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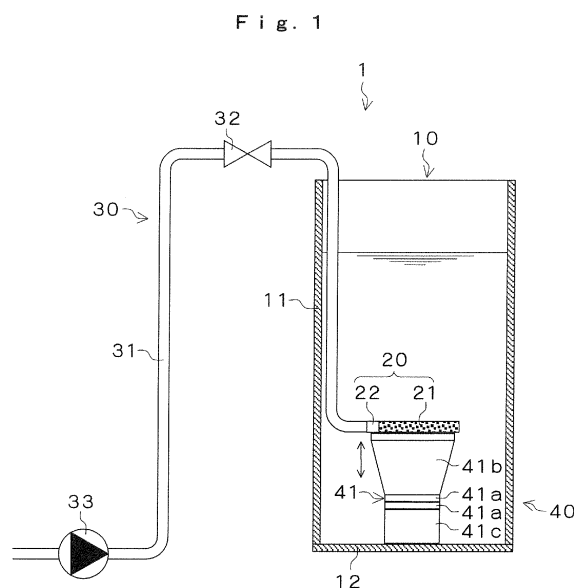
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(54) **GAS INTRODUCING/RETAINING DEVICE, GAS INTRODUCING/RETAINING METHOD, AND GAS RELEASE HEAD**

(57) [Object] To provide a gas introducing/retaining device and a gas introducing/retaining method capable of increasing the amount of a gas dissolved in a liquid, and a gas discharge head used in the gas introducing/retaining device.

[Solution] The present invention is provided with: a liquid storage tank 10 in which a liquid is stored; a gas discharge head 20 having a large number of micropores each having a pore size not larger than 2.5 μm ; gas supply means 30 that supplies a gas to the gas discharge head 20; and oscillation application means 40 having an oscillator 41 that applies oscillation to the gas discharge head 20. The gas is discharged from the gas discharge head 20 while oscillation is continuously applied to the gas discharge head 20 immersed in the liquid. The oscillation applied to the gas discharge head 20 by the oscillator 41 is set to have a frequency not lower than 30 kHz and an amplitude not greater than 1 mm. The amount of the gas supplied to the gas discharge head 20 is adjusted so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of the gas discharge head 20)/(oscillation frequency [Hz] of the oscillator 41) ≤ 300 .



Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a gas introducing/retaining device and a gas introducing/retaining method for introducing a gas into a liquid and retaining the gas in the liquid, and a gas discharge head used in the gas introducing/retaining device.

BACKGROUND ART

10 **[0002]** As a method for introducing a gas into a liquid and retaining the gas in the liquid, a bubble dissolution method is commonly adopted, in which a gas is blown, in the form of bubbles, into a liquid by bubbling using a diffuser tube or the like, thereby dissolving the gas in the liquid. However, normal bubbles discharged into the liquid rapidly rise and burst at the surface of the liquid. Therefore, most of the gas discharged in the form of bubbles into the liquid is diffused
15 into the atmosphere without being dissolved in the liquid, and the gas cannot be efficiently dissolved in the liquid.

[0003] Meanwhile, bubbles (hereinafter referred to as microbubbles), the diameter at generation of which is micronized to 50 μm or less, have such properties that the bubbles have a low rising speed in a liquid, and gradually contract while causing a gas contained therein to be efficiently dissolved, and in some cases, vanish before reaching the surface of the liquid.

20 **[0004]** Therefore, various methods for generating microbubbles in liquids have been proposed. Specifically, the following methods have been proposed: a method for generating microbubbles by utilizing a phenomenon in which, when a pumice-like galactose is dissolved in water or the like, bubbles are created and separated from gaps of crystals; a method for generating microbubbles by utilizing the property that the amount of gas dissolved increases in proportion to a pressure (pressure dissolution method); a method for generating microbubbles by agitating a liquid and a gas (gas-
25 liquid two-phase swirl flow method); and the like.

[0005] However, since solubility of a gas in a liquid under a constant temperature and a constant pressure is determined for each combination of a gas and a liquid that dissolves the gas, even when a gas can be efficiently dissolved in a liquid, the gas cannot be dissolved exceeding the solubility thereof. Therefore, there are limitations on the gas dissolution methods utilizing microbubbles.

30 **[0006]** Meanwhile, it has been known that some of microbubbles generated in a liquid do not simply vanish but temporarily remain, in their extremely micronized states, in the liquid. These bubbles have diameters smaller than several hundred nanometers, and are called nano-bubbles (ultrafine bubbles). Therefore, if a large amount of nano-bubbles can be stably generated in the liquid, the gas can be dissolved in the liquid, exceeding the solubility thereof.

35 **[0007]** In recent years, a method has been proposed, in which nano-bubbles are generated by causing microbubbles generated in a liquid to rapidly contract and crush through application of physical stimulation to the microbubbles, and the generated nano-bubbles are stabilized by adding electrolyte ions to the liquid in order to retain the nano-bubbles.

CITATION LIST

40 [PATENT LITERATURE]

[0008]

[PTL 1] Japanese Laid-Open Patent Publication No. 2014-217813

45 [PTL 2] Japanese Patent No. 4144669

[PTL 3] Japanese Laid-Open Patent Publication No. 2013-166143

SUMMARY OF THE INVENTION

50 PROBLEMS TO BE SOLVED BY THE INVENTION

[0009] However, the aforementioned nano-bubble generation method utilizing crushing of microbubbles has the following drawbacks. That is, due to a rapid temperature rise and a shock wave generated when the microbubbles crush, the gas once dissolved in the liquid is spontaneously discharged from a gas-liquid surface, and therefore, it is difficult
55 to increase the amount of the gas dissolved in the liquid. Moreover, since the shock wave generated when the microbubbles crush is continuously amplified, the nano-bubbles themselves are crushed by the amplified shock wave, which makes it difficult to simply retain the generated nano-bubbles.

[0010] Therefore, an object of the present invention is to provide a gas introducing/retaining device and a gas intro-

ducing/retaining method capable of increasing the amount of a gas dissolved in a liquid, and a gas discharge head used in the gas introducing/retaining device.

SOLUTION TO THE PROBLEMS

[0011] To achieve the above object, the invention of claim 1 provides a gas introducing/retaining device configured to introduce a gas into a liquid, and retain the gas in the liquid. The gas introducing/retaining device includes: a gas discharge head having micropores, and being immersed in the liquid; gas supply means configured to supply the gas to the gas discharge head; and an oscillator configured to continuously apply oscillation to the gas discharge head that is discharging the gas into the liquid. The micropores of the gas discharge head each have a pore size not larger than 2.5 [μm]. The oscillation applied to the gas discharge head by the oscillator has a frequency not lower than 30000 [Hz] and an amplitude not greater than 1 [mm]. The amount of the gas supplied to the gas discharge head is adjusted so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore)/(the oscillation frequency [Hz] of the oscillator) $\leq$ 300.

