as the underwater oxygen dissolving apparatus 1, however, depending on a length of the distance L_3 , even when a second standing wave is not formed, bubbles 12a, 12b and the like can be sufficiently crushed.

Further, the ultrasonic oscillators 23 are housed in a storage vessel 14b, and second emission surfaces 24 of the ultrasonic oscillators 23 are covered by a plate-like vibrator 26. The vibrator 26 forms an upper surface of the storage vessel 14b, and is arranged parallel to the second emission surface 24.

To efficiently resonate the vibrator 26, it is desirable that the second emission surface 24 and the plate-like vibrator 26 be brought into face contact with each other.

Other configurations of the underwater oxygen dissolving apparatus 22 are substantially equal to the corresponding configurations of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0045]

In the underwater oxygen dissolving apparatus 22 having such a configuration, when the fluid 10 which has fallen from the descending pipe 5 is made to fall at a

position of the node 25a, bubbles generated by the cavitation and bubbles 12a, 12b are efficiently crushed. Further, when the vibrator 26 resonates with a frequency of ultrasonic waves emitted from the second emission surface 24 of the ultrasonic oscillator 23, an amplitude of the ultrasonic waves is increased so that a pressure of the ultrasonic waves is increased.

As a result, according to the underwater oxygen dissolving apparatus 22, a large amount of bubbles 12a, 12b and the like can be surely crushed with small inputted energy. That is, an amount of power consumption of the ultrasonic oscillator 23 can be reduced and, at the same time, concentration of oxygen dissolved into the fluid 10 can be further enhanced.

The manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 22 other than the above-mentioned manner of operation and advantageous effects are substantially equal to the manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0046]

Subsequently, an underwater oxygen dissolving apparatus according to a modification of the embodiment 2 is described in detail with reference to FIG. 10. FIG. 10 is a side view of an ultrasonic oscillator which forms a part of the underwater oxygen dissolving apparatus according to the modification of the embodiment 2. Constitutional elements shown in FIG. 10 are also given the same symbols used in FIG. 1 to FIG. 9, and the description of such elements is omitted.

As shown in FIG. 10, the underwater oxygen dissolving apparatus 22a according to the modification of the embodiment 2 is formed by omitting the vibrator 26 from the underwater oxygen dissolving apparatus 22 of the embodiment 2 and by housing the ultrasonic oscillators 23 in a cylindrical housing 27 having opening portions 27a, 27b on both end surfaces of the cylindrical housing 27. The housing 27 is fixed to a reservoir 8 (see FIG. 1) by means of a support member not shown in the drawing.

Other configurations of the underwater oxygen dissolving apparatus 22a are substantially equal to the corresponding configurations of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

[0047]

In the underwater oxygen dissolving apparatus 22a having such a configuration, a water flow 21b and a water flow (not shown in the drawing) which is formed due to the reflection of a water flow 21a on the housing 27 and the water surface 10b merge with each other thus forming a water flow 21c, and the water flow 21c gently spreads in the reservoir 8 through the opening portion 27a.

As a result, according to the underwater oxygen dissolving apparatus 22a, the fluid 10 stored in the reservoir 8 is agitated and hence, the concentration of dissolved oxygen in the inside of the reservoir 8 can be made uniform.

The manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 22a other than the above-mentioned manner of operation and advantageous effects are substantially equal to the manner of operation and advantageous effects of the underwater oxygen dissolving apparatus 1 of the embodiment 1.

Embodiment 3

[0048]

Subsequently, an underwater oxygen dissolving method according to an embodiment 3 of a mode for carrying out the present invention is described in detail with reference to FIG. 11. FIG. 11 is a view showing steps of the underwater oxygen dissolving method according to the embodiment 3. Constitutional elements shown in FIG. 11 are also given the same symbols used in FIG. 1 to FIG. 10, and the description of such elements is omitted.

As shown in FIG. 11, the underwater oxygen dissolving method 28 according to the embodiment 3 includes a vortex forming step (step S1), a bubble forming step (step S2), a storing step (step S3) and a bubble crushing step (step S4). Symbols used in this embodiment mean symbols in FIG. 1 to FIG. 10.

The vortex forming step (step S1) is a step where a falling hole 2a is formed in a bottom portion 2b of a cylindrical tank 2 thus enabling a fluid 10 filled into the cylindrical tank 2 to form a vortex 11.

In this step, the vortex 11 is formed in the inside of the cylindrical tank 2 so that bubbles 12a are formed. This step also functions as a preparation step for sucking air into the fluid 10 in the bubble forming step (step S2).

Accordingly, in this step, bubbles 12a can be formed without using power equipment such as an impeller and hence, power saving can be acquired.

