

A MICROBUBBLE GENERATOR

TECHNICAL FIELD

The present invention relates to a microbubble generator and method of generating
5 microbubbles, and an apparatus and method for treating a liquid using microbubbles.

BACKGROUND

Availability of fresh or potable water and waste water treatment remains a pressing
concern in many regions of the world. The World Health Organization (WHO) reported
10 that about 41% of the Earth's population lives in water-stressed areas and the number of
people in the water scarce regions may climb to 3.5 billion by the year 2025.

Treatment of water to be potable and of waste water for discharge and reuse typically
involves using both organic and inorganic chemicals for the various unit processes of
15 the treatment system. These chemicals may remain in the treated water as residue, as
by-products of chemical reaction with the pollutants, or separate out as sludge which is
not only difficult to handle and dispose of, but is also extremely expensive to remove,
increasing the life cycle cost of the system. Some chemicals like chlorine in water
treatment are also known to produce harmful by-products of chlorination like
20 trihalomethanes (THMs), which are known carcinogens.

Hence, there is a great need for more efficient and environmentally-friendly water and
waste water treatment processes without the use of harmful chemicals and without the
sludge produced by chemical addition.

25

SUMMARY

Generating microbubbles of gas in a liquid result in formation of a microbubble gas-
liquid emulsion. The microbubble generator is configured to mix any gas in liquid for
30 producing microbubbles of either positive or negative charge, depending on the liquid
pH and the nature of the gas (acid or basic). To treat a liquid, which may be the same as
or different from the liquid in which the microbubbles are generated, two reaction

vessels or chambers are preferably provided, one for solid/gas-liquid separation in concurrent flow and the other for oxidation, disinfection & pH adjustment purposes in counter current flow.

- 5 Introduction of the microbubble gas-liquid emulsion into a liquid to be treated leads to efficient removal of suspended matter such as submicron, non-polar suspended particles or solids from the liquid to be treated. This is effected by attachment of the charged microbubbles to these suspended matter, thereby increasing buoyancy of the microbubbles, making them rise faster along with the suspended matter in the liquid, to
- 10 eventually float on the surface of the liquid. The floating suspended matter can then be skimmed off. Submicron charged particles in the suspended matter can also be neutralized by oppositely charged microbubbles, thereby destabilizing the emulsion, making them agglomerate to float or sink based on their specific gravity. The microbubbles can strip dissolved gases in the liquid. Oxidation and disinfection of the
- 15 liquid can also be effected by collapsing the microbubbles by forming hydroxyl radicals without any external stimuli. Nanobubbles may be produced by collapsing the microbubbles, which then remain in the liquid for a longer duration for more effective water treatment. The microbubble gas-liquid emulsion also accelerates the formation of gas hydrates and increases the dissolved gas constituent in the liquid. Removal of oil
- 20 and grease from the liquid can also be achieved, together with lowering of the chemical oxygen demand (COD) and biochemical oxygen demand (BOD) measurements that indicate the amount of organic pollution in the liquid.

According to a first exemplary aspect, there is a microbubble generator comprising: a

25 pump configured to mix a liquid and a gas to form a pressurized gas-liquid mixture therein; a contact chamber in fluid connection with the pump and configured to enhance dissolution of the gas in the pressurized gas-liquid mixture therein; and a valve in fluid connection with the contact chamber and configured to discharge a microbubble emulsion comprising the liquid and microbubbles of the gas.

30

The microbubble generator may further comprise a vent in fluid connection with the contact chamber, the vent configured to release undissolved gas from the pressurized

gas-liquid mixture.

According to a second exemplary aspect, there is provided a method of generating microbubbles in a liquid, the method comprising: mixing a liquid and a gas in a pump to
5 form a pressurized gas-liquid mixture; enhancing dissolution of the gas in the pressurized gas-liquid mixture in a contact chamber; and discharging a microbubble emulsion comprising the liquid and microbubbles of the gas through a valve in fluid connection with the contact chamber.

- 10 The method may further comprise releasing undissolved gas from the pressurized gas-liquid mixture prior to discharging the microbubble emulsion through the valve.

According to a third exemplary aspect, there is provided an apparatus for treating a liquid, the apparatus comprising: a first chamber having an inlet for receiving a liquid to
15 be treated and an outlet for discharging treated liquid; and a first microbubble generator according to the first aspect for providing a first microbubble emulsion into the first chamber to allow microbubbles to attach to suspended matter in the liquid to form a scum that is separable from the liquid.