[0012] The invention of claim 2 is characterized in that, in the gas introducing/retaining device according to the invention of claim 1, the gas discharge head has a plate-shaped head main body, at least one of both surfaces of which serves as a gas discharge surface, and the oscillator applies the oscillation in a direction in which a smaller angle, of angles formed with the gas discharge surface of the head main body, is within a range of -15° to 15° .

[0013] The invention of claim 3 provides a gas discharge head used for the gas introducing/retaining device according to claim 1. The gas discharge head includes a plate-shaped head main body formed of a porous material having a large number of micropores each having a pore size not larger than 2.5 [μm]. A plurality of gas supply paths extending in different directions along the surface of the head main body are formed in the head main body.

[0014] The invention of claim 4 provides a gas introducing/retaining method for introducing a gas into a liquid, and retaining the gas in the liquid. The gas introducing/retaining method includes: continuously applying oscillation having a frequency not lower than 30000 [Hz] and an amplitude not greater than 1 [mm] to a gas discharge head that has a large number of micropores each having a pore size not larger than 2.5 [μm], and is immersed in the liquid; and simultaneously with applying the oscillation, discharging the gas from the gas discharge head into the liquid so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore)/(the oscillation frequency [Hz] of the oscillator) $\leq$ 300.

[0015] The invention of claim 5 is characterized in that, in the gas introducing/retaining method according to claim 1, 0.01% or more by weight of hydrogen peroxide is added to the liquid.

ADVANTAGEOUS EFFECTS OF THE INVENTION

[0016] As described above, in the gas introducing/retaining device according to the invention of claim 1 and the gas introducing/retaining method according to the invention of claim 4, the gas, which is discharged from the micropores, of the gas discharge head, each having the pore size not larger than 2.5 [μm] so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore)/(the oscillation frequency [Hz] of the oscillator) $\leq$ 300, is discharged into the liquid while being separated into microbubbles due to the oscillation, applied to the gas discharge head, having the frequency not lower than 30000 [Hz] and the amplitude not greater than 1 [mm], and then the microbubbles in the liquid demonstrate Brownian movement while slowly contracting, and therefore, can be retained as nano-sized bubbles in the liquid.

[0017] As described above, in the gas introducing/retaining device and the gas introducing/retaining method according to the present invention, nano-bubbles can be generated without crushing microbubbles. Therefore, in contrast to the conventional nano-bubble generation method utilizing crushing of microbubbles, it is possible to avoid the situation that the gas once dissolved in the liquid is spontaneously discharged from the gas-liquid surface due to a temperature rise that occurs when microbubbles crush, and the situation that nano-bubbles once generated are crushed due to a shock wave that is generated when microbubbles crush, and is continuously amplified. Thus, the amount of the gas dissolved in the liquid can be certainly increased.

[0018] According to the invention of claim 2, the gas discharge head has the plate-shaped head main body, at least one of both surfaces of which serves as a gas discharge surface, and the oscillator applies the oscillation in a direction in which a smaller angle, among angles formed with the gas discharge surface of the head main body, is within a range of -15° to 15° . Therefore, the gas discharged from the gas discharge surface can be efficiently separated into microbubbles.

[0019] The gas discharge head according to the invention of claim 3 has the plate-shaped head main body formed of a porous material having a large number of micropores each having a pore size not larger than 2.5 [μm], and a plurality of gas supply paths extending in different directions along the surface of the head main body are formed in the head main body. Therefore, the gas supplied to the head main body is discharged substantially uniformly from the both surfaces of the plate-shaped head main body, and moreover, sufficient strength of the head main body can be ensured as compared with the case where the plate-shaped head main body has a completely hollow structure.

[0020] In particular, in the gas introducing/retaining method according to the invention of claim 5 in which 0.01% or more by weight of hydrogen peroxide is added to the liquid, the added hydrogen peroxide turns into OH radicals due to electric charges of microbubbles, and encompasses the microbubbles, whereby the nano-sized bubbles are stabilized, and the existence time of the nano-sized bubbles in the liquid can be significantly increased.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

[FIG. 1] FIG. 1 is a schematic cross-sectional view showing one embodiment of a gas introducing/retaining device according to the present invention.

[FIG. 2] FIG. 2 is a schematic plan view showing the above gas introducing/retaining device.

[FIG. 3] FIG. 3 is a graph showing changes in the amounts of dissolved oxygen in Examples and Comparative Examples in which oxygen is introduced into pure water by using the above gas introducing/retaining device, and in Conventional Example in which oxygen is introduced into pure water by using a conventional device.

[FIG. 4] FIG. 4 is a schematic cross-sectional view showing another embodiment of a gas introducing/retaining device.

[FIG. 5] FIG. 5 is a schematic plan view showing the above gas introducing/retaining device.

[FIG. 6] FIG. 6 is a front view showing a modification of a gas discharge head used in the gas introducing/retaining device.

[FIG. 7] FIG. 7 is a side view showing the above gas discharge head.

[FIG. 8] FIG. 8 is a diagram for explaining the direction of oscillation applied to a gas discharge head having a plate-shaped head body.

DESCRIPTION OF EMBODIMENTS

[0022] With reference to the drawings, an embodiment is described. FIGS. 1 and 2 show a schematic structure of a gas introducing/retaining device according to the present invention. As shown in FIGS. 1 and 2, the gas introducing/retaining device 1 includes: a liquid storage tank 10 in which a liquid is stored; a gas discharge head 20 that is immersed in the liquid stored in the liquid storage tank 10; gas supply means 30 that supplies a gas to the gas discharge head 20; and oscillation application means 40 that applies oscillation to the gas discharge head 20. The gas introducing/retaining device 1 is configured to discharge the gas from the gas discharge head 20 into the liquid while continuously applying oscillation to the gas discharge head 20 immersed in the liquid.

[0023] As shown in FIGS. 1 and 2, the liquid storage tank 10 is composed of: a polygonal tubular body part 11 formed of a synthetic resin plate; and a bottom part 12 that is formed of a synthetic resin plate, and closes a lower-end opening of the body part 11. The gas discharge head 20 is accommodated and held in the liquid storage tank 10.

