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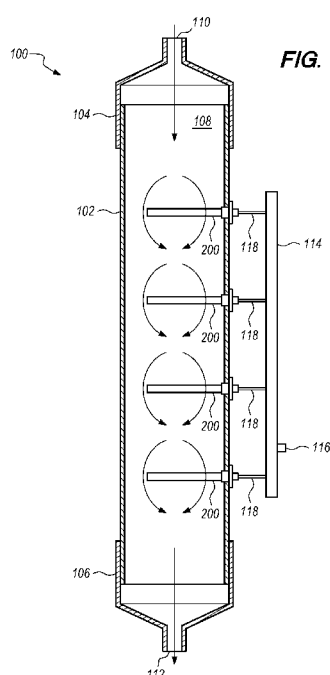
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(54) Title: MODULAR DEVICES AND SYSTEMS FOR INFUSING GAS INTO A LIQUID AND METHODS OF MANUFACTURE AND USE THEREOF



(57) Abstract: The present invention provides modular devices and systems for infusing gas into a liquid and methods of manufacture and use thereof. In accordance with an embodiment, a modular device for infusing gas into a liquid is provided. The modular device comprises a plurality of microporous hollow fibers, and a cap covering open ends of the microporous hollow fibers. The cap is configured to receive a gas into an opening and to deliver the gas into the open ends of the microporous hollow fibers. The cap is further configured to removably mount the modular device to a fixture. A system for infusing gas into a liquid may include one or more of the modular gas infusion devices configured to be removably mounted to a fixture such that the microporous hollow fibers are within a hollow cavity.

MODULAR DEVICES AND SYSTEMS FOR INFUSING GAS INTO A LIQUID AND METHODS OF MANUFACTURE AND USE THEREOF

This application claims priority of U.S. Provisional Application No. 62/643,321, filed March 15, 2015, the entire contents of which are hereby incorporated by reference.

Background of the Invention

[0001] The present invention relates to the field of infusing gas into liquids.

[0002] There are a number of applications for infusing gas into liquids. For example, it is known that plants require water into order to receive nutrients into the plant.

However, for the nutrients to be used by the plant, oxygen must also be present. It has been found that increasing the dissolved oxygen content of water used for irrigation can increase plant health as well as crop production yields. Additional applications for infusing gas into liquids can include, for example, aquaculture, distilled spirits production, and treatment of blood disorders.

[0003] Various techniques have been used to introduce gas into liquids, such as bubblers and aerators. In addition, porous membranes can be used at the gas-liquid interface to cause gas to be absorbed by, and removed from, liquids. For example, U.S. Patent No. 4,268,279 discloses a gas transfer process using a hollow fiber membrane. More particularly, this patent discloses a process which comprises allowing a liquid to contact the inside of a microporous hollow fiber and a fluid to contact the outside, thereby allowing the gaseous components contained in both fluids to transfer between them.

[0004] In order to maximize the benefits of dissolving oxygen into water used for plant irrigation, it is desired to maximize the amount of dissolved oxygen as well as the time that the oxygen remains dissolved in the water. It is also desired to produce water having increased levels of dissolved oxygen in a manner that is both time-effective and cost-effective. Therefore, what is needed are improved devices and methods for infusing gas into a liquid and, more particularly, for infusing oxygen into water.

Summary of the Invention

[0005] The present invention provides modular devices and systems for infusing gas into a liquid and methods of manufacture and use thereof. In accordance with an embodiment, a modular device for infusing gas into a liquid is provided. The modular device comprises plurality of microporous hollow fibers, and a cap covering open ends of the microporous hollow fibers. The cap is configured to receive a gas into an opening and to deliver the gas into the open ends of the microporous hollow fibers. The cap is further configured to removably mount the modular device to a fixture.

[0006] In accordance with a further embodiment, a modular system for infusing gas into a liquid is provided. The system includes a fixture comprising a hollow cavity, a first opening configured to receive a liquid, and a second opening configured to discharge the liquid infused with a gas. The system further comprises one or more modular gas infusion devices configured to be removably mounted to the fixture such that the microporous hollow fibers are within the hollow cavity.

[0007] These and other embodiments are described herein.

Brief Description of the Drawings

[0008] The present invention is described with respect to particular exemplary embodiments thereof and reference is accordingly made to the drawings in which:

[0009] Figures 1A-B illustrate a system for infusing gas into a liquid in accordance with an embodiment of the present invention;

[0010] Figures 2A-B illustrate a modular device for infusing gas into a liquid in accordance with an embodiment of the present invention;

[0011] Figures 3A-E illustrate a process of manufacturing a modular device for infusing gas into a liquid in accordance with an embodiment of the present invention;

[0012] Figures 4A-C illustrate a cap component of a modular device for infusing gas into a liquid in accordance with an embodiment of the present invention;

[0013] Figure 5 illustrates an alternative system for infusing gas into a liquid in accordance with an embodiment of the present invention;

[0014] Figure 6 illustrates a submersible system for infusing gas into a liquid in accordance with an embodiment of the present invention; and

[0015] Figure 7 illustrates an alternative submersible system for infusing gas into a liquid in accordance with an embodiment of the present invention.

Detailed Description of a Preferred Embodiment of the Invention

[0016] The present invention is directed toward modular devices and systems for infusing gases into liquids and methods of manufacture and use thereof. A modular device (also referred herein as a "module") for infusing gas into liquid may include a plurality of microporous hollow fibers and a cap covering open ends of the microporous hollow fibers.

[0017] The microporous hollow fibers may be bundled together and surrounded by a mesh sleeve. In an embodiment, the microporous hollow fibers are water-repellant. The microporous hollow fibers may be folded or looped such that both ends of the fibers are open and covered by the cap. Alternatively, ends of the microporous hollow fibers that are opposite to those covered by the cap may be sealed or otherwise closed.

[0018] The cap covering open ends of the microporous hollow fibers is configured to receive a gas into an opening and to deliver the gas into the open ends of the microporous hollow fibers. The cap is preferably configured to removably mount the modular device to a fixture. For example, the cap may be fitted with tapered threads or a quick connect fitting.

[0019] A system for infusing gas into a liquid may include one or more of the modular devices and a fixture into which the modular devices can be mounted. In an embodiment, the modular devices can be removed from the fixture and replaced. This facilitates maintenance of the system, for example, to replace one or more of the modular devices that has failed or is otherwise no longer performing as desired.

[0020] An exemplary fixture is comprised of a hollow cavity, a first opening configured to receive a liquid, and a second opening configured to discharge liquid infused with gas. In such a configuration, the one or more modular gas infusion devices are mounted to the fixture such that the microporous hollow fibers are at least partially within the hollow cavity. The openings configured to receive gas are preferably accessible from outside the hollow cavity in order to facilitate delivery of gas to the

modular devices. The fixture is preferably equipped with fittings to accommodate the modular devices; these fittings can be, for example, threaded or quick connect fittings.

