Method and Device for Mixing Gases into Liquids

The invention relates to a device and to a method for mixing gases into liquids.

Mixing or even dissolving gases into liquids has many purposes of use. Among other things, the dissolution of ozone in aqueous solutions containing organic and inorganic substances provides a highly effective oxidation of these substances. The targeted and efficient addition of oxygen and the dissolution of this oxygen or atmospheric oxygen in wastewater is one of the most important principles underlying today's aerobic water treatment plants.

Further possible applications include bleaching processes, stripping processes, or any other form of enrichment and increase in the dissolved concentration of a gas in a liquid.

Aquaculture, which is becoming increasingly important for supplying a steadily growing global population with healthy protein, also requires a significant portion of an adequate and efficient oxygen supply to the fish to ensure economical production while maintaining high fish health.

Mixing solutions already containing gas with other liquids is important in the chemical industry, including for the production of various substances and groups of substances. Uniform mixing can increase the safety of specific manufacturing methods, as excessively high local concentrations of certain substances are avoided and thus adverse processes, such as exothermic reactions, cannot occur at all.

Various methods for mixing gas into liquids are known. For example, document US 4,007,920 describes a rotating disk which includes axial bores and is used to mix air present at the surface of the disk with water present on the underside of the disk.

EP 2 125 174 B1 describes a mechanical cavitation element by means of which gas is mixed with liquid. This is achieved by introducing the gas directly at the surface of the cavitation element and by moving this cavitation element. This prior art describes how gas enters the liquid through the cavitation process. In a second step, ultrasound is applied to the gas and the liquid, which reduces the

size of the generated gas bubbles. This ultimately results in a sonochemical dissolution of the gas in the liquid.

DE 2 300 205 A discloses a device for mixing gases into liquids. The device comprises a container in which a rotationally symmetrical mixing body in the form of an impeller is arranged, which is driven by a drive means. The drive means is connected to the impeller via a shaft section. The impeller has a conical shape and thus, at least at its end facing away from the drive, a diameter which is wider than that of the shaft section.

DE 36 08 201 A1 describes a mixer for mixing a material to be mixed, comprising a mixing trough and a mixing tool projecting into the mixing trough. During mixing, sticking or caking of material to be mixed on the mixing tool is to be prevented.

The object of the invention is to improve the mixing of gases into liquids or the mixing of gas-containing liquids into other, less gas-containing or non-gas-containing liquids using a single device, to achieve the least possible gas loss.

This object is achieved by a device for mixing gases into liquids, comprising a container and a mixer projecting into the container and rotating about an axis of rotation, which, except for at least one predetermined imbalance point, has a rotationally symmetrical shape which has a missing or additional mass compared to a mixer designed without the imbalance point but otherwise identical, ideally rotationally symmetrical, wherein the missing or additional mass amounts to at least 1% and preferably a maximum of 5% of the own mass of the mixer and imparts an imbalance to the mixer upon rotation about the axis of rotation. The mixer has a shaft section connected to a rotary drive and a mixer body which is positioned within the container, is mounted on the shaft section and has an enlarged diameter compared to the shaft section.

With regard to its definition of imbalance and missing mass, the device according to the invention refers to a brand-new, i.e., unused mixer. This mixer is caused to rotate within the container at a relatively high rotational speed and is intended to undergo lateral deflection deliberately caused by an imbalance, so that movements superimpose on one another and the motion of the outer surface of the mixer body does not follow a purely circular path.

The research conducted by the applicant has shown that this imbalance significantly improves mixing quality due to the additional motion caused by the imbalance.

This flexibility can be achieved either through an appropriately “soft” mounting, through an elasticity of the shaft section, or through a combination thereof.

The device according to the invention results in improved mixing of gases into liquids due to the additional frequency and vibration forced by the imbalance.

The imbalance is deliberately generated during the manufacturing process of the mixer by the specific and clearly defined removal or addition of mass at one or more points on the mixer in the area of the mixer body. The resulting harmonic vibration can be adjusted with regard to the magnitude of the amplitude and frequency by changing the rotational speed.

Extensive tests have shown that gases are mixed so effectively that the gas can also be dissolved in the liquid. The device is thus a device for introducing, mixing, and also dissolving (the generic term for mixing) gas into liquid.