- 20 The liquid received by the pump of the first microbubble generator may be obtained from a same source as the liquid to be treated.

The apparatus may further comprise a second chamber having an inlet for receiving the treated liquid discharged from the first chamber and an outlet for discharging the treated
25 liquid; and a second microbubble generator according to the first aspect for providing a second microbubble emulsion into the second chamber, wherein in-flow of the liquid to be treated and in-flow of the first microbubble emulsion in the first chamber are in a same direction, and wherein in-flow of the treated liquid and in-flow of the second microbubble emulsion in the second chamber are in opposing directions.

30

The liquid received by the pump of the second microbubble generator may be the treated water discharged from the first chamber.

According to a fourth aspect, there is provided method of treating a liquid, the method comprising: providing a liquid to be treated to a first chamber; providing a first microbubble emulsion generated according to the method of the second aspect into the first chamber; and discharging treated liquid from the first chamber.

The liquid mixed by the pump of the first microbubble generator may be obtained from a same source as the liquid to be treated.

The method may further comprise providing the treated liquid from the first chamber to a second chamber, providing a second microbubble emulsion generated according to the method of the second aspect into the second chamber; and discharging the treated liquid from the second chamber, wherein in-flow of the liquid to be treated and in-flow of the first microbubble emulsion in the first chamber are in a same direction, and wherein in-flow of the treated liquid and in-flow of the second microbubble emulsion in the second chamber are in opposing directions.

The liquid mixed by the pump of the second microbubble generator may be the treated liquid obtained from the first chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described, by way of example only, and with reference to the accompanying figures in which:

FIG. 1 is a schematic diagram of an exemplary microbubble generator;

FIG. 2 is a schematic diagram of an exemplary application of microbubble injection in concurrent and counter flow chambers;

FIG. 3 is a flowchart of an exemplary method of generating microbubbles; and

FIG. 4 is a flowchart of an exemplary method of liquid treatment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of a microbubble generator 10, an apparatus 50 for treating a liquid, a method 100 of generating microbubbles and a method 500 of treating a liquid according to the present invention will now be described with reference to FIGS. 1 to 4.

As shown in FIG. 1, the microbubble generator 10 comprises a pump 20 configured to mix a liquid and a gas to form a pressurized gas-liquid mixture therein 102. The pump 20 is preferably a two phase high pressure pump of up to 6 bar pressure. The pump 20 is configured to receive liquid provided through a liquid line 31 from a liquid supply 30 at a first inlet 21 of the pump 20, 102. A gate valve 11 is preferably provided to control liquid suction pressure and flow to the pump 20. Suction pressure may be indicated by a vacuum gauge 12 provided at the first inlet 21. The pump 20 is also configured to receive gas from a gas supply 32 to be mixed with the liquid. The gas is provided through a gas line 33 to the pump 20 at a second inlet 22 of the pump 20, 102, preferably via an electrical solenoid valve 13 and a mechanical non-return valve 14 at the second inlet 22. The amount of gas being introduced can be controlled by a flow regulator 15 in the gas line 33. The gas-liquid ratio is mainly dependent on solubility of the gas in the liquid phase and its partial pressure. In a preferred embodiment, an industry standard of up to 0.2 gas-to-liquid ratio was chosen for gas comprising a mixture of air, oxygen and ozone gas 34. The pump 20 draws in the gas and the liquid, preferably simultaneously, in order to produce a pressurized gas-liquid mixture at a desired gas-to-liquid ratio, by appropriate adjustment of the suction valve 11 and a discharge valve 16 provided downstream of the pump 20.

An outlet 23 of the pump 20 is in fluid connection with an inlet 41 of a liquid-gas contact chamber 40. The pressurized gas-liquid mixture from the pump 20 is channelled to the contact chamber 40. The contact chamber 40 is preferably configured to provide a contact time of about 2 minutes or more for enhancing dissolution of the gas in the pressurized gas-liquid mixture 104. A pressure gauge 17 and the discharge valve 16 are provided downstream of the contact chamber 40 in order to regulate flow of the pressurized gas-liquid mixture at a desired pump pressure. A vent 18 is installed at an outlet 42 of the contact chamber 40 to allow removal of undissolved gas from the pressurized gas-liquid mixture. The vent 18 may comprise a needle valve.