[0021] In use, gas may be introduced into the opening of each of the modular devices. The gas may be delivered via a manifold, hoses or other gas delivery system. Liquid may also be introduced into the first opening of the fixture. The liquid can then make contact with the fibers. The gas can then cross the microporous membrane of the fibers and enter the liquid so that the gas becomes dissolved in the liquid. The gas can be, for example, primarily oxygen. Alternatively, other gasses may be used. Also, different gasses can be introduced via different ones of the modular devices so that multiple different gasses can be dissolved into the same liquid. The liquid can be, for example, primarily water. Alternatively, other liquids, including liquid mixtures and liquids with dissolved solids (e.g., plant fertilizers) may be used. The gas and/or the liquid can be pressure regulated. For example, the system can be controlled such that the gas has a greater pressure than that of the liquid. In an embodiment, the system can be used to increase the dissolved oxygen content of water.

[0022] Various different sizes, capacities and configurations of fixtures can be provided. This facilitates configuring and scaling of the system for different applications. The modular devices can be identical to each other, or similar to each other, regardless of fixture size, capacity, configuration or application. This allows a single, or limited number, of variations of modules to be used in a wide variety of applications, thereby simplifying manufacturing processes as well as maintenance and inventory requirements.

[0023] Figures 1A-B illustrates a system for infusing gas into a liquid in accordance with an embodiment of the present invention. Figure 1A shows a side elevation view of the system while Figure 1B shows a side sectional view of the system. As shown in Figures 1A-B, the system includes a fixture 100. The fixture 100 includes a housing 102 having a first end cap 104 and a second end cap 106. Within the housing 102 is a hollow cavity 108. In this example, the housing 102 is tubular and can be constructed of a hollow plastic or metal tube, though it will be apparent that other materials, or a combination of materials, can be used. In the case of a plastic tube, the end caps 104, 106 can be, for example, permanently bonded to the tube. In the case of a metal tube, the end caps 104, 106 can be, for example, welded to the tube or attached with clamps.

[0024] An opening 110 in the first end cap 104 is provided for introducing liquid (or fluid) into the fixture 100. An opening 112 in the second end cap 106 is provided for discharging the liquid (or fluid) from the fixture. Arrows in Figure 1B show generally the direction of liquid flow within the fixture.

[0025] Also shown in Figures 1A-B are a number of modular devices 200 (also shown in more detail in Figures 2A-B and 3A-E). While four such devices 200 are shown in Figures 1A-B, the fixture 100 may be equipped with as few as one such device 200 or any suitable number of devices 200 so as to achieve a desired level of gas dissolution in the liquid. The devices 200 are preferably removably mounted to the fixture 100.

[0026] Also shown in Figures 1A-B is a means for delivering gas into the modular devices 200. In this example, a gas manifold 114 is provided to deliver gas to the devices 200. The manifold 114 is equipped with a gas inlet 116 and a number of gas outlets 118. A gas outlet is connected to each device 200. Rather than a manifold, a plurality of gas hoses can be used to deliver the gas to the devices 200.

[0027] Figures 2A-B illustrates a modular device 200 for infusing gas into a liquid in accordance with an embodiment of the present invention. Figure 2A shows a side elevation view of the device 200 while Figure 2B shows a cross-sectional view. Referring to Figure 2A, the device 200 is composed of a plurality of microporous hollow fibers 202 and a cap 204. The cap 204 covers open ends of the microporous hollow fibers 202. The cap 204 is equipped with an opening 206 and is configured to receive a gas into the opening 206 and to deliver the gas into the open ends of the microporous hollow fibers 202. More particularly, the cap 204 may be composed of an outer cap 208 and an inner cylindrical sleeve 210 that encircles the microporous hollow fibers 202. Figure 2B shows a cross-sectional view of the device 200, including the inner sleeve 210, however, the outer cap 208 is not shown in Figure 2B. Referring to Figure 2B, a potting compound 212, such as epoxy, can be used to hold the microporous hollow fibers 202 in place within the sleeve 210.

[0028] The microporous hollow fibers 202 may be folded or looped such that both ends of the fibers are open and covered by the cap 204. Alternatively, ends 214 of the microporous hollow fibers that are opposite to those covered by the cap may be sealed or otherwise closed. In either case, all of the open ends are preferably covered by the cap

204. The microporous hollow fibers 202 may be bundled together within a mesh sleeve 216. The sleeve 216 may help to prevent damage to the microporous hollow fibers 202 during use and when the device 200 is inserted and removed from the fixture 100 (Figures 1A-B).

[0029] The opening 206 in the cap 204 may be equipped with internal threads (which may be tapered), a quick connect fitting or some other type of fitting that allows a gas hose, pipe, conduit or manifold to be connected to the device 200 for delivering gas into the microporous hollow fibers 202. Such a fitting should provide a gas seal to prevent escape of gas from the system. The cap 204 may also be equipped with external threads 218 so as to allow the device 200 to be removably mounted to the fixture 100 (Figures 1A-B). Alternatively, the device 200 can be equipped with a quick connect fitting or some other type of fitting that allows the device 200 to be removably mounted to the fixture 100. Such a fitting should provide a liquid seal to prevent escape of liquid from the system. The fixture 100 is preferably equipped with corresponding fittings to those of the device 200, (e.g., threaded or quick connect) so that the device 200 can be easily removed and replaced in the fixture 100.

[0030] Figures 3A-E illustrate a process of manufacturing a modular device for infusing gas into a liquid in accordance with an embodiment of the present invention. Referring to Figure 3A, a plurality of the microporous hollow fibers 202 are obtained. The microporous hollow fibers 202 are preferably arranged in a bundle and surrounded by the mesh 216. Additionally, an inner cap 302 (also referred to herein as a potting cup) is obtained.

[0031] As shown in Figures 3B-C, ends of the microporous hollow fibers 202 are inserted into the potting cup 302. In Figure 3B, the potting cup 302 is shown cut away (in sectional view) for illustrative purposes such that the ends of the microporous hollow fibers 202 can be seen within the potting cup 302. The microporous hollow fibers 202 may be folded or looped such that both ends of the fibers are inserted into the potting cup 302. Alternatively, ends 214 of the microporous hollow fibers that are opposite to those inserted into the potting cup 302 may be sealed or otherwise closed. In either case, all of the open ends are preferably inserted into potting cup 302. In Figure 3C, the potting cup

302 is shown not cut away such that the ends of the microporous hollow fibers 202 are obscured by the potting cup 302.

[0032] Potting compound can then be added into the potting cup 302. This is preferably performed such that the potting compound fills any voids between the fibers 202, secures the mesh sleeve 216 and the fibers 202 to each other and to the potting cup 302. The potting compound can be for example, epoxy or other suitable material. The potting compound is preferably added after the fibers 202 and mesh 216 are inserted into the potting cup 302 though the potting compound can alternatively be added to the potting cup 302 before the fibers 202 and mesh 216 are inserted.

[0033] A portion of the potting cup 302 and ends of the fibers 202 are then removed to expose open ends 304 of the microporous hollow fibers 202. This can be accomplished by cutting through the potting cup 302 and fibers 202. The result after the removal is shown in Figure 3D. Referring to Figure 3D, a remaining portion of the potting cup 302 (also referred to herein as the inner sleeve 210) surrounds the microporous hollow fibers 202. This step ensures that the ends of the fibers 202 are open for receiving gas and are not clogged with potting compound or some other substance.