After adding gas, which should preferably take place near the mixer body, a so-called transfer zone forms in the region of the surface of the mixer body. This zone arises from the formation of a film or an interface generated between the respectively present gaseous, gas-containing, and liquid phases. The reason for this transfer zone is the kinetic energy at the surface of the mixer body. The resulting interface influences the partial pressure prevailing at this location. Due to the additional motion caused by the imbalance, the kinetic energy at the surface is higher, so that the partial pressure rises and an increased gas transfer rate is achieved.

The rotationally symmetrical mixer body creates a suction effect at its surface, the so-called hydrodynamic paradox, as well as the Magnus effect. These two effects ensure that the introduced phase, in this case, the gas, is sucked toward the surface of the moving body. This means that when the gas is introduced into the liquid near the mixer body, it is sucked onto the surface and then mixed into the liquid there.

As previously emphasized, the mixing may even lead to the dissolution of the gas in the liquid, for example, ozone or oxygen in a liquid. This results in extremely fine micro- and nanobubbles having diameters ranging from 120 nm to 10 µm.

The container may be a tank, a vessel, a basin, any of which may be closed or open, or a channel through which the liquid flows.

In the case of a channel, for example, the mixer body may be arranged in a bypass or a main channel to enrich a partial flow or the entire flow of liquid with gas.

One embodiment of the invention provides that the missing or additional mass, compared to a mixer designed without the imbalance but otherwise identical and ideally rotationally symmetrical, amounts to at least 2% of the own mass of the mixer, and/or that the mixer body has a completely closed outer contour and/or is designed without any steps.

A completely closed outer contour means that no through-holes are provided, as is sometimes the case in the prior art. To create an imbalance by removing material, the mixer body has a recess.

If the outer contour of the mixer body is designed without steps, this means that it has a continuous curvature in every direction, without edges or steps, to prevent flow separation.

According to a preferred embodiment, the mixer body has a spherical, disc-shaped, or bell-shaped form, which have proven to be very advantageous in tests.

The container is, in particular, a flow-through container, having an inlet opening for liquid and an opposite outlet opening for liquid mixed with gas, as well as a gas inlet upstream of the mixer located between the inlet opening and the outlet opening.

In particular, the gas inlet may be directed toward the surface of the mixer body. Due to the very high mixing capacity of the device according to the invention, it is possible to operate it in a continuous-flow mode.

The surface of the mixer body preferably has a roughness in the range of Rz 2 to Rz 6.3.

It has been found that the roughness plays a role that should not be underestimated with regard to the capacity of the device.

The mixer body may be surface-coated, i.e., it may have a metal coating, a plastic or ceramic coating, or be coated with composite materials.

The surface coating may optionally consist of a material which hinders or even prevents the deposition and formation of crystals on the surface. With certain liquids, iron and manganese might otherwise adhere, which is prevented by the surface coating. For example, nickel or a polymer, such as a polymer hydrogel, may be used for the surface coating.

Alternatively or in addition thereto, heat treatment is used to alter the composition of the material on the surface of the mixer body such that this material on the surface hinders or prevents the deposition and formation of crystals, compared to the surface of the mixer body without the heat treatment. For example, the heat treatment alters the material on the surface of the mixer body so that microfine grooves are present on the surface. The groove structure may correspond to that of the skin of a shark. Such a structure is particularly effective at preventing crystals from forming or settling on the surface. Specifically, the microfine grooves ensure that crystals have less contact with the surface and thus cannot settle or can detach more easily. This prevents the crystals from coalescing into a tenacious layer.

Instead of heat treatment, the surface may also be treated using photolithography to create the microfine grooves.

According to one embodiment of the invention, the container and the mounting of the mixer allow the angle at which the axis of rotation projects into the container to be adjustable, as this also enables different effects to be achieved.

A further distinctive feature arises from the fact that one or more drive units are provided which, in addition to the rotation of the mixer about its axis of rotation, impart a superimposed oscillatory or vibrational motion in a radial

direction, obliquely to the axial direction, or in the axial direction. This means that, in addition to the rotational motion and the additional motion caused by the imbalance, one or more motion patterns are superimposed, which result in further improvements in the mixing capacity of the device. One example is the aforementioned vibrational motion, in which the shaft section is moved, for example, up and down axially, more specifically at a frequency of preferably more than 20 Hz.

The rotary drive is designed such that it can drive the mixer at a speed in a range of 10 to 10,000 revolutions per minute, wherein, in principle, higher rotational speeds are required for mixer bodies with smaller maximum diameters than for those with very large diameters. Such large-volume mixer bodies are used, for example, in wastewater treatment plants.