[0024] As shown in FIGS. 1 and 2, the gas discharge head 20 includes: a rod-shaped hollow head main body 21 that has a closed distal end, and is formed of, for example, a gas-permeable porous material made of ceramic or the like; and a connection fitting 22 attached to a proximal end of the head main body 21, for connecting the gas supply means 30 to the head main body 21. The head main body 21 has a large number of micropores, each having a pore size not larger than 2.5 μm , which allow the hollow part of the head main body 21 to communicate with the outside. Therefore, when a gas is supplied to the hollow part of the head main body 21, the gas is discharged through the micropores to the outside. The smaller the pore sizes of the micropores are, the more nano-bubbles are likely to be generated. However, if the pore sizes of the micropores are too small, discharge resistance of the gas increases. Therefore, the pore sizes of the micropores are preferably set within a range of 0.01 μm to 2.5 μm , and more preferably within a range of 0.1 μm to 1.0 μm . The number of the micropores each having the pore size not larger than 2.5 μm is not particularly limited. The larger the number of the micropores is, the more preferable because more gas can be introduced into the liquid.

[0025] As shown in FIGS. 1 and 2, the gas supply means 30 includes: a gas supply tube 31 connected to the connection fitting 22 of the gas discharge head 20; a flow regulating valve 32 attached to the tube 31; and a pump 33 that supplies the gas to the gas discharge head 20 via the tube 31. The amount of the supplied gas is adjusted by adjusting the opening degree of the flow regulating valve 32 and/or the voltage of the pump 33.

[0026] As shown in FIGS. 1 and 2, the oscillation application means 40 includes an water-proofed oscillator 41 accommodated in the liquid storage tank 10, and a high-frequency converter circuit (not shown). As the oscillator 41, a Langevin type oscillator is adopted, in which two piezo-electric elements 41a, 41a are held between two metal blocks 41b and 41c.

[0027] The oscillator 41 is disposed such that the metal block 41b on the oscillation radiation side turns up while the other metal block 41c is fixed to the bottom part 12 of the liquid storage tank 10. The head main body 21 of the gas discharge head 20 is adhesively fixed to the oscillation emitting surface of the metal block 41b.

[0028] Oscillation applied to the head main body 21 of the gas discharge head 20 by the oscillator 41 is set so as to

have a frequency not lower than 30000 Hz and an amplitude not greater than 1 mm, and the amount of the gas supplied to the gas discharge head 20 is adjusted so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of the oscillator) ≤ 300 . The smaller the value of (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of the oscillator) is, the more nano-bubbles are likely to be generated. Therefore, this value is preferably set to be not larger than 200, and more preferably, not larger than 100.

[0029] As described above, when the gas is discharged from the micropores, of the gas discharge head 20, each having the size not larger than $2.5 \mu\text{m}$ while applying, to the gas discharge head, oscillation having the frequency not lower than 30000 Hz and the amplitude not greater than 1 mm so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of the oscillator) ≤ 300 , the gas discharged from the micropores of the gas discharge head 20 is discharged into the liquid while being separated into microbubbles due to the oscillation applied to the gas discharge head 20, and the microbubbles discharged into the liquid demonstrate Brownian movement while slowly contracting, and therefore, are retained in the liquid as nano-sized bubbles.

[0030] Hereinafter, with reference to Tables 1 and 2, a description is given of Examples 1 to 6 and Comparative Examples 1 to 4 of the present invention, in which oxygen gas is introduced and retained in pure water by using the aforementioned gas introducing/retaining device 1, and Conventional Example in which oxygen gas is introduced and retained in pure water by using a conventional device. However, it is needless to say that the present invention is not limited to the examples described below.

(Example 1)

[0031] As shown in Table 1, at a room temperature of 20°C , pure water 21 was introduced into the liquid storage tank 10, and oscillation having a frequency of 40000 Hz and an amplitude of 0.5 mm was continuously applied to the gas discharge head 20 for two minutes, while discharging oxygen gas having a concentration not lower than 99.7% by volume, at $4000 \text{ mm}^3/\text{min}$, from the gas discharge head 20 in which the head main body 21 has about 3 millions of micropores having the average pore size of $1 \mu\text{m}$. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 33 is satisfied.

(Example 2)

[0032] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that the head main body 21 having about 480 thousands (average number) of micropores each having a pore size of $2.5 \mu\text{m}$ was adopted. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 208 is satisfied.

(Example 3)

[0033] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that oscillation having a frequency of 30000 Hz and an amplitude of 0.5 mm was applied to the gas discharge head 20. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 44 is satisfied.

(Example 4)

[0034] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that oscillation having a frequency of 40000 Hz and an amplitude of 1 mm was applied to the gas discharge head 20. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 33 is satisfied.

(Example 5)

[0035] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that the amount of the oxygen gas discharged from the gas discharge head 20 was $36000 \text{ mm}^3/\text{min}$. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 300 is satisfied.

(Example 6)

[0036] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that 0.01% by weight of hydrogen peroxide was added to 2 liters of pure water introduced into the liquid storage tank 10. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 33 is satisfied.

(Comparative Example 1)

[0037] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that the head main body 21 having about 300 thousands (average number) of micropores each having a pore size of 3 μm was adopted. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 333 is satisfied.

(Comparative Example 2)

[0038] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that oscillation having a frequency of 25000 Hz and an amplitude of 0.5 mm was applied to the gas discharge head 20. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 53 is satisfied.

(Comparative Example 3)

[0039] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that oscillation having a frequency of 40000 Hz and an amplitude of 2 mm was applied to the gas discharge head 20. Under this condition, (the amount of the oxygen gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 33 is satisfied.

(Comparative Example 4)

[0040] As shown in Table 1, oxygen gas was introduced into pure water by the same method as that for Example 1 except that the amount of the oxygen gas discharged from the gas discharge head 20 was 40000 mm^3/min . Under this condition, (the amount of the oxygen gas

[0041] [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 333 is satisfied.

[Table 1]

	Addition amount of hydrogen peroxide [wt%]	Gas supply head		Applied oscillation		Discharge amount of oxygen gas [mm^3/min]	$\frac{A \times 10^9}{B \times C}$
		Average pore size [μm]	Average number of pores [ten thousand]	Frequency [Hz]	Amplitude [mm]		
Ex. 1	0	1	300	40000	0.5	4000	33
Ex. 2	0	2.5	48	40000	0.5	4000	208
Ex. 3	0	1	300	30000	0.5	4000	44
Ex. 4	0	1	300	40000	1	4000	33
Ex. 5	0	1	300	40000	0.5	36000	300
Ex. 6	0.01	1	300	40000	0.5	4000	33
Comp. Ex. 1	0	3	30	40000	0.5	4000	333
Comp. Ex. 2	0	1	300	25000	0.5	4000	53

(continued)

	Addition amount of hydrogen peroxide [wt%]	Gas supply head		Applied oscillation		Discharge amount of oxygen gas [mm ³ /min]	$\frac{A \times 10^9}{B \times C}$
		Average pore size [μm]	Average number of pores [ten thousand]	Frequency [Hz]	Amplitude [mm]		
Comp. Ex. 3	0	1	300	40000	2	4000	33
Comp. Ex. 4	0	1	300	40000	0.5	40000	333

A: discharge amount of oxygen gas from entire gas supply head [μm³/min]

B: average number of micropores of gas supply head [pieces]

C: applied oscillation frequency [Hz]

(Conventional Example)

[0042] As a conventional device, a micro/nano-bubble generator (ΣPM-5 manufactured by Sigma-Technology Inc.) was used. In this micro/nano-bubble generator, a gas and a liquid are simultaneously sucked by using a suction force of a pump and supplied to a gas-liquid mixing tank, and the gas-dissolved liquid, in the gas-liquid mixture state, stored in the gas-liquid mixing tank is jetted at a pressure not less than the atmospheric pressure, from the outside of a nozzle having two or more small through-holes via the small through-holes, to cause the jets of the gas-dissolved liquid to collide with each other in the nozzle, thereby generating micro/nano-bubbles.