[0034] The remaining portion of the potting cup 302 is then attached to a means for removably mounting the modular device to a fixture. This can be accomplished by inserting sleeve 210 into an outer cap 208 (also shown in Figures 1A-B). The outer cap 208 can be, for example, press-fit or glued to the sleeve 210 so that they are permanently mated together. Figure 3E shows the sleeve 210 after having been inserted into the outer cap 208. Also shown in Figure 3E is the opening 206 in the cap 208 for receiving gas into the device 200. In an embodiment, a cavity 306 is present between the outer cap 208 and the cut ends of the fibers 202. This cavity 306 provides a pathway for gas received into the opening 206 to enter the open ends of the fibers 202.

[0035] Figures 4A-C illustrate a cap component of a modular device for infusing gas into a liquid in accordance with an embodiment of the present invention. More particularly, Figure 4A shows a top view of the outer cap 208, while Figure 4B shows a side view of the cap 208. Figure 4C shows a side sectional view through a section 4C-4C shown in Figure 4A. Figures 4A and 4C show the opening 206. Figure 4B shows the threads 218. As is also shown in Figures 4A-B, the cap 208 may have a hexagonal shape

so that the cap 208 can be tightened and loosened with a wrench for mounting in the fixture 100. Figure 4C illustrates the cavity 306 which is connected to the opening 206 for allowing gas to enter the cap 208 and to enter the microporous hollow fibers 202 via the cavity 306. As is also shown in Figure 4C, the cap 208 may be equipped with a shoulder 308. The shoulder 308 may engage with the sleeve 210 when the sleeve 210 is inserted into the cap 208 so as to provide a positive stop for the sleeve 210 and to aid with sealing the cap 208 and sleeve 210 together.

[0036] Figure 5 illustrates an alternative system for infusing gas into a liquid in accordance with an embodiment of the present invention. The system of Figure 5 is similar to that of Figures 1A-B except that the housing 402 of Figure 5 is configured to accept twelve of the modular devices 200. Additionally, Figure 5 shows that the modules 200 are mounted such that a longitudinal axis of the modules 200 is at an angle of less than 90 degrees with outer walls of the housing (unlike the system of Figures 1A-B in which a longitudinal axis of the devices 200 are mounted at 90 degrees with respect to walls of the housing). The housing 402 may be equipped with end caps as in Figures 1A-B though they are not shown in Figure 5.

[0037] Figure 6 illustrates a submersible system for infusing gas into a liquid in accordance with an embodiment of the present invention. As shown in Figure 6, a modular device 200 is removably mounted to a submersible fixture 502. The device 200 and submersible fixture 502 can be submerged in a liquid 504 within a container 506. In this example, the submersible fixture 502 is tubular or cylindrical and is configured to accommodate mounting of a single device 200 at one end of the tube or cylinder. The submersible fixture 502 is preferably gas and liquid permeable. For example, the fixture can be comprised of mesh or perforated material. Additionally, an end opposite to the one in which the device 200 is mounted can be open or covered with mesh or perforated material. An assembly of the submersible fixture 502 and the device 200 mounted thereto is preferably heavier than the liquid displaced so that the assembly sinks rather than floats in the liquid. Weights can be added to achieve this. A tether 508 can be used to suspend the assembly within the container 506. Also shown in Figure 6, a hose 510 can be connected to the device 200 for providing gas to the device 200.

[0038] In operation, liquid 504 in the container 506 comes in contact with the microporous hollow fibers of the device 200 and becomes infused with gas received via the hose 510. The liquid will tend to circulate through the permeable walls of the fixture and within the container 506 due to the gas infusion action, as well as due to other influences, such as filling and emptying of the container 506.

[0039] It will be apparent that other shapes of submersible fixtures can be utilized and that the submersible fixture 502 can be configured to accommodate a plurality of modules 200.

[0040] Figure 7 illustrates an alternative submersible system for infusing gas into a liquid in accordance with an embodiment of the present invention. As shown in Figure 7, a modular device 200 is removably mounted to a submersible fixture 602. The submersible fixture 602 is mounted to the outlet of a submersible agitation pump 604. An assembly which includes the device 200, the submersible fixture 602 and the pump 604 can be submerged in a liquid 606 within a container 608. In this example, the submersible fixture 602 is tubular and is configured to accommodate mounting of a single device 200 at one end of the tube. The outlet of the pump 604 is mounted to the other end of the tubular structure of the fixture 602. The submersible fixture 502 is preferably gas and liquid permeable. For example, the fixture can be comprised of mesh or perforated material. Also shown in Figure 6, a hose 610 can be connected to the device 200 for providing gas to the device 200. In operation, the pump 604 draws liquid from the container 608 and directs the liquid into the end of the fixture 602 where it encounters the device 200 and becomes infused with gas received via the hose 610. The infused gas can then exit the fixture 602 through the mesh or perforated walls of the fixture 602 and mix with liquid in the container 608. Arrows in Figure 7 show generally the direction of liquid flow within the fixture 602. It will be apparent that other shapes of submersible fixtures can be utilized and that the submersible fixture 602 can be configured to accommodate a plurality of modules 200. Additionally, it will be apparent that the pump 604 or a portion of the pump 604, such as its motor, can be mounted outside of the container 608.

[0041] The foregoing detailed description of the present invention is provided for the purposes of illustration and is not intended to be exhaustive or to limit the invention to

the embodiments disclosed. Accordingly, the scope of the present invention is defined by the appended claims.

Claims

What is claimed is:

- 1 1. A modular device for infusing gas into a liquid comprising:
2 a plurality of microporous hollow fibers; and
3 a cap covering open ends of the microporous hollow fibers and the cap
4 being configured to receive a gas into an opening and to deliver the gas into the
5 open ends of the microporous hollow fibers, and the cap being configured to
6 removably mount the modular device to a fixture.
- 1 2. The modular device according to claim 1, further comprising a potting
2 compound configured to adhere the microporous hollow fibers to the cap.
- 1 3. The modular device according to claim 1, wherein the cap comprises:
2 a sleeve that surrounds the open ends of the fibers wherein the potting
3 compound adheres the microporous hollow fibers to the sleeve; and
4 a plug attached to the sleeve and the plug having a means for mounting the
5 modular device to the fixture.
- 1 4. The modular device according to claim 3, wherein the plug comprises the
2 opening in the cap.
- 1 5. The modular device according to claim 3, wherein the means for mounting
2 the modular device to the fixture comprises tapered threads.
- 1 6. The modular device according to claim 3, wherein the means for mounting
2 the modular device to the fixture comprises a quick connect fitting.
- 1 7. The modular device according to claim 1, wherein the opening in the cap
2 is threaded.

1 8. The modular device according to claim 1, wherein the opening in the cap
2 is configured to accept a quick connect fitting.

1 9. The modular device according to claim 1, wherein the microporous hollow
2 fibers are looped such that the cap covers two open ends of each of the
3 microporous hollow fibers.

1 10. A method of manufacturing a modular device for infusing gas into a liquid
2 comprising:

3 inserting ends of a plurality of microporous hollow fibers into a potting
4 cup;

5 adding potting compound into the potting cup;

6 cutting through the potting cup and fibers to expose open ends of the
7 microporous hollow fibers and thereby a remaining portion of the potting cup
8 surrounds the microporous hollow fibers;

9 attaching the remaining portion of the potting cup to a means for
10 removably mounting the modular device to a fixture.