Preferably, the rotational speed to which the rotary drive is adjustable is controlled such that the maximum rotational frequency in the outer quarter of the diameter of the mixer body is between 5 m/sec and 160 m/sec. Since the rotational frequency increases with the radius, this value is measured at a point corresponding to 75% of the maximum diameter of the mixer body, as at the beginning of the outermost quarter, this area is the slowest-moving part of outermost quarter. The aforementioned velocity range is important for achieving sufficient mixing effects with liquids, particularly water.

The imbalance should be created by the manufacturer through localized, mechanical surface removal on the mixer body or by attaching a local additional weight to the remainder of the mixer body. As mentioned, this refers to the manufacture of the device.

A further improvement is achieved in that vibration sensors are provided which determine the occurring vibrations of the mixer body to achieve a control of the rotational speed based on the vibrations that occur. This also allows the optimal operating point to be set and maintained. Furthermore, the device can thus also be checked for damage. For example, if changes in vibration or recurring vibration peaks occur, this may indicate a change in the mounting of the shaft section or other emerging damage. Thus, predictive damage detection may be performed.

The above-mentioned object can also be achieved by a method for manufacturing a device according to the invention, in which a mixer is manufactured and, subsequently, in a separate, subsequent method step, material is removed from or added to the surface of the mixer so that the aforementioned imbalance is created.

Finally, the above-mentioned object is also achieved by a method for mixing gas into liquids, characterized by the following steps:

introducing liquid and gas into a container, and

mixing the gas and liquid in the container using a mixer which rotates about an axis of rotation and comprises a shaft section which is coupled to a rotary drive and a mixer body which is mounted on the shaft section and has a rotationally symmetrical shape except for a predetermined imbalance point, wherein the imbalance point has a missing or additional mass compared to a mixer designed without the imbalance point but otherwise identical, ideally rotationally symmetrical, which amounts to at least 1% of the own mass of the mixer and imparts an imbalance to the mixer upon rotation about the axis of rotation. Preferably, the mass difference amounts to a maximum of 5% of the own mass of the mixer.

As previously explained, the mixer body should be brought to a rotational speed between 10 and 10,000 revolutions per minute, and the gas should be agitated in the container until microbubbles or nanobubbles having a diameter between 120 nm and 10 µm are generated.

According to a further variant, in addition to the rotational motion, the mixer body is driven so as to perform a superimposed oscillatory motion or vibrational motion, more specifically, in a radial direction, obliquely to the radial direction, or in an axial direction, to mix the gas and the liquid.

To increase throughput, the method can be carried out in a continuous flow through a channel.

As already explained, the vibrations of the mixer body during operation are detected by means of a vibration sensor system, and based thereon, the

rotational speed of the mixer body can be adjusted or damage detection can be performed.

Finally, it is advantageous for the flow rate to be monitored by sensors and controlled so that, on the one hand, the liquid and gas are not left in the vicinity of the mixer body for too long and throughput is increased, and, on the other hand, they remain there just long enough to achieve the desired mixture or the dissolution of the gas in the liquid.

Further features and advantages of the invention will become apparent from the following descriptions and from the following drawings, to which reference is made and in which:

- Figure 1 shows a schematic view of a first variant of the device according to the invention for carrying out the method according to the invention,
- Figure 2 shows a schematic view of a second variant of the device according to the invention for carrying out the method according to the invention,
- Figure 3 shows a third variant of the device according to the invention for carrying out the method according to the invention,
- Figure 4 shows a fourth variant of the device according to the invention for carrying out the method according to the invention,
- Figure 5 shows a fifth variant of the device according to the invention for carrying out the method according to the invention,
- Figure 6 shows a sixth variant of the device according to the invention for carrying out the method according to the invention,
- Figure 7 shows a seventh variant of the device according to the invention for carrying out the method according to the invention,
- Figure 8 shows an eighth variant of the device according to the invention for carrying out the method according to the invention,
- Figure 9 shows a perspective view of a variant of the mixer body of the device according to the invention,

- Figure 10 shows a further variant of the mixer body of the device according to the invention,
- Figure 11 shows yet another variant of the mixer body of the device according to the invention, and
- Figure 12 shows an additional variant of the mixer body of the device according to the invention.

Figure 1 shows a device for mixing gases into liquids. The device comprises a container 10, here in the form of a pipe, having an inlet opening 12 at one end and an outlet opening 14 at the opposite end.