The principle behind the microbubble generator 10 is to dissolve the gas in the liquid phase under high pressure in the pump 20, with further enhancement of gas dissolution by passing the gas-liquid mixture through the contact chamber 40. The liquid becomes

saturated with the gas at high pressure in the pump 20 and in the contact chamber 40 because of elevated solubility due to high partial pressure.

After passing through the contact chamber 40, the saturated liquid is subjected to
5 throttling by the discharge valve 16. This is achieved by establishing a gauge pressure or difference in pressure of about 4 to 6 bars between the pump 20 and the discharge valve 16, so that upon passing the pressurized gas-liquid mixture through the discharge valve 16, a microbubble emulsion comprising the liquid and microbubbles of the gas is discharged 106. This occurs because pressure in the gas-liquid mixture reduces after
10 throttling such that the gas-liquid mixture loses equilibrium and becomes supersaturated. Upon discharge through the discharge valve 16, the excess gas comes out of the liquid phase in the form of extremely fine, charged bubbles, i.e., microbubbles, due to a shearing and decompression phenomenon at the valve throttle 16. The bubbles are so fine and electrically charged that a microbubble emulsion, i.e.,
15 an emulsion of gas and liquid, is formed, turning the liquid medium milky white by the suspension of the gas microbubbles in it. It is estimated that the microbubbles have a 20-50 micron size.

The presence of similar charges on the extremely fine gas bubbles prevent them from
20 coalescing, and reduce its rising velocity in the liquid medium. This in turn increases the residence time of the microbubbles in a reactor or flow chamber into which the microbubble emulsion may be channelled for treating a liquid, thereby enhancing the effectiveness of the microbubbles binding with suspended matter in the liquid for their subsequent removal from the liquid being treated.

25 As the surface area of the microbubble is inversely proportional to its diameter, this increases the surface area of the gas-in-liquid emulsion, increasing the mass transfer co-efficient. From a literature survey, it has been reported that the volumetric mass transfer co-efficient can increase 5-to-6 fold by this technique. As the microbubble slowly rises
30 in the liquid medium, the high surface area of the microbubble transfer the gas in the microbubble to the surrounding liquid. The increased mass transfer of the gas to the liquid medium thus further reduces the size/volume of the microbubble, thereby increasing the pressure of the gas (Laplace pressure) within the microbubble. The

reduction in size of the microbubble increases the mass transfer rate and the surface charge of the bubble, thereby increasing its Zeta potential ζ .

When the microbubble emulsion is passed into a liquid to be cleaned, the increased
5 surface charge and Zeta potential of each microbubble attract submicron suspended particles to it, thereby increasing its buoyancy and lifting it to the liquid surface to form a layer of scum comprising suspended matter such as the suspended submicron particles and oil and grease. This scum can be readily skimmed off the liquid surface. Since the submicron suspended particles are smaller than the microbubble, each microbubble can
10 attach numerous suspended submicron particles so that the total suspended solids (TSS) in the liquid can be reduced and the water clarity improved tremendously. This removal of fine suspended particles from the liquid medium in the form of scum reduces the COD and BOD of the liquid medium, requiring less or no chemicals to be used, and reducing the number of treatment steps needed in downstream operations.

15 Furthermore, as each microbubble slowly rises and reduces in size due to mass transfer, the pressure inside the microbubble eventually increases to such an extent that it bursts. This bursting of micron sized bubbles due to the increased pressure is reported to produce radicals and nanobubbles. The production of radicals by collapsing of
20 microbubbles aids in oxidation and disinfection due to its higher oxidation reduction potential.

The microbubble generator 10 therefore requires no high pressure large contact tank in order for saturation and dissolution of the gas in the liquid medium to take place
25 effectively. This allows the microbubble generator 10 to be compact and portable so that it can be readily brought to locations where water treatment is required to be performed to remove suspended matter in the water.