1 11. The method according to claim 10, wherein the means for mounting
2 further is configured to receive a gas into an opening and to deliver the gas into
3 the open ends of the microporous hollow fibers.

1 12. The method according to claim 11, wherein the means for mounting
2 comprises tapered threads for mounting the modular device to the fixture.

1 13. The method according to claim 11, wherein the means for mounting
2 comprises a quick connect fitting for mounting the modular device to the fixture.

1 14. The method according to claim 11, wherein the opening in the means for
2 mounting is threaded.

1 15. The method according to claim 11, wherein the opening in the means for
2 mounting is configured to accept a quick connect fitting.

1 16. The method according to claim 11, wherein the microporous hollow fibers
2 are looped such that cutting through the potting cup and fibers to exposes two
3 open ends of each fiber.

1 17. A method of using a modular system for infusing gas into a liquid
2 comprising:
3 removably mounting one or more modular devices to a fixture, wherein
4 each modular device comprises a plurality of microporous hollow fibers and an
5 opening configured to receive a gas and is configured to deliver the gas into open
6 ends of the microporous hollow fibers, and wherein the fixture comprises a
7 hollow cavity, a first opening configured to receive a liquid, and a second opening
8 configured to discharge the liquid infused with the gas, wherein when the one or
9 more modules are mounted to the fixture, the microporous hollow fibers are
10 within the hollow cavity;
11 introducing gas into the opening of each of the modular devices; and
12 introducing liquid into the first opening of the fixture.

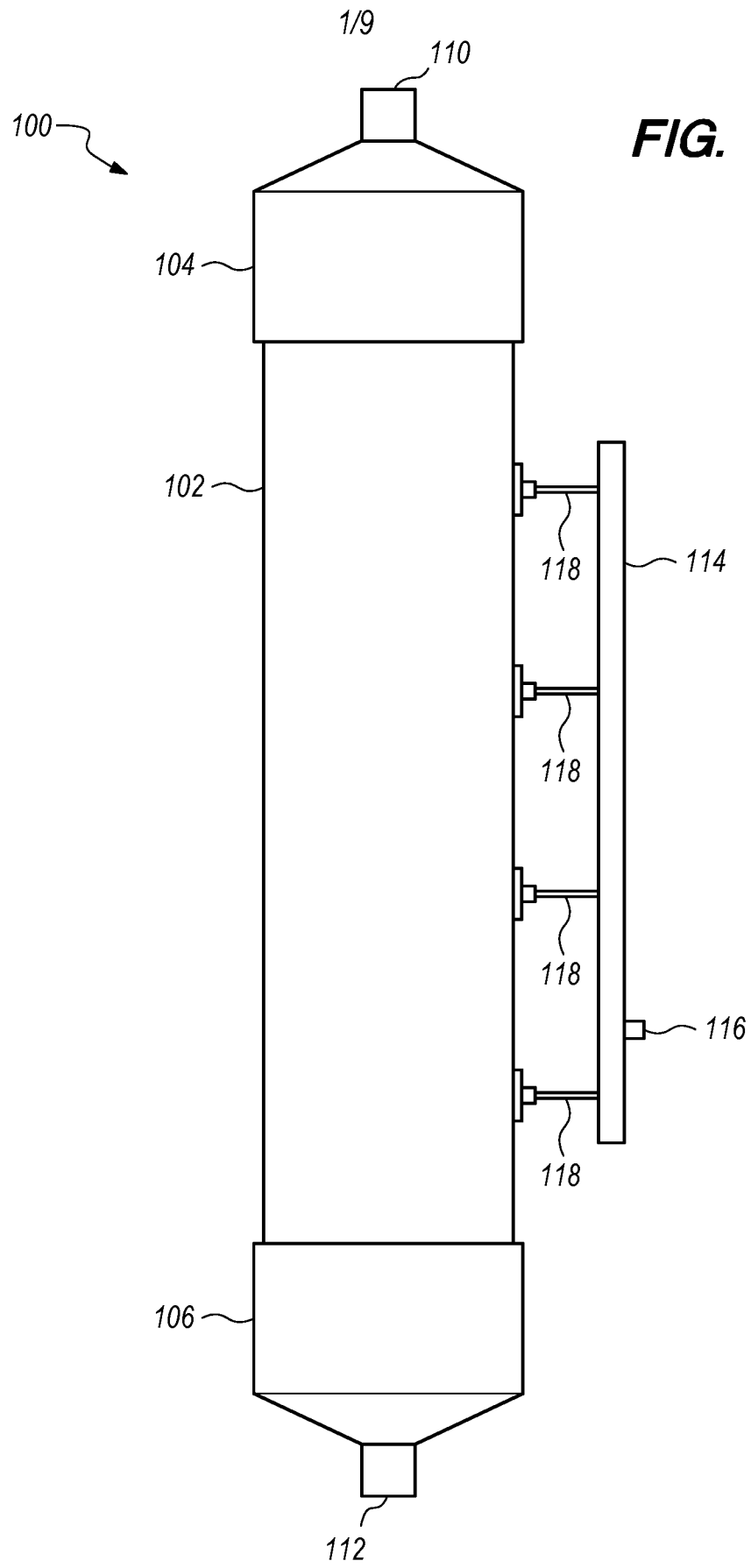
1 18. The method according to claim 17, wherein the gas is primarily oxygen
2 and the liquid is primarily water.