[0043] A liquid suction port and a discharge port of the conventional device were immersed in pure water stored in another container, and preliminary operation was performed for 10 minutes while circulating the pure water at 1 liter/min until stabilization was achieved. Thereafter, the liquid suction port and the discharge port were immersed in 2 liters of pure water stored in a liquid storage tank, and the pure water in the liquid storage tank was circulated for 2 minutes at 1 liter/min.

[0044] For each of the aforementioned Examples 1 to 6, Comparative Examples 1 to 4, and Conventional Example, the amount of dissolved oxygen was measured by using a dissolved oxygen meter (CGS-5 manufactured by Central Kagaku Corp.) at time points when predetermined periods have passed (operation start point, point when 30 seconds has passed, point when 60 seconds has passed, point when 90 seconds has passed, and point when 120 seconds has passed) during operation of the device, and the results are shown in Table 2 and the graph of FIG. 3. In the graph of FIG. 3, "amount of dissolved oxygen corresponding to solubility (volume [cm³] when 1 atm. of oxygen dissolves in 1 cm³ of water at 20°C = 0.031)" is $0.031[1/1]/22.4[1/\text{mol}] \times 32[\text{g}/\text{mol}] \times 10^3 = 44.3 [\text{mg}/\text{l}]$.

[Table 2]

	Amount of dissolved oxygen [mg/l]						
	Initial concentration	After lapse of 30 sec.	After lapse of 60 sec.	After lapse of 90 sec.	After lapse of 120 sec.	After lapse of 15 days	After lapse of 30 days
Ex. 1	0.21	20.09	40.38	60.47	>80.00	24.26	17.64
Ex. 2	0.21	22.85	39.23	52.08	58.46	-	-
Ex. 3	0.21	13.11	29.81	45.92	59.62	-	-
Ex. 4	0.21	15.65	31.97	47.62	63.94	-	-
Ex. 5	0.21	12.19	24.45	34.64	45.90	-	-
Ex. 6	0.21	20.18	40.44	60.63	>80.00	75.68	68.86
Comp. Ex. 1	0.21	3.79	5.50	8.29	11.00	-	-

(continued)

	Amount of dissolved oxygen [mg/l]						
	Initial concentration	After lapse of 30 sec.	After lapse of 60 sec.	After lapse of 90 sec.	After lapse of 120 sec.	After lapse of 15 days	After lapse of 30 days
Comp. Ex. 2	0.21	3.18	4.15	7.26	8.21	-	-
Comp. Ex. 3	0.21	8.84	13.52	16.36	17.04	-	-
Comp. Ex. 4	0.21	10.98	18.15	23.13	25.20	-	-
Conv. Ex.	0.21	10.98	22.15	33.13	45.20	-	-

[0045] As seen from Table 2 and FIG. 3, in the gas introducing/retaining device 1, the amount of dissolved oxygen after a lapse of 2 minutes, at which the operation is stopped, is much less than the amount of dissolved oxygen corresponding to the solubility in each of: Comparative Example 1 in which the pore size of the micropores of the gas discharge head 20 is 3 μm ($> 2.5 \mu\text{m}$); Comparative Example 2 in which the frequency of the oscillation applied by the oscillator 41 is 25000 Hz ($< 30000 \text{ Hz}$); Comparative Example 3 in which the amplitude of the oscillation applied by the oscillator 41 is 2 mm ($> 1 \text{ mm}$); and Comparative Example 4 in which (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 333 (> 300) is satisfied. On the other hand, in Examples 1 to 5 in which the pore size of the micropores of the gas discharge head 20 is not larger than 2.5 μm , the frequency of the oscillation applied by the oscillator 41 is not lower than 30000 Hz, the amplitude of the oscillation applied by the oscillator 41 is not greater than 1 mm, and (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) ≤ 300 is satisfied, the amount of dissolved oxygen after a lapse of 2 minutes, at which the operation is stopped, is greater than the amount of dissolved oxygen (44.3 mg/l) corresponding to the solubility, and thus oxygen can be dissolved in the pure water, exceeding the solubility thereof.

[0046] Also in Conventional Example, the amount of dissolved oxygen after a lapse of 2 minutes, at which the operation is stopped, is 45.2 mg/l which is a little greater than the amount of dissolved oxygen (44.3 mg/l) corresponding to the solubility. However, in Examples 1 to 4, the amount of dissolved oxygen after a lapse of 2 minutes is not less than 58 mg/l, and particularly in Example 1, the amount of dissolved oxygen is not less than 80 mg/l and is much greater than the amount of dissolved oxygen (44.3 mg/l) corresponding to the solubility, which reveals that Example 1 has excellent oxygen introducing/retaining performance.

[0047] Comparing Example 1 and Example 2 which are different from each other only in the size (number) of the micropores of the gas discharge head 20 among the pore size of the micropores of the gas discharge head 20, the frequency of the oscillation applied by the oscillator 41, and the amplitude of the oscillation, since the amount of dissolved oxygen after a lapse of 2 minutes is by 20 mg/l or more higher in Example 1 in which the pore size of the micropores of the gas discharge head 20 is 1 μm than in Example 2 in which the pore size of the micropores of the gas discharge head 20 is 2.5 μm , it is desirable that the pore size of the micropores of the gas discharge head 20 is set to be not larger than 1 μm .

[0048] Comparing Example 1 and Example 3 which are different from each other only in the frequency of the oscillation applied by the oscillator 41 among the pore size of the micropores of the gas discharge head 20, the frequency of the oscillation applied by the oscillator 41, and the amplitude of the oscillation, since the amount of dissolved oxygen after a lapse of 2 minutes is by 20 mg/l or more higher in Example 1 in which the frequency of the oscillation applied by the oscillator 41 is 40000 Hz than in Example 3 in which the frequency of the oscillation applied by the oscillator 41 is 30000 Hz, it is desirable that the frequency of the oscillation applied by the oscillator 41 is set to be not lower than 40000 Hz.