The arrows indicate the direction of flow.

The channel 16 formed by the pipe does not necessarily have to be completely filled with liquid, it may also be only partially filled with liquid, preferably at least two-thirds full.

The liquid must have a viscosity such that it remains flowable.

It may originate and be supplied from a tank or a basin.

A mixer 18, which is adapted to rotate about an axis of rotation A, projects into the channel 16 and comprises a mixer body 20, which preferably extends entirely into the liquid and is attached to a shaft section 22. The shaft section 22 is coupled to a rotary drive 24, which can bring the mixer 18 up to a rotational speed of 10 to 10,000 revolutions per minute.

The rotary drive 24 does not need to be capable of operating across the entire speed range; it is sufficient if it can achieve an appropriate rotational speed or appropriate speed range tailored to the dimensions of the mixer body 20, the liquid, and the gas to be mixed.

Upstream of the mixer body 20, a gas inlet 26 is provided for the gas to be mixed in and is positioned and projects into the channel 16 far enough that the gas is entrained by the flow of the liquid and strikes the outer surface of the mixer body 20.

The gas comes from a container 28, which is coupled to the gas inlet 26 via a line 29.

The mixer body 20 has a rotationally symmetrical shape with respect to the axis of rotation A.

However, it has an imbalance point 32 already provided by the manufacturer and specified by design, which gives the mixer body 20 an overall imbalance.

This imbalance point 32 can be created by intentionally removing material using a manufacturing machine or by intentionally and purposefully applying an additional weight previously designed and matched to the size and mass of the mixer body 20, which is attached to the remainder of the mixer body 20, in particular by soldering, gluing, welding, or using a mechanical connection.

Optionally, the mixer body 20, the shaft section 22, or the rotary drive 24 may be coupled to an additional drive unit 34, which ensures that, during the rotation of the mixer body 20, an oscillatory or vibrational motion is also imposed thereon in a radial direction, obliquely to the axial direction, or in the axial direction A.

This motion superimposes, on the one hand, the rotational motion and, on the other hand, the wobble motion caused by the imbalance.

To ensure that the imbalance actually results in an additional motion or an additional component of the motion of the mixer body 20, the imbalance point is designed such that the mass missing due to it or the additional mass added by it amounts to at least 1% of the own mass of the mixer, compared to a mixer designed without the imbalance point but otherwise identical and ideally rotationally symmetrical.

The mountings of the mixer 18 and those of the rotary drive 24, and the bending stiffness of the shaft section 22 must be coordinated such that this non-negligible imbalance actually results in an additional lateral movement of the mixer body.

The lateral movement should preferably be greater than 0.5 mm, in particular greater than 1 mm, to achieve an effective result.

Preferably, the aforementioned missing or additional mass is even at least 2% of the own mass of the mixer. To determine either the volume of the missing mass or that of the additional mass, an ideally rotationally symmetrical mixer is used as a reference, in which the rotational symmetry either covers the missing section or cuts off the additional mass to determine the missing or additional mass, respectively.

An imbalance, where the missing mass or the additional mass exceeds 5% of the own mass, appears to have little practical benefit in light of the resulting bearing problems and additional strength issues.

In the embodiment according to Figure 1, the mixer body 20 is disc-shaped, with the central axis of the disc coinciding with the axis of rotation A.

The following describes the method for mixing gas into the liquid passed through.

Liquid, e.g., water, is fed into channel 16 via the inlet opening 12, wherein at least two-thirds of the channel 16 is filled with water. At the same time, gas, such as ozone, is transported via the container 28 to the gas inlet 26; the corresponding gas bubbles 40 are still relatively large in this area but are shown exaggeratedly large.

The flow entrains the gas introduced upstream of the mixer body 20 and breaks it up into small gas bubbles on the surface of the mixer body 20, which rotates at high speed, forming the finest micro- and nanobubbles. These bubbles then mix homogeneously into the liquid, as can be seen from the small circles depicted near the outlet opening 14.

To optimally control the mixing of the gas, a vibration sensor system 48 may be provided, which detects the vibration of the mixer body 20 at a suitable location and transmits the correspondingly measured values to a control unit. These detected vibrations can be used to determine whether the mixer body 20 is moving as intended, whether due to the imbalance or due to the additional movement imposed by the drive unit 34.

The embodiment according to Figure 2 substantially corresponds to that shown in Figure 1, so that only the differences need to be discussed below.