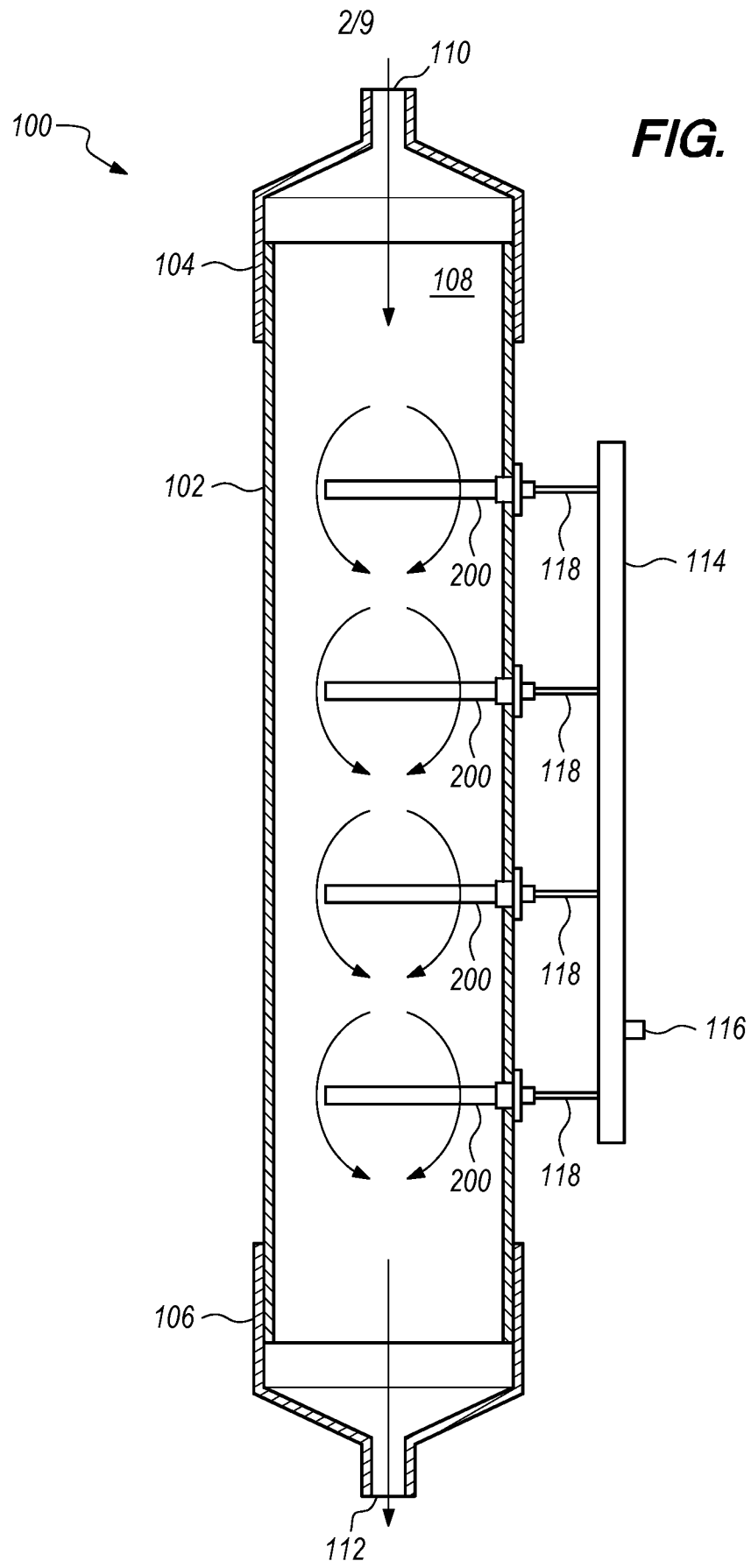
1 19. The method according to claim 17, further comprising maintaining a
2 pressure of the gas higher than a pressure of the liquid.

1 20. The method according to claim 17, further comprising removing one or
2 more of the modular devices and replacing the removed modular devices with
3 replacement modular devices.

- 1 21. A modular system for infusing gas into a liquid comprising:
2 a fixture; and
3 one or more modules, each module comprising:
4 a plurality of microporous hollow fibers; and
5 a cap surrounding open ends of the microporous hollow fibers and
6 the cap being configured to receive the gas into an opening and to
7 deliver the gas into the open ends of the microporous hollow
8 fibers, and the end cap being configured to removably mount the
9 module to the fixture.
- 1 22. The modular system according to claim 21, wherein the fixture comprises:
2 a hollow cavity;
3 a first opening configured to receive a liquid; and
4 a second opening configured to discharge the liquid infused with a gas.
- 1 23. The modular system according to claim 22, wherein when the one or more
2 modules are mounted to the fixture, the microporous hollow fibers are within the
3 hollow cavity.
- 1 24. The modular system according to claim 21, wherein the system is
2 submersible in the liquid.
- 1 25. The modular system according to claim 24, further comprising a
2 submersible pump mounted within a container wherein the submersible pump is
3 configured to draw liquid from the container and to direct the liquid into the
4 fixture.
- 1 26. The modular system according to claim 21, wherein the fixture comprises
2 one or more receptacles configured to removably receive the one or more
3 modules.

- 1 27. The modular system according to claim 26, wherein the one or more
2 receptacles comprise a threaded fitting.
- 1 28. The modular system according to claim 26, wherein the one or more
2 receptacles comprise a quick connect fitting.
- 1 29. The modular system according to claim 21, further comprising a manifold
2 configured to deliver the gas to the opening of the cap of each module.
- 1 30. The modular system according to claim 29, further comprising a gas
2 pressure regulator.
- 1 31. The modular system according to claim 21, comprising at least two of the
2 modules.





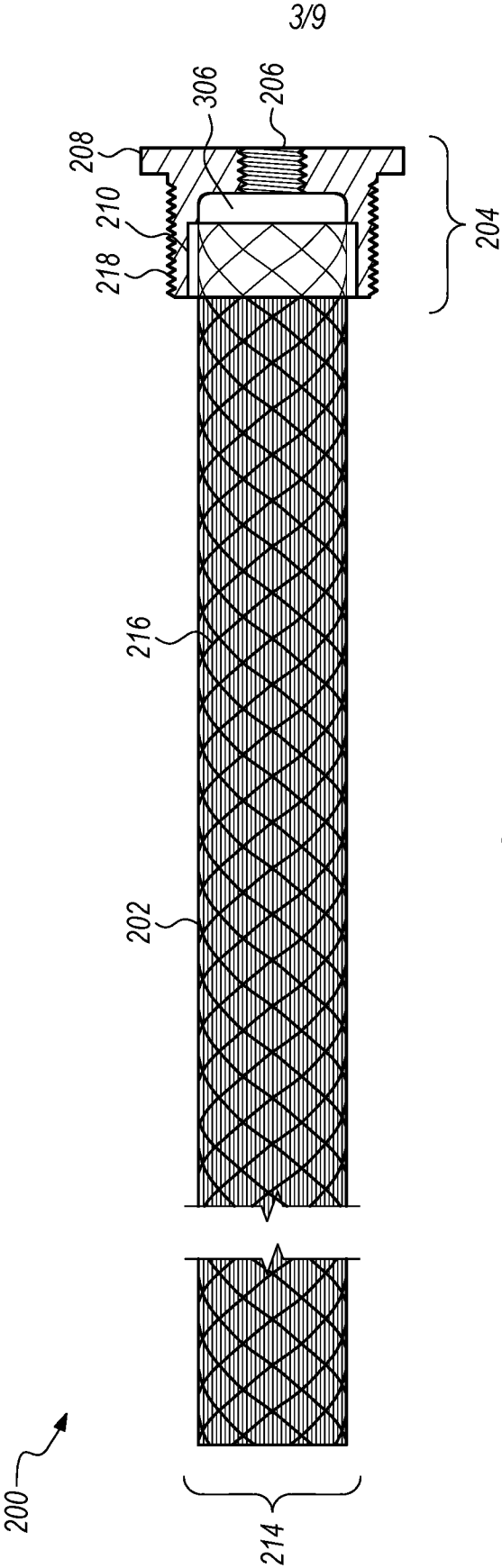
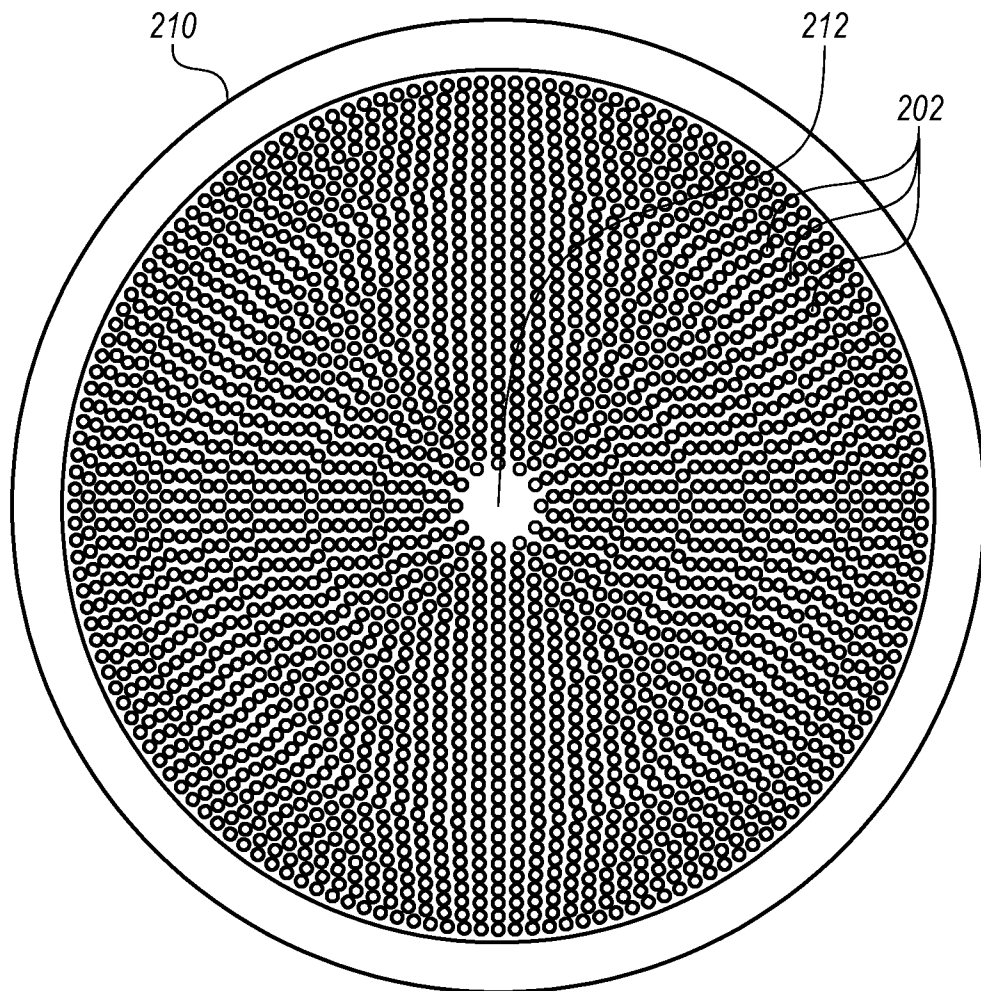