[0049] Comparing Example 1 and Example 4 which are different from each other only in the amplitude of the oscillation applied by the oscillator 41 among the pore size of the micropores of the gas discharge head 20, the frequency of the oscillation applied by the oscillator 41, and the amplitude of the oscillation, since the amount of dissolved oxygen after a lapse of 2 minutes is by 20 mg/l or more higher in Example 1 in which the amplitude of the oscillation applied by the oscillator 41 is 0.5 mm than in Example 4 in which the amplitude of the oscillation applied by the oscillator 41 is 1 mm, it is desirable that the amplitude of the oscillation applied by the oscillator 41 is set to be not greater than 0.5 mm.

[0050] Comparing Example 1 and Example 5 which are different from each other only in (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) among the

pore size of the micropores of the gas discharge head 20, the frequency of the oscillation applied by the oscillator 41, the amplitude of the oscillation, and (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41), since the amount of dissolved oxygen after a lapse of 2 minutes is by 30 mg/l or more higher in Example 1 in which (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) = 33 than in Example 5 in which (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator) = 300, it is preferable that (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore of head main body 21)/(oscillation frequency [Hz] of oscillator 41) is set to be not greater than 200, and more preferably, not greater than 100.

[0051] Comparing Example 1 and Example 6 which are different from each other only in that hydrogen peroxide is added to the pure water in Example 6, since the rate of reduction in the amount of dissolved oxygen after the operation of the device is stopped is more suppressed in Example 6 in which 0.01% by weight of hydrogen peroxide is added to the pure water than in Example 1 in which hydrogen peroxide is not added to the pure water, it is desirable that 0.01% or more by weight of hydrogen peroxide is added when the oxygen dissolved state needs to be retained for long hours.

[0052] In each of Examples described above, oxygen is introduced in pure water. However, the present invention is not limited thereto. Any of various gases such as air, ozone, hydrogen, carbon dioxide, and nitrogen can be introduced and dissolved in any of various liquids such as tap water, seawater, hot spring water, contaminated water, and oil.

[0053] In the embodiments described above, the oscillator 41 is accommodated and held in the liquid storage tank 10. However, the present invention is not limited thereto. For example, as shown in FIGS. 4 and 5, a liquid storage tank 10A may be composed of a tank main body 13 in which a liquid is stored, and a rectangular tubular pedestal 15 that supports the tank main body 13, and the oscillator 41 may be disposed in the pedestal 15 beneath the tank main body 13.

[0054] Specifically, a bottom part of the tank main body 13 is formed of a metal plate 14, and a bolt 42 inserted in a bolt insertion hole formed through the metal plate 14 is screwed and fastened to an oscillation emitting surface of the oscillator 41 to fix the oscillator 41 to the metal plate 14. In addition, the head main body 21 of the gas discharge head 20 is adhesively fixed to a head portion of the bolt 42 projecting at the upper surface of the metal plate 14, whereby oscillation of the oscillator 41 is applied to the head main body 21 through the bolt 42 while resonating the metal plate 14 that forms the bottom part of the tank main body 13.

[0055] In the embodiments described above, the gas discharge head 20 having the bar-shaped hollow head main body 21 having the closed distal end is used. However, the present invention is not limited thereto. For example, as shown in FIGS. 6 and 7, a gas discharge head 20A having a plate-shaped head main body 21A can be adopted.

[0056] When adopting the plate-shaped head main body 21A, as shown in FIGS. 6 and 7, a chamber 22A to which the tube 31 of the gas supply means 30 is connected is provided so as to be connected to a lower end portion of the head main body 21A, and a plurality of vertical gas supply paths 21Aa that extend in the vertical direction along the surface of the head main body 21A and are opened to the chamber 22A, and a plurality of horizontal gas supply path 21Ab that extend in the horizontal direction along the surface of the head main body 21A and communicate with the vertical gas supply paths 21Aa, are formed in the head main body 21A. Thereby, the gas supplied to the head main body 21A via the chamber 22A is discharged substantially uniformly from the both surfaces of the plate-shaped head main body 21A, and moreover, sufficient strength of the plate-shaped head main body 21A can be ensured as compared with the case where the plate-shaped head main body 21A has a completely hollow structure.

[0057] When adopting the plate-shaped head main body 21A as described above, as shown in FIG. 8, the head main body 21A is fixed to the oscillation emitting surface of the oscillator 41 (metal block 41b) such that oscillation is applied in a direction in which a smaller angle α , among angles formed with the gas discharge surface f of the head main body 21A, is within a range of -15° to 15° , whereby the gas discharged from the gas discharge surface can be efficiently separated into microbubbles. In particular, when oscillation is applied in a direction in which the angle formed with the gas discharge surface of the head main body 21A is 0° , that is, a direction along the gas discharge surface of the head main body 21A, since the oscillation is applied in a direction orthogonal to the gas discharge direction, the gas discharged from the gas discharge surface can be separated into microbubbles most efficiently.

[0058] In the embodiments described above, the Langevin type oscillator is adopted as the oscillator 41 of the oscillation application means 40. However, the present invention is not limited thereto, and various types of oscillators can be adopted.

INDUSTRIAL APPLICABILITY

[0059] The gas introducing/retaining device according to the present invention can dissolve various types of gases into various types of liquids at high concentration, and therefore, can be used in various fields including: industrial waste-liquid treatment; washing; sterilization; disinfection; retention of freshness of perishables; culture of fishery products; etc. by appropriately selecting a liquid and a gas to be introduced into the liquid.

DESCRIPTION OF THE REFERENCE CHARACTERS

[0060]

5	1	gas introducing/retaining device
	10, 10A	liquid storage tank
	11	body part
	12	bottom part
	13	tank main body
10	14	metal plate
	15	pedestal
	20, 20A	gas discharge head
	21, 21A	head main body
	21Aa	vertical gas supply path
15	21Ab	horizontal gas supply path
	22	connection fitting
	22A	chamber
	30	gas supply means
	31	tube
20	32	flow regulating valve
	33	pump
	40	oscillation application means
	41	oscillator
	41a	piezo-electric element
25	41b, 41c	metal block
	42	bolt