An exemplary apparatus 50 for treating a liquid such as liquid using the microbubble
30 generator 10 described above is shown in FIG. 2. The apparatus 50 comprises a first flow chamber 51 into which a liquid to be treated 60 is provided 501. A first microbubble emulsion 61 is also provided into the first flow chamber 51, 502. Within the first flow chamber 51, preferably, the liquid to be treated 60 flows in a same

direction 71 as a direction 71 of introduction of the microbubble emulsion 61. In this way, the first flow chamber 51 functions as a concurrent flow chamber. Preferably, the liquid to be treated 60 and the liquid supplied 60 to a microbubble generator 10-1 for formation of the microbubble emulsion are provided from a same source 30. Both the liquid to be treated 60 and the microbubble emulsion 61 are preferably introduced into a bottom end 52 of the first flow chamber 51. At a top end 53 of the first flow chamber 51, scum 80 that comprises suspended matter such as suspended particles, oil, grease and other undesirable gasses such as ammonia, that have been separated out from the liquid 60 by the microbubbles, can then be separated from the treated liquid 62 by skimming the scum 80 off into a scum tank 82 using a separator or skimming device (not shown), leaving a treated liquid 62 that is discharged 503 from the first flow chamber 51. The scum may be removed continuously by a separator or skimming device

The treated liquid 62 may be channelled out of the top end 53 of the first flow chamber 51 into a second flow chamber 54. The second flow chamber 54 is provided for promoting oxidation, disinfection and pH adjustment etc. of the treated liquid 62. Within the second flow chamber 54, preferably, the treated liquid 62 flows in an opposite direction 72 as a direction 73 of introduction of another microbubble emulsion 63 into the second flow chamber 54. By configuring the second flow chamber 54 to provide a counter flow function, retention time of microbubbles in the treated water is maximized, to allow for collapsing of the microbubbles to produce radicals and nanobubbles to better oxidize and disinfect the treated liquid 62. Some of the same treated liquid 62 from the first flow chamber 51 may be diverted to a second microbubble generator 10-2 for formation of the microbubble emulsion 63 that is fed into the counter flow chamber 54. The microbubble emulsion 63 is preferably introduced into a bottom end 55 of the counter flow chamber 54 while the treated liquid 62 is preferably introduced into a top end 56 of the counter flow chamber 54. The treated liquid 62 is finally discharged from the counter flow chamber 54, preferably through an outlet at the bottom end 55.

The extremely small size of the microbubbles makes it impossible to break them by physical means due to the high energy requirements. It is therefore safe to pump such a

microbubble emulsion to the suction of high pressure pumping systems without any cavitations inside the pumps. This property makes it ideal for applications in membrane systems for the following reasons:

- (i) pH adjustments may be made using carbon dioxide gas;
- 5 (ii) membrane fouling can be prevented by the scouring action of the microbubbles on membrane surfaces;
- (iii) occasional bursting of the microbubbles produce radicals which oxidize organics and bio-fouling of the membranes;
- (iv) dissolved gases can pass through the membranes, without increasing the total
10 dissolved solids (TDS) of the reject. This is very critical in zero discharge membrane systems where the TDS of the reject can build up due to chemical additions.

The microbubble generator 10 thus provides a clean technology with no harmful
15 chemicals, using only harmless gases such as air, oxygen, ozone, carbon dioxide, nitrogen etc. Treating water with the microbubble emulsion separates the suspended solids, oil and grease and strips unwanted gases in the bulk liquid while producing no additional sludge in the process.

20 Table 1 below shows the improvement in water quality of waste water from washing of tanker ship hulls after air flotation and ozone treatment using the liquid treatment apparatus 50 with the microbubble generator 10 and as described above.

	Oil and grease mg/L	% reduced	TSS, mg/L	% reduced	COD, mg/L	% reduced	BOD, mg/L	% reduced
Raw water	1,098	-	3,640	-	1,346	-	214	-
Discharge limit	60	-	400	-	600	-	400	-
Air flotation with coagulant	11	99.0	52	98.6	522	61.2	189	11.7
Subsequent ozone treatment	<5	99.5	7	99.8	68	95.0	32	85.0

The microbubble liquid treatment apparatus 50 and method 500 can be easily adapted for cleaning or treating a wide range of liquids with varying amounts of solids, pH and for a wide variety of gases. Exemplary applications include the following:

- 5 - Laundry water treatment for washing and recycling
- Ship Ballast water treatment
- Pond water treatment
- Oil palm waste water treatment
- Solids liquid separation by microbubble floatation
- 10 - Gas liquid mixing without any off-gassing
- Pre treatment, pH control and membrane fouling control
- Efficient aeration system for biological waste water treatment systems
- Water and Waste water treatment and recycling
- Increase yield of agricultural crops by increased soil aeration by drip lines and in
- 15 Hydroponics
- Increase yield and harvesting of algae for Bio-diesel production
- Hydrogenation of vegetable oils
- Ozone mixing
- Fish/ prawn farming to increase Dissolved oxygen levels, reduce ammonia, nitrite
- 20 removal and in oxidation and disinfection.
- Swimming pool, water features and spa industry
- Post harvest washing and rinsing of fresh produces with ozone water and recycling
- Oil field produce water treatment
- 25 Whilst there has been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design or construction may be made without departing from the present invention. For example, the flow chambers 51, 54 may each comprise a single column or a plurality of columns, being designed to meet
- 30 process flow rates in the apparatus 50. The scum 80 may be removed by the separator or skimming device either continuously or at time intervals.

CLAIMS

1. A microbubble generator comprising:
 - a pump configured to mix a liquid and a gas to form a pressurized gas-liquid mixture therein;
 - a contact chamber in fluid connection with the pump and configured to enhance dissolution of the gas in the pressurized gas-liquid mixture therein; and
 - a valve in fluid connection with the contact chamber and configured to discharge a microbubble emulsion comprising the liquid and microbubbles of the gas.
2. The microbubble generator of claim 1, further comprising a vent in fluid connection with the contact chamber, the vent configured to release undissolved gas from the pressurized gas-liquid mixture.
3. A method of generating microbubbles in a liquid, the method comprising:
 - mixing a liquid and a gas in a pump to form a pressurized gas-liquid mixture;
 - enhancing dissolution of the gas in the pressurized gas-liquid mixture in a contact chamber; and
 - discharging a microbubble emulsion comprising the liquid and microbubbles of the gas through a valve in fluid connection with the contact chamber.
4. The method of claim 3, further comprising releasing undissolved gas from the pressurized gas-liquid mixture prior to discharging the microbubble emulsion through the valve.
5. An apparatus for treating a liquid, the apparatus comprising:
 - a first chamber having an inlet for receiving a liquid to be treated and an outlet for discharging treated liquid; and
 - a first microbubble generator according to claim 1 or claim 2 for providing a first microbubble emulsion into the first chamber to allow microbubbles to attach to suspended matter in the liquid to form a scum that is separable from the liquid.

6. The apparatus of claim 5, wherein the liquid received by the pump of the first microbubble generator is obtained from a same source as the liquid to be treated.
7. The apparatus of claim 5 or claim 6, further comprising a second chamber having an inlet for receiving the treated liquid discharged from the first chamber and an outlet for discharging the treated liquid; and a second microbubble generator according to claim 1 or claim 2 for providing a second microbubble emulsion into the second chamber, wherein in-flow of the liquid to be treated and in-flow of the first microbubble emulsion in the first chamber are in a same direction, and wherein in-flow of the treated liquid and in-flow of the second microbubble emulsion in the second chamber are in opposing directions.
8. The apparatus of claim 7, wherein the liquid received by the pump of the second microbubble generator is the treated water discharged from the first chamber.
9. A method of treating a liquid, the method comprising:
 - providing a liquid to be treated to a first chamber;
 - providing a first microbubble emulsion generated according to the method of claim 3 or claim 4 into the first chamber for microbubbles to attach to suspended matter in the liquid to form a scum that is separable from the liquid; and
 - discharging treated liquid from the first chamber.
10. The method of claim 9, wherein the liquid mixed by the pump of the first microbubble generator is obtained from a same source as the liquid to be treated.
11. The method of claim 9 or claim 10, further comprising
 - providing the treated liquid from the first chamber to a second chamber,
 - providing a second microbubble emulsion generated according to the method of claim 3 or claim 4 into the second chamber; and discharging the treated liquid from the second chamber,
 - wherein in-flow of the liquid to be treated and in-flow of the first microbubble emulsion in the first chamber are in a same direction, and wherein in-flow of the

treated liquid and in-flow of the second microbubble emulsion in the second chamber are in opposing directions.

- 5 12. The method of claim 11, wherein the liquid mixed by the pump of the second microbubble generator is the treated liquid obtained from the first chamber.