FIG. 2A

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**FIG. 2B**

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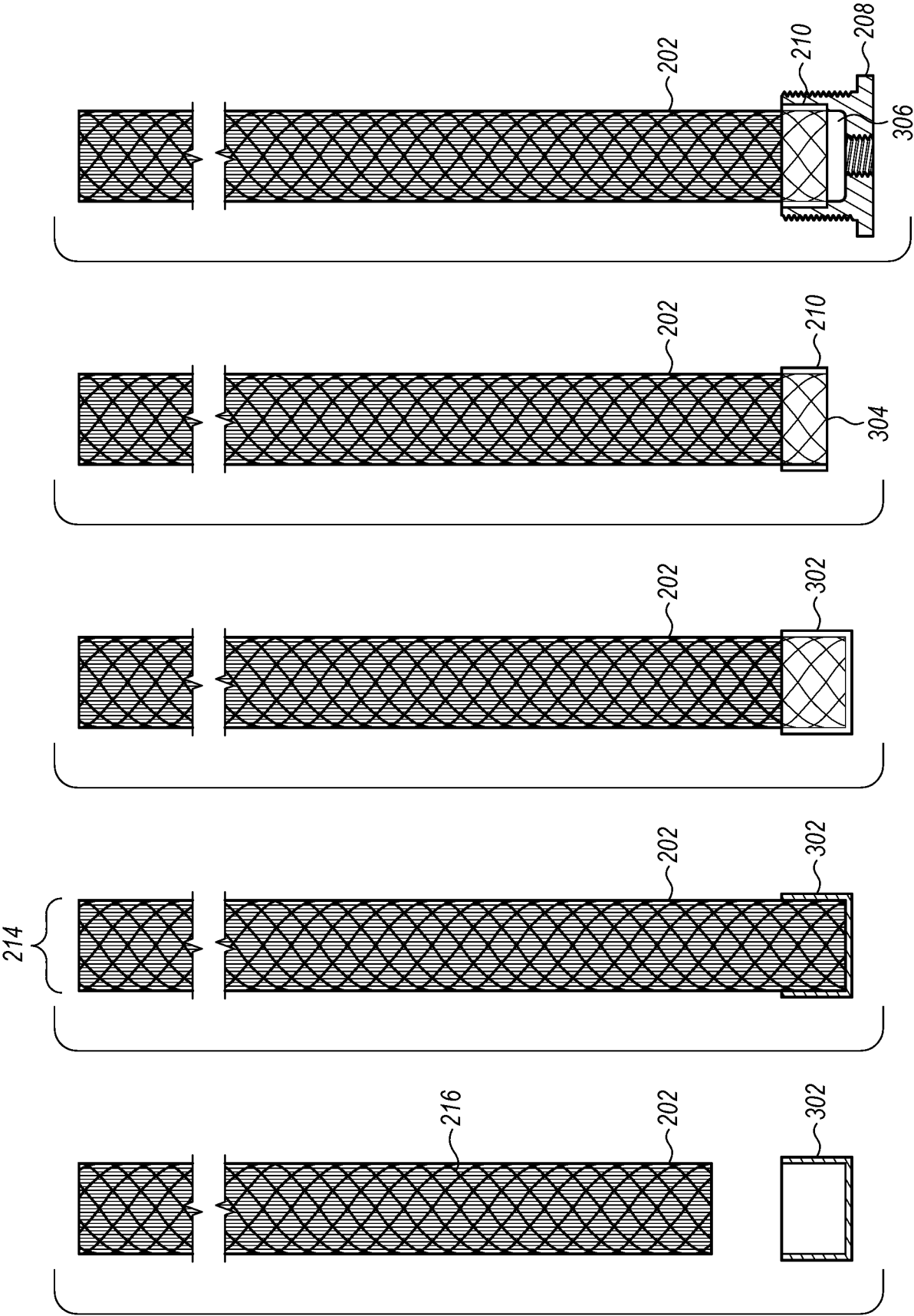