Claims

- 30
1. A gas introducing/retaining device configured to introduce a gas into a liquid, and retain the gas in the liquid, the device comprising:
- 35
- a gas discharge head having micropores, and being immersed in the liquid;
gas supply means configured to supply the gas to the gas discharge head; and
an oscillator configured to continuously apply oscillation to the gas discharge head that is discharging the gas into the liquid, wherein
the micropores of the gas discharge head each have a pore size not larger than 2.5 [μm],
the oscillation applied to the gas discharge head by the oscillator has a frequency not lower than 30000 [Hz]
40 and an amplitude not greater than 1 [mm], and
an amount of the gas supplied to the gas discharge head is adjusted so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore)/(the oscillation frequency [Hz] of the oscillator) $\leq$ 300.
- 45
2. The gas introducing/retaining device according to claim 1, wherein
the gas discharge head has a plate-shaped head main body, at least one of both surfaces of which serves as a gas discharge surface, and
the oscillator applies the oscillation in a direction in which a smaller angle, of angles formed with the gas discharge surface of the head main body, is within a range of -15° to 15° .
- 50
3. A gas discharge head used for the gas introducing/retaining device according to claim 1, including a plate-shaped head main body formed of a porous material having a large number of micropores each having a pore size not larger than 2.5 [μm], wherein
a plurality of gas supply paths extending in different directions along the surface of the head main body are formed in the head main body.
- 55
4. A gas introducing/retaining method for introducing a gas into a liquid, and retaining the gas in the liquid, the method comprising:

continuously applying oscillation having a frequency not lower than 30000 [Hz] and an amplitude not greater than 1 [mm] to a gas discharge head that has a large number of micropores each having a pore size not larger than 2.5 [μm], and is immersed in the liquid; and
simultaneously with applying the oscillation, discharging the gas from the gas discharge head into the liquid so as to satisfy (the amount of the gas [$\mu\text{m}^3/\text{min}$] discharged from one micropore)/(oscillation frequency [Hz] of the oscillator) ≤ 300 .

5. The gas introducing/retaining method according to claim 4, wherein 0.01% or more by weight of hydrogen peroxide is added to the liquid.

Fig. 1

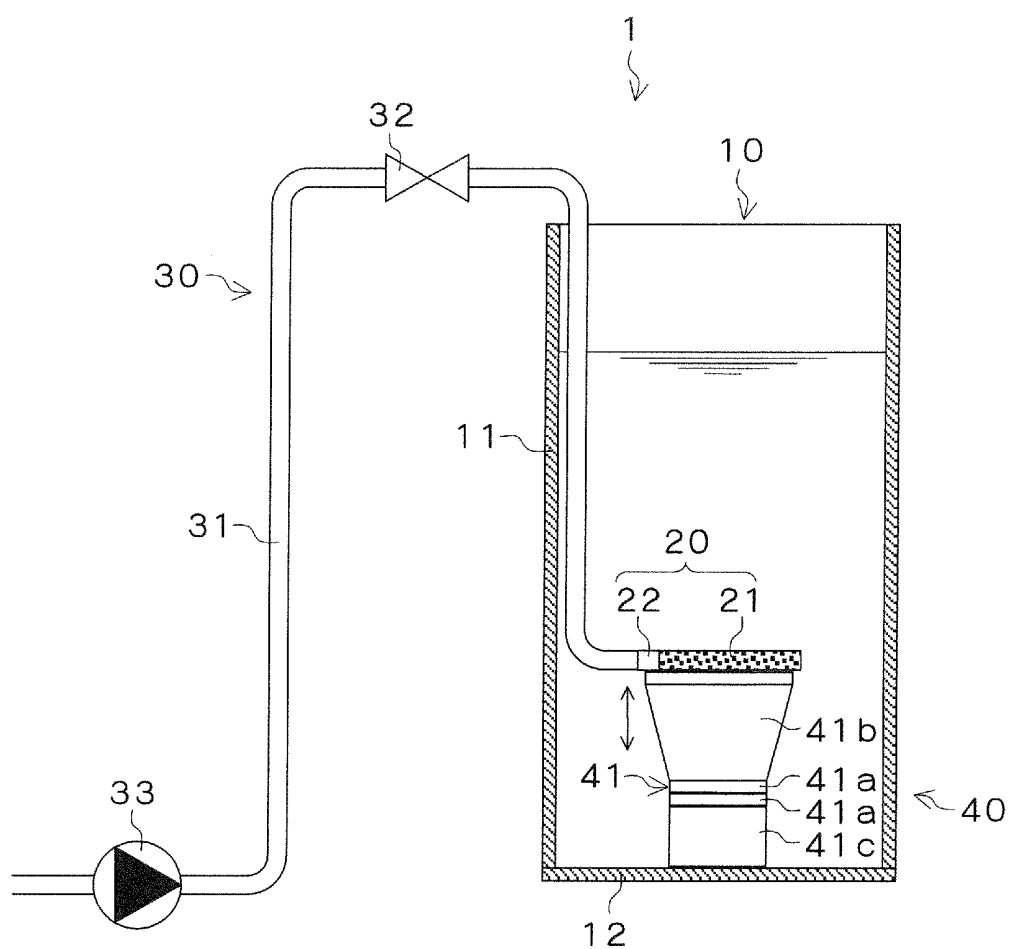
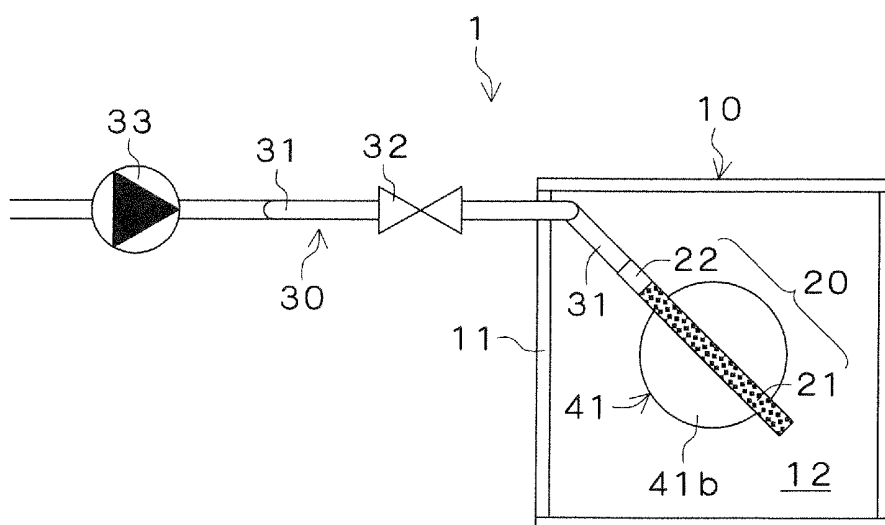