[0049]

The bubble forming step (step S2) is a step performed using a cylindrical descending pipe 5. The cylindrical descending pipe 5 includes: an inner pipe 3 having an upper end 3a which communicates with the falling hole 2a and a side wall 2c in which a plurality of suction holes 6 are formed; and an outer pipe 4 disposed around the inner pipe 3, forming a closed space 13 between the outer pipe 4 and the inner pipe 3, and provided with an air supply unit 7 which supplies air into the closed space 13. In the bubble forming step, air is sucked into the fluid 10 from a periphery of the vortex 11 through the air supply unit 7 and the plurality of suction holes 6 when the fluid 10 passes through the inner pipe 3 so that bubbles 12b are formed in the fluid 10.

In this step, when the fluid 10 passes through the inner pipe 3 downward, air is sucked into the inside of the vortex 11 and hence, bubbles 12b are formed and, at the same time, oxygen is dissolved into an inner surface of the vortex 11.

Accordingly, in this step, bubbles 12b can be efficiently formed in the fluid 10.

[0050]

The storing step (step S3) is a step where the fluid 10 in which the bubbles 12a, 12b are formed falls into and is stored in the reservoir 8.

In this step, the bubbles 12a, 12b move into the inside of the reservoir 8 and, at the same time, the turbulence of a water surface 10b of the stored fluid 10 is generated so that oxygen is dissolved into the fluid 10.

Accordingly, in this step, ultrasonic waves from the ultrasonic oscillator 9 can be irradiated to bubbles generated in the fluid 10 by cavitation and the bubbles 12a, 12b and, further, even before ultrasonic waves are irradiated from the ultrasonic oscillator 9, concentration of dissolved oxygen can be increased.

[0051]

The bubble crushing step (step S4) is a step where the ultrasonic wave is emitted from the ultrasonic oscillator 9 immersed in the fluid stored in the reservoir 8 toward the fluid 10 which is stored in the reservoir 8 and in which the bubbles 12a, 12b and the like are formed so that the bubbles 12a, 12b and the like are crushed.

In this step, due to the cavitation generated by ultrasonic waves, bubbles 12a, 12b and the like are efficiently crushed and hence, oxygen is dissolved into the fluid 10 stored in the reservoir 8.

Accordingly, in this step, concentration of dissolved oxygen can be remarkably increased and hence, a harmful substance or the like in the fluid 10 can be surely decomposed.

[0052]

As has been described above, according to the underwater oxygen dissolving method 28 of the embodiment 3, an advantageous effect substantially equal to the advantageous effect acquired by the underwater oxygen dissolving apparatus 1 according to the embodiment 1 can be acquired.

[0053]

The structures of the underwater oxygen dissolving apparatuses 1 to 1d of the present invention are not limited to the structures described in the embodiments. For example, in the underwater oxygen dissolving apparatus 1, the ultrasonic oscillator 9 and the side wall 8b of the reservoir 8 may be disposed so as not to generate the first standing wave 17. In the underwater oxygen dissolving apparatus 1c, the cylindrical tank 2, the descending pipe 5 and the like may be also additionally provided. Further, the vibrator 26 may be disposed on the first emission surface of the ultrasonic oscillator 9.

In the underwater oxygen dissolving apparatus 22, the ultrasonic oscillator 23 may be additionally provided, and the vibrator 26 may be omitted. The distance L_3 between the ultrasonic oscillator 23 and the water surface 10b may be adjusted so as not to generate the second standing wave 25. In the bubble crushing step which forms the step S4 in the underwater oxygen dissolving method 28, ultrasonic waves emitted from the ultrasonic oscillator 9 may be continuously emitted or may be emitted in a pulse form at a desired timing.

INDUSTRIAL APPLICABILITY

[0054]

The present invention is also applicable to an underwater oxygen dissolving apparatus and an underwater oxygen dissolving method using the same for increasing concentration of oxygen dissolved into water for the purpose of breeding aquatic creatures for admiration or farming creatures for research or business purposes or for the purpose of improvement of water quality in a closed region such as a sewage disposal system, a lake or the like.

DESCRIPTION OF REFERENCE SIGNS

[0055]

- 1, 1a to 1d: Underwater oxygen dissolving apparatus
- 2: Cylindrical tank
- 2a: Falling hole
- 2b: Bottom portion
- 2c: Side wall
- 2d: Upper opening portion
- 3: Inner pipe
- 3a: Upper end
- 3b: Side wall
- 4: Outer pipe
- 5: Descending pipe
- 6: Suction hole
- 7: Air supply unit
- 8: Reservoir
- 8a, 8b: Side wall
- 9: Ultrasonic oscillator
- 9a: Ultrasonic wave vibration element
- 9b: Horn
- 10: Fluid
- 10a: Recess
- 10b: Water surface
- 11: Vortex
- 11a: Downward flow
- 11b: Rotational flow
- 11c: Small vortex
- 12 to 12c: Bubbles
- 13: Closed space
- 14, 14b: Storage vessel
- 14a: Flange