FIG. 3E

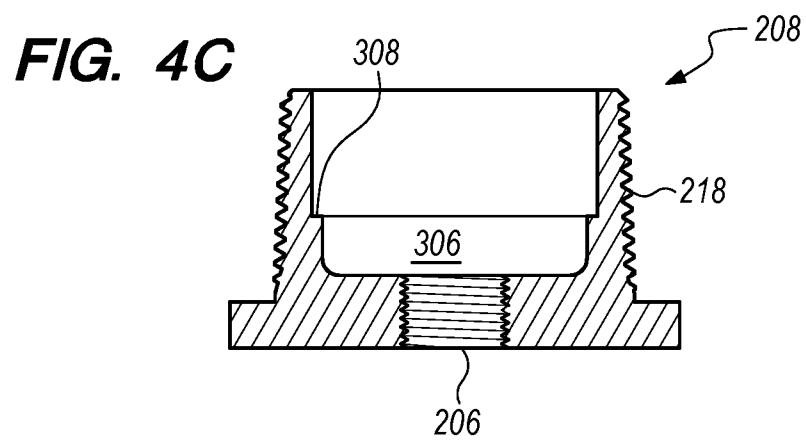
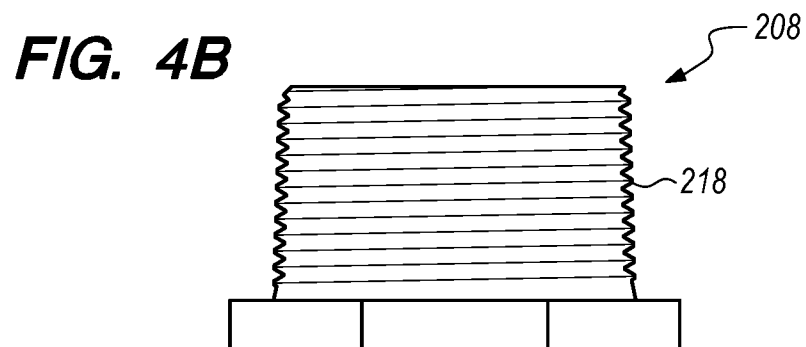
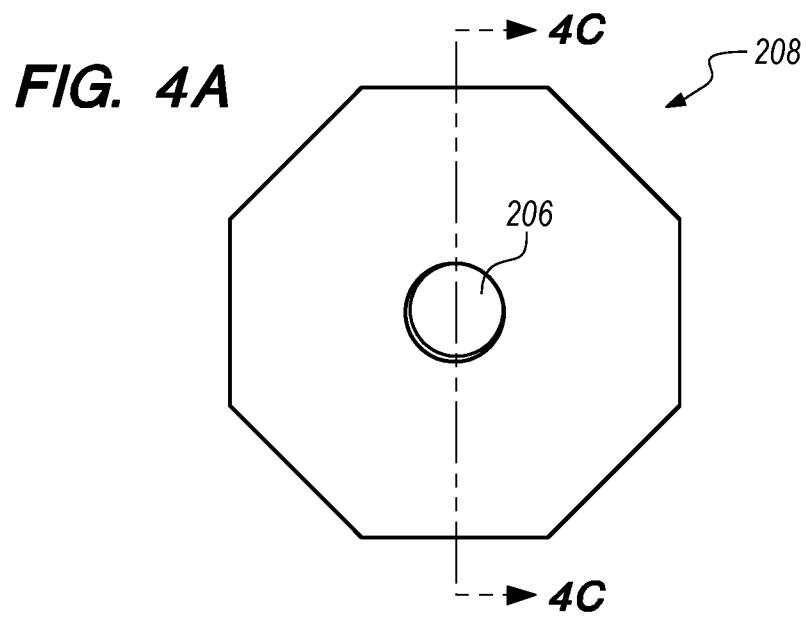
FIG. 3D