Instead of a disc-shaped surface, the mixer body 20 in this embodiment has a spherical surface including a recess which creates an imbalance point 32.

The axis of rotation A is not aligned vertically but at an angle α to the vertical, which results in an upward, oblique direction of motion for the liquid and the gas.

Alternatively, the mounting of the mixer 18, for example, on the container 10, can be designed such that the angle α at which the axis of rotation A extends into the container 10 is adjustable, possibly even in two dimensions. As experiments have shown (in V), this influences the mixing properties.

Here, too, additional movements, in addition to the imbalance, can be generated by a separate drive unit 34. For the sake of clarity, neither this additional drive unit 34 nor the rotary drive 24 is shown in Figure 2.

The path of the gas here is initially horizontal, more precisely, parallel to the upper and lower walls of the container 10, and then rises obliquely upward due to the inclined position of the axis of rotation A.

As indicated by the circles, the cross-section of the gas bubbles decreases as the gas travels further, so that the mixing is best at the upper right end of the container 10. An outlet opening 14 may then also be provided here, if the entire end face of the channel 16 does not itself form the outlet opening 14.

The variant according to Figure 3 substantially corresponds to that shown in Figure 1; here, too, the unbalanced point 32 is achieved by material removal.

However, the inlet opening 12 and the outlet opening 14 form only a portion of the opposing end walls. The gas inlet 26 is oriented in the direction of flow.

This modified gas outlet is also implemented accordingly in the variant of Figure 4, which otherwise corresponds to the variant according to Figure 2.

In the variant according to Figure 4, it can also be seen that the outlet opening 14 is located at the upper end of the container 10 downstream of the mixer body 20, that is, roughly in the direction in which a radial plane to the axis of rotation A also extends.

The inlet opening 12, on the other hand, is located approximately at the level of the mixer body 20.

In the variant according to Figure 5, the container 10 is a type of tank having an overflow 50.

The mixer body 20 is a hemisphere or a hollow hemisphere having an imbalance at an imbalance point 32, which is formed by an additional weight in the form of an additional body on the surface of the hemisphere.

The inlet opening 12 and, aligned therewith, the outlet opening 14 are provided below the mixer body.

The gas inlet 26 is directed directly onto the surface of the hemisphere.

The embodiment according to Figure 6 has a mixer body 20 in the form of a cylinder with flattened sections provided on the circumference and a horizontal axis of rotation A. The flattened sections are shown here in an exaggerated manner and serve to form imbalance points 32.

In the variant according to Figure 7, unlike the variant according to Figure 3, the inlet opening 12 and the outlet opening 14 are offset vertically.

The line 30 projects from the end wall, on which the inlet opening 12 is provided, in the direction of flow into the interior of the container 10, which is cylindrical here, and terminates just before, i.e., just upstream of the mixer body 20, which is disc-shaped here.

The variant according to Figure 8 corresponds largely to that according to Figure 3, wherein a cone, possibly a solid cone or a cone hollow from the bottom, is however used as the mixer body 20, with an imbalance point 32 formed by a recess.

Further shapes of mixer bodies 20 are shown in Figures 9 to 12. Figure 9 shows a ring-shaped mixer body 20 the upper surface of which has a closed, circumferential groove 60, wherein a tapered pin or a tapered sleeve extends from the center toward the axis of rotation A.

The imbalance point 32 here can be either a recess or a separately attached body.

The mixer body shown in Figure 10 is a hemisphere having centrally circumferential grooves 64. These grooves further increase the surface of the mixer body 20.

The mixer body 20 according to Figure 11 has an annular bead that forms the outer circumference, wherein a coaxial recess 66 extends from the top surface and a pin-shaped raised portion 68 is again provided at the center, which forms the transition to the shaft section.

A plurality of imbalance points 32 may be provided here.

In contrast to all previous mixer bodies, the variant according to Figure 20 does not have a completely closed outer contour, as the mixer body has some through-holes 70 that impart an imbalance thereto. The shape of the mixer body 20 is that of a hemispherical shell with a sleeve 72 rising from the interior, which opens into the bottom of the shell at a rounded section 74.

For all embodiments of the mixer body 20, the surface has a roughness in the range of Rz 2 to Rz 6.3 and/or may be surface-coated.

This surface coating consists, for example, of metal, plastic, ceramic, or a composite material, for example, nickel, a nickel alloy, or a polymer. As an alternative to the coating, but for the same purpose, the surface may be heat-treated to modify the material at the surface.