- 15: First emission surface
- 16: Reflector
- 17: First standing wave
- 17a: Node
- 17b: Antinode
- 18: Projection
- 19: Ultrasonic oscillator
- 19a: Horn
- 20: Housing
- 20a: Opening portion
- 21a to 21c: Water flow
- 22, 22a: Underwater oxygen dissolving apparatus
- 23: Ultrasonic oscillator
- 23a: Ultrasonic wave vibration element
- 23b: Horn
- 24: Second emission surface
- 25: Second standing wave
- 26: Vibrator
- 27: Housing
- 27a, 27b: Opening portion
- 28: Underwater oxygen dissolving method

CLAIMS

1. An underwater oxygen dissolving apparatus (1) comprising:
 - a cylindrical tank (2) where a falling hole (2a) is formed in a bottom portion (2b) of the cylindrical tank (2) thus enabling a fluid (10) filled into the cylindrical tank (2) to form a vortex (11);
 - a cylindrical descending pipe (5) comprising: an inner pipe (3) having an upper end (3a) which communicates with the falling hole (2a) and a side wall (3b) in which a plurality of suction holes (6) are formed; and an outer pipe (4) disposed around the inner pipe (3), forming a closed space (13) between the outer pipe (4) and the inner pipe (3), and provided with an air supply unit (7) which supplies air into the closed space (13), the descending pipe (5) being configured such that air is sucked into the fluid (10) from a periphery of the vortex (11) through the air supply unit (7) and the plurality of suction holes (6) when the fluid (10) passes through the inner pipe (3) so that bubbles (12) are formed in the fluid (10);
 - a box-type reservoir (8) arranged vertically downward the descending pipe (5) , the reservoir (8) being configured such that the fluid (10) in which the bubbles (12) are formed falls into and is stored in the box-type reservoir (8); and
 - an ultrasonic oscillator (9) immersed in the fluid (10) stored in the reservoir (8), the ultrasonic oscillator (9) emitting the ultrasonic wave to the fluid (10) stored in the reservoir (8) thus crushing the bubbles (12).

2. The underwater oxygen dissolving apparatus (1a) according to claim 1, wherein
 - the ultrasonic oscillator (9) is arranged with a long axis thereof extending along a horizontal direction,
 - the reservoir (8) is provided with a reflector (16) on a wall surface (8b) thereof or in the inside thereof, the reflector (16) which forms a first reflected wave by reflecting a first ultrasonic wave emitted from a first emission surface (15) of the ultrasonic oscillator (9) (hereinafter referred to as “first incident wave”), and
 - the reflector (16) is arranged in a spaced-apart manner from the first emission surface (15) such that the first incident wave and the first reflected wave are synthesized thus producing a first standing wave (17).

3. The underwater oxygen dissolving apparatus (22) according to claim 1, wherein
 - the ultrasonic oscillator (19) is arranged with a second emission surface (24) extending vertically upward,
 - the reservoir (8) includes a reflection surface which forms a second reflected wave by reflecting a second ultrasonic wave emitted from the second emission surface (24) (hereinafter referred to as “second incident wave”), and
 - the second emission surface (24) is arranged in a spaced-apart manner from the reflection surface such that the second incident wave and the second reflected wave are

synthesized thus producing a second standing wave (25).

4. The underwater oxygen dissolving apparatus (1d, 22a) according to any one of claims 1 to 3, wherein

the ultrasonic oscillator (9, 23) is housed in a housing (20, 27) provided with an opening portion on at least one end surface thereof.

5. The underwater oxygen dissolving apparatus (1, 22) according to any one of claims 1 to 4, wherein

the ultrasonic oscillator (9, 23) includes a vibrator (26) mounted on an emission surface thereof.

6. An underwater oxygen dissolving method comprising:

a vortex forming step (S1) where a falling hole is formed in a bottom portion of a cylindrical tank thus enabling a fluid filled into the cylindrical tank to form a vortex;

a bubble forming step (S2) where, in a cylindrical descending pipe which includes: an inner pipe having an upper end which communicates with the falling hole and a side wall in which a plurality of suction holes are formed; and an outer pipe disposed around the inner pipe, forming a closed space between the outer pipe and the inner pipe, and provided with an air supply unit which supplies air into the closed space, air is sucked into the fluid from a periphery of the vortex through the air supply unit and the plurality of suction holes when the fluid passes through the inner pipe so that bubbles are formed in the fluid;

a storing step (S3) where the fluid in which the bubbles are formed falls into and is stored in the reservoir; and

a bubble crushing step (S4) where an ultrasonic wave is emitted from an ultrasonic oscillator immersed in the fluid stored in the reservoir toward the fluid which is stored in the reservoir and in which the bubbles are formed so that the bubbles are crushed.