Fig. 2



F i g . 3

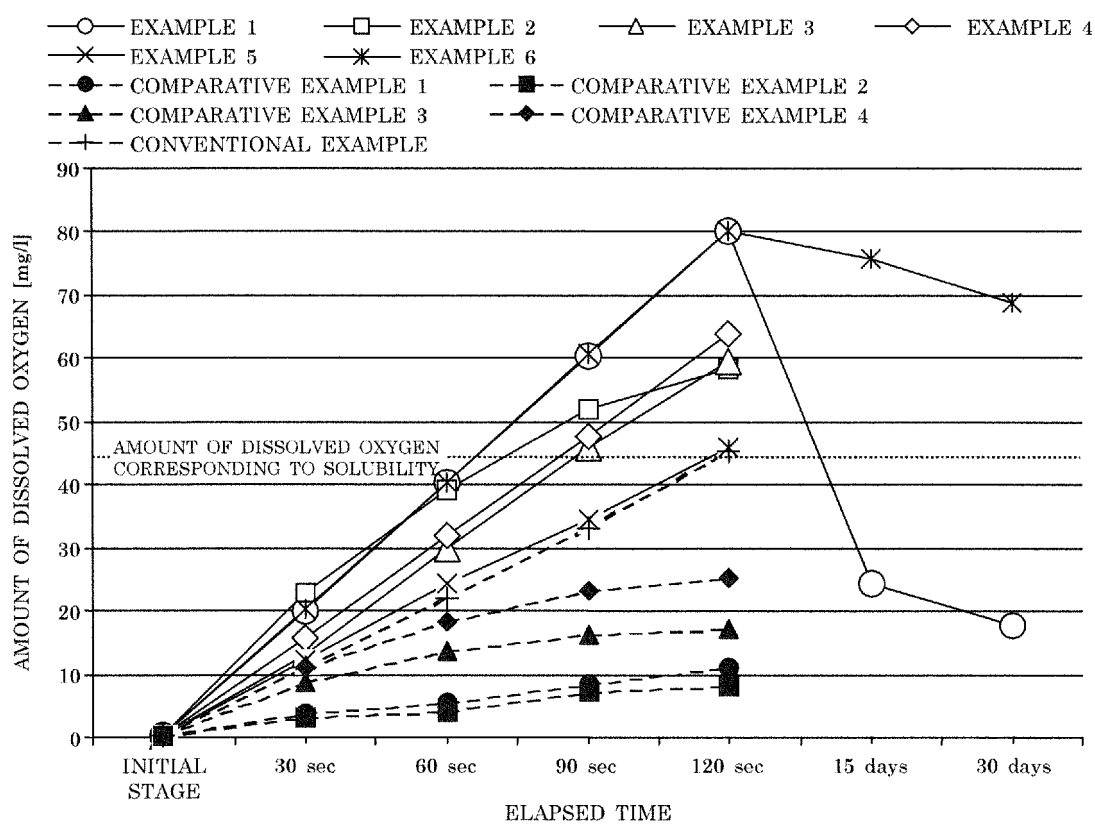


Fig. 4

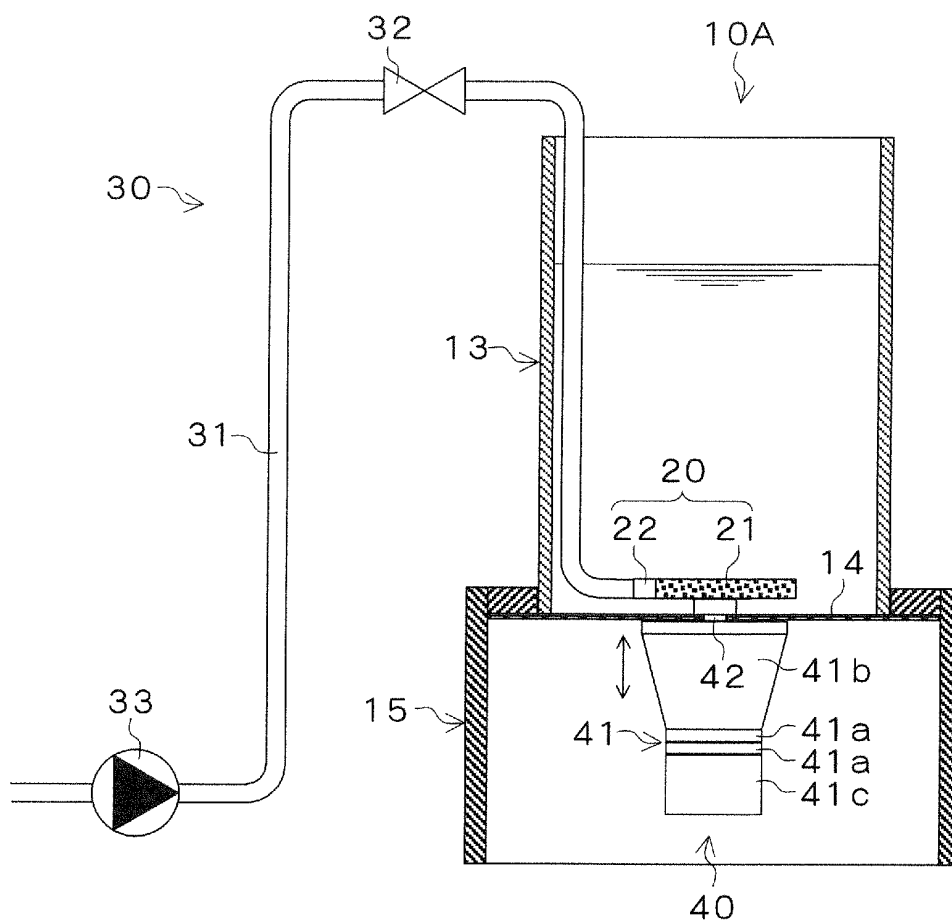


Fig. 5

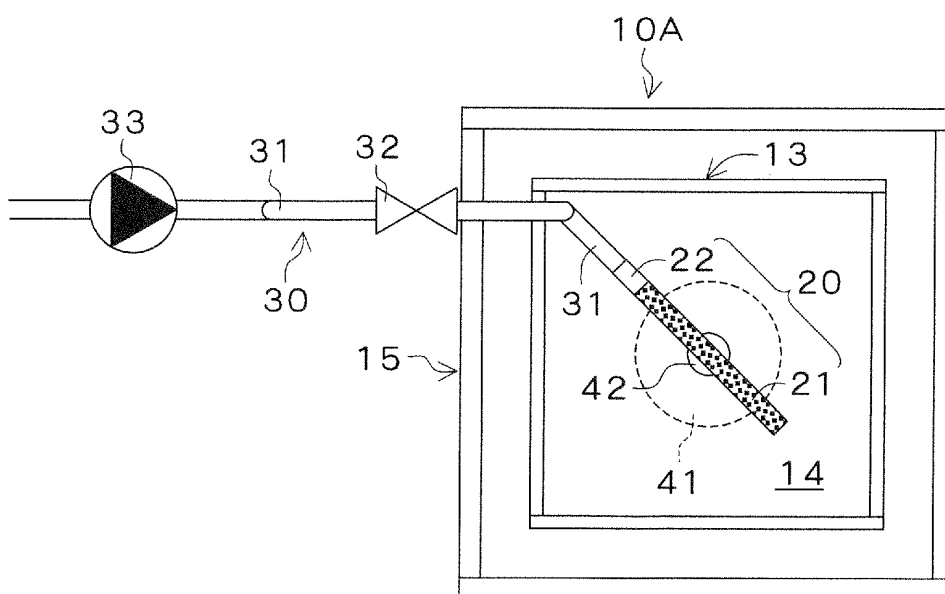


Fig. 6

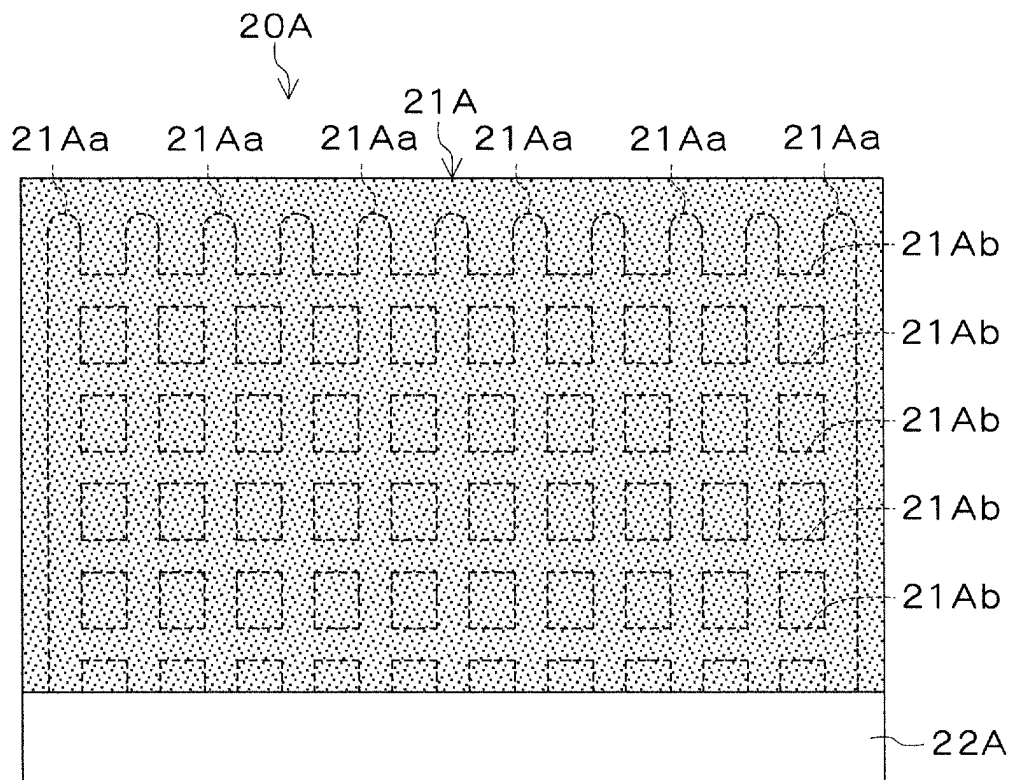
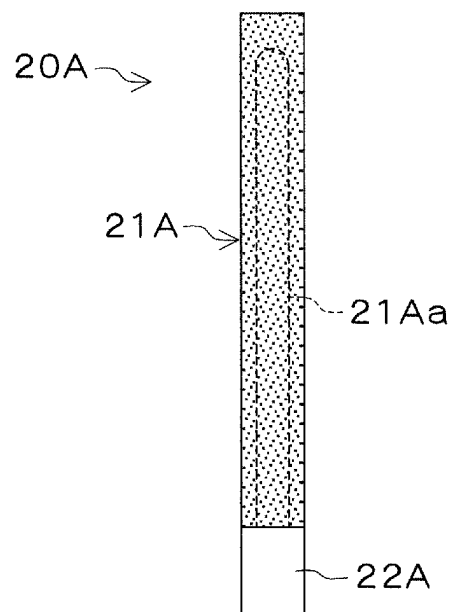
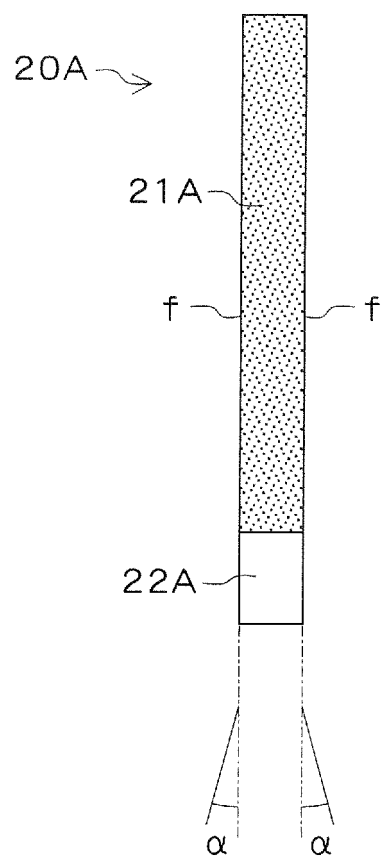


Fig. 7



F i g . 8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/056247

A. CLASSIFICATION OF SUBJECT MATTER

B01F3/04(2006.01)i, B01F11/00(2006.01)i, B01F15/02(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B01D53/14-53/18, B01F1/00-5/26, B01F11/00-11/04, B01F15/02, B01J4/00, B01J19/10, C02F1/00, C02F1/34-1/36, C02F1/74, C02F7/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2016
Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

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

JSTPlus/JST7580(JDreamIII), DWPI(Thomson Innovation)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2003-93858 A (NKK Corp.), 02 April 2003 (02.04.2003), claims; paragraphs [0022] to [0027]; fig. 1, 2 (Family: none)	1-5
A	JP 2006-87984 A (NGK Insulators, Ltd.), 06 April 2006 (06.04.2006), claims; paragraphs [0005], [0036] to [0095]; fig. 1 to 17 (Family: none)	1-5

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

09 May 2016 (09.05.16)

Date of mailing of the international search report

31 May 2016 (31.05.16)

Name and mailing address of the ISA/

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Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/056247

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2005-169359 A (Miyazaki-Ken), 30 June 2005 (30.06.2005), claims; examples 1 to 3; fig. 1 to 5 & US 2006/0284325 A1 examples 1 to 3; page 4, right column, line 39 to page 5, right column, line 4 & EP 1695758 A1	1-5

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 4144669 B [0008]
- JP 2013166143 A [0008]