According to an exemplary embodiment, microfine grooves are formed on the surface.

It also applies to all mixer bodies 20 that they can either be driven solely by a rotary drive or can also undergo a superimposed motion by means of one or more additional drive units.

The surface of the mixer body 20 does not necessarily have to be smooth or very smooth; it can also be designed to be porous, the imbalance being however caused by the imbalance point 32.

Claims

1. A device for mixing gases into liquids, comprising a container (10) and a mixer (18) projecting into the container (10) and rotating about an axis of rotation (A), which, except for at least one predetermined imbalance point (32), has a rotationally symmetrical shape which has a missing or additional mass compared to a mixer (18) designed without the imbalance point (32) but otherwise identical, ideally rotationally symmetrical, which mass amounts to at least 1% of the own mass of the mixer (18) and imparts an imbalance to the mixer (18) upon rotation about the axis of rotation (A), wherein the mixer (18) has a shaft section (22) connected to a rotary drive (24) and a mixer body (20) which is positioned within the container (10), is mounted on the shaft section (22) and has an enlarged diameter compared to the shaft section (22).

2. The device according to claim 1, characterized in that the missing or additional mass, compared to a mixer (18) designed without the imbalance point (32) but otherwise identical and ideally rotationally symmetrical, amounts to at least 2% of the own mass of the mixer (18), and/or in that the mixer body (20) has a completely closed outer contour and/or is designed without steps.

3. The device according to claim 1 or 2, characterized in that the mixer body (20) has a spherical, disc-shaped, or bell-shaped form.

4. The device according to any of the preceding claims, characterized in that the container (10) is a flow-through container, having an inlet opening (12) for liquid and an opposite outlet opening (14) for the liquid mixed with gas, as well as a gas inlet (26) upstream of the mixer (18) located between the inlet opening (12) and the outlet opening (14).

5. The device according to any of the preceding claims, characterized in that the mixer body (20) has a roughness in the range of Rz 6.3 to Rz 2 and/or is surface-coated.

6. The device according to any of the preceding claims, characterized in that the container (10) and the mounting of the mixer (18) are designed such that the angle at which the axis of rotation (A) projects into the container (10) is adjustable.

7. The device according to any of the preceding claims, characterized in that a drive unit (34) is provided which, in addition to the rotation about its axis of rotation (A), imparts a superimposed oscillatory motion or vibrational motion to the mixer (18) in a radial direction, obliquely to the axial direction, or in the axial direction.

8. The device according to any of the preceding claims, characterized in that the rotary drive (24) is designed so as to be adapted to drive the mixer (18) at a rotational speed in a range of 10 to 10,000 revolutions per minute.

9. The device according to any of the preceding claims, characterized in that the imbalance is generated by a localized mechanical surface removal on the mixer body (20) or by attaching a local additional weight to the remainder of the mixer body (20).

10. The device according to any of the preceding claims, characterized in that a vibration sensor system (48) is provided for determining the vibrations of the mixer body (20).

11. A method for mixing gas into liquids, characterized by the following steps:

introducing liquid and gas into a container (10), and

mixing the gas and liquid in the container (10) using a mixer (18) which rotates about an axis of rotation (A) and comprises a shaft section (22) which is coupled to a rotary drive (24) and a mixer body (20) which is mounted on the shaft section (22) and has a rotationally symmetrical shape except for a predetermined imbalance point (32), wherein the imbalance point (32) has a missing or additional mass compared to a mixer (18) designed without the imbalance point (32) but otherwise identical, ideally rotationally symmetrical, which amounts to at least 1% of the own mass of the mixer (18) and imparts an imbalance to the mixer (18) upon rotation about the axis of rotation (A).

12. The method according to claim 11, characterized in that the mixer body (20) is brought to a rotational speed between 10 and 10,000 revolutions per minute, and the gas is agitated in the container until microbubbles or nanobubbles having a diameter between 120 nm and 10 µm are generated.

13. The method according to claim 11 or 12, characterized in that the mixer body (20) performs, in addition to the rotational motion, a superimposed oscillatory motion or vibrational motion to mix the gas and the liquid.

14. The method according to any of claims 11 to 13, characterized in that the method is carried out in a continuous flow through a channel (16).

15. The method according to any of claims 11 to 14, characterized in that the vibrations of the mixer body (20) during operation are detected by means of a vibration sensor system (48), and based thereon, the rotational speed of the mixer body (20) is adjusted or damage detection is performed.