FIG. 3C

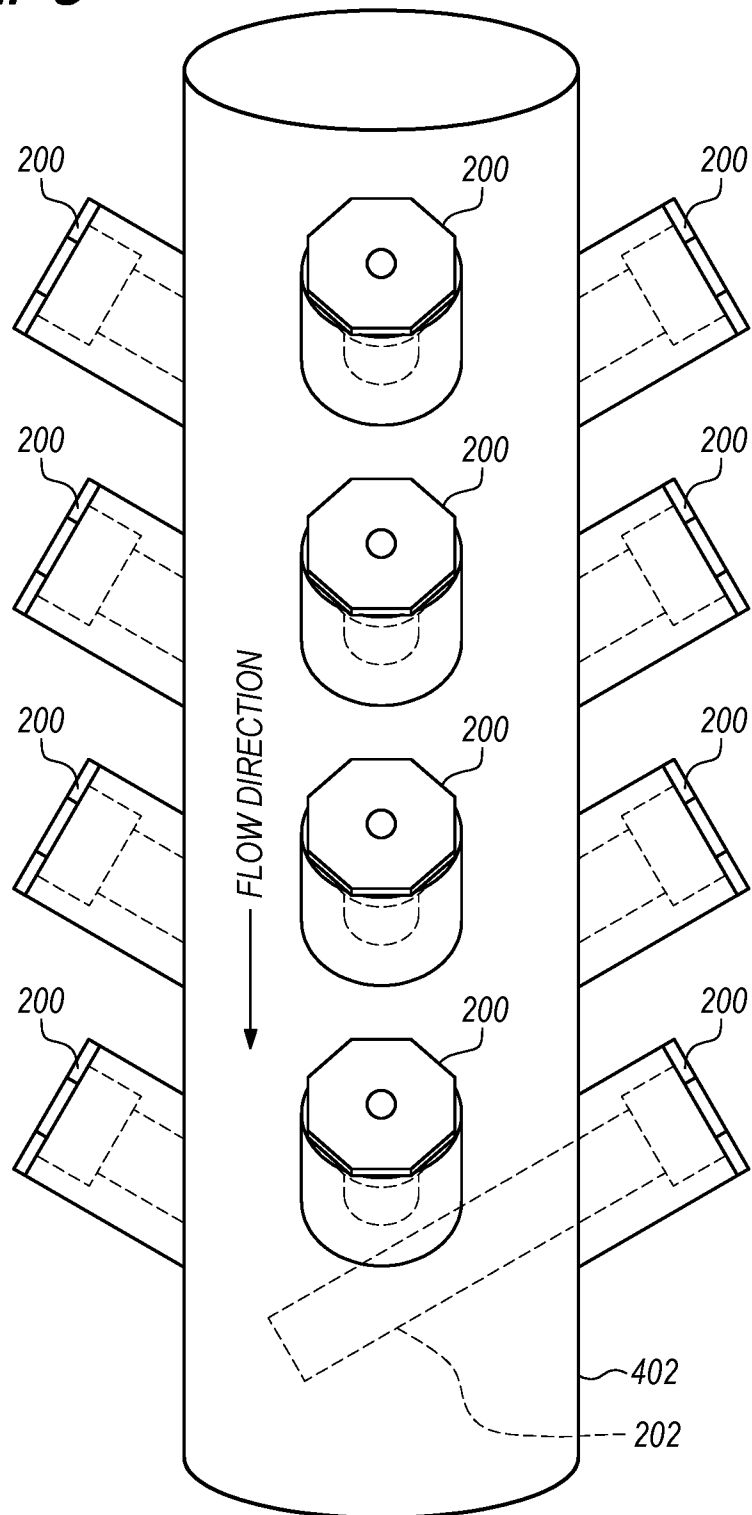
FIG. 3B

FIG. 3A

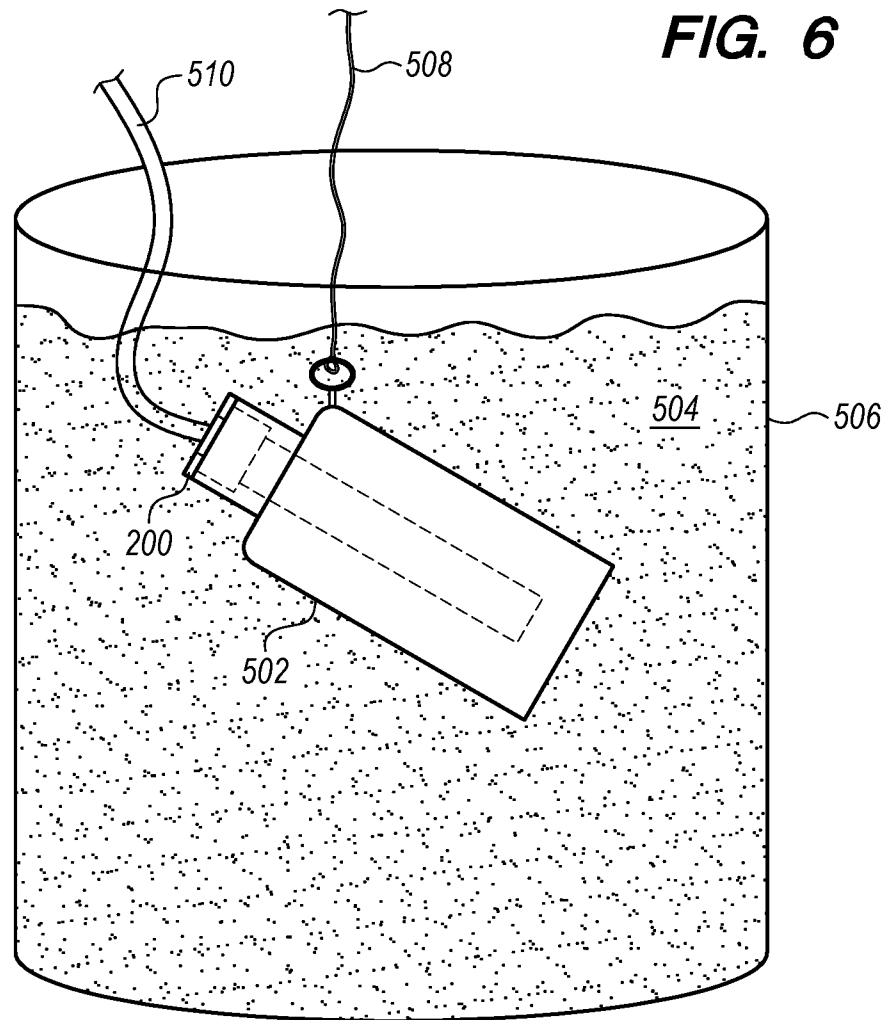
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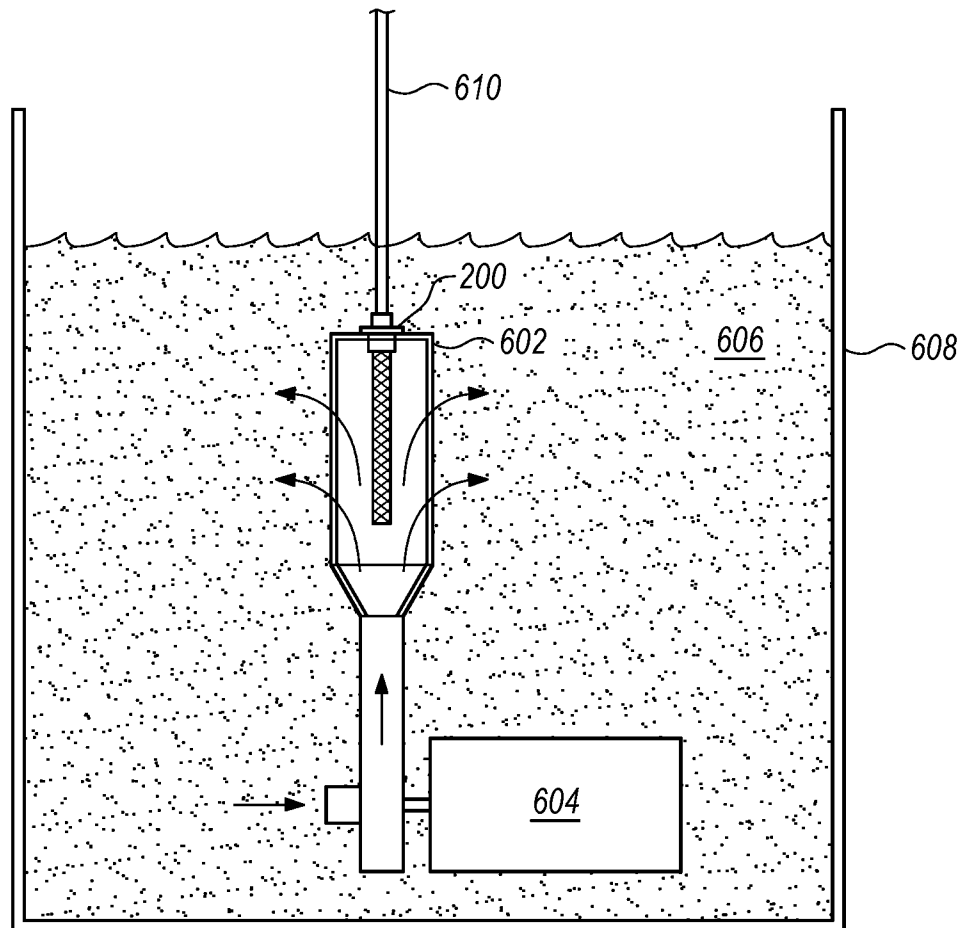
FIG. 5

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FIG. 7



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/22127

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B01D 35/30, B01D 61/18, B01D 61/20, B01D 63/02, B01D 63/04, B01D 65/00 (2019.01)
 CPC - B67D 1/0057, B01D 63/024, B01D 2313/06, B01D 2313/125, B01D 2313/13, B01D 2313/21, B01D 2313/54, B01D 65/08

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)

See Search History Document

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

See Search History Document

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

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/0188339 A1 (MURKUTE et al.) 30 September 2004 (30.09.2004), entire document	1-4, 6, 8, 10-11, 13, 15, 17-24, 26-29, 31
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Y		25, 30
X	US 4,975,247 A (BADOLATO et al.) 4 December 1990 (04.12.1990), entire document	1, 5, 7, 9-12, 14, 16
Y	US 6,511,602 B1 (MIYASHITA et al.) 28 January 2003 (28.01.2003), entire document	25
Y	US 4,931,186 A (FORD et al.) 5 June 1990 (05.06.1990), entire document	30
A	US 4,389,363 A (MOLTHOP) 21 June 1983 (21.06.1983), entire document	1-31
A	US 6,149,817 A (PETERSON et al.) 21 November 2000 (21.11.2000), entire document	1-31
A	US 2001/0027950 A1 (RABIE et al.) 11 October 2001 (11.10.2001), entire document	1-31
A	US 2006/0175243 A1 (MAHENDRAN et al.) 10 August 2006 (10.08.2006), entire document	1-31

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

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

8 MAY 2019

Date of mailing of the international search report

31 MAY 2019

Name and mailing address of the ISA/US

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