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(54) **Title**: GRAYWATER SEPARATION DEVICE

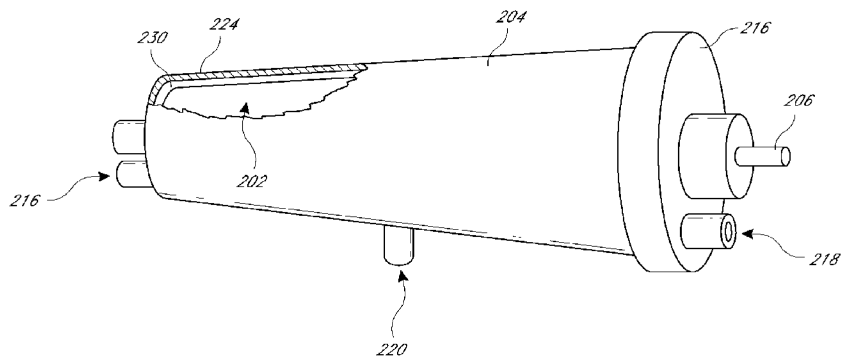

FIG. 3

(57) **Abstract**: Embodiments of the present disclosure are directed to a device and method for the filtration of gray water from a household. In some embodiments, the gray water can be filtered using a conical rotor and filtration media, which can provide enhanced filtration through the use of Taylor vorticity filtration. The filtered water can have various uses back in the household after filtration.

WO 2013/181426 A2

GRAYWATER SEPARATION DEVICE

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

[0001] Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57.

CROSS-REFERENCE TO RELATED APPLICATIONS

[0002] This application claims priority to U.S. Provisional Application No. 61/654,735, filed on June 1, 2012. This application is related to U.S. Patent No. 7,425,265, U.S. Patent No. 7,220,354, U.S. Patent No. 7,374,677, and U.S. Publication No. 2011/0190495, all of which are incorporated by reference herein in their entireties.

BACKGROUND

Field

[0003] Aspects of the present disclosure relate to using a conical-shaped rotor inside a conical-shaped housing to perform Taylor vorticity-enhanced filtration of gray water.

Description of the Related Art

[0004] One of the challenges in any type of filtration process, including filtration of gray water, is filter clogging, scientifically described as "concentration polarization." As a result of the selective permeability properties of the filtration membrane, the filtered material that cannot pass through the membrane becomes concentrated on the surface of the membrane. This phenomenon is illustrated in the case of a "dead-end" filter, such as a coffee filter. During the course of the filtration process, the filtered material (coffee grounds) building up on the filter creates flow resistance to the filtrate, the fluid (coffee), which can pass through the filter. Consequently, filtrate flux is reduced and filtration performance diminishes.

[0005] Various solutions to the problem of concentration polarization have been suggested. These include: increasing the fluid velocity and/or pressure (Merin *et al.*, (1980) *J. Food Proc. Pres.* 4(3):183-198); creating turbulence in the feed channels (Blatt *et al.*, Membrane Science and Technology, Plenum Press, New York, 1970, pp. 47-97); pulsing the feed flow over the filter (Kennedy *et al.*, (1974) *Chem. Eng. Sci.* 29:1927-1931); designing flow paths to create tangential flow and/or Dean vortices (Chung *et al.*, (1993) *J. Memb. Sci.* 81:151-162); and using rotating filtration to create Taylor vortices (see e.g., Lee and Lueptow (2001) *J. Memb. Sci.* 192:129-143 and U.S. Pat. Nos. 5,194,145, 4,675,106, 4,753,729, 4,816,151, 5,034,135, 4,740,331, 4,670,176, and 5,738,792), all of which are incorporated herein in their entirety by reference thereto).

[0006] One application of the Taylor vorticity-enhanced filtration technology (herein referred to as "T-V technology") is in the separation of human blood into cell free plasma and concentrated blood cells. The concentrated blood cells are returned to the blood donor. The cell free plasma is the commercially desired product. In some applications, the T-V technology device may operate for about 30 minutes and may then be discarded. Due to its relatively short duration of use, costs that come with the needs of longevity are avoided, and the device can be made at minimum expense. The relatively high worth of the harvested human blood cell free plasma helps to justify the cost of the single use device.

[0007] In some T-V technology used for blood separation, the filter media is on a rotor, and because of this, a rotary fluid transport seal is used. This rotary fluid transport seal allows extraction of the filtered plasma, which is rotating with the rotor, to transit to the stationary case. An inexpensive rotary fluid transport seal works well in the whole blood separation application because it only needs to operate for 30 minutes or so. However, having a rotary seal survive for years of service may be considerably more demanding and expensive.

SUMMARY

[0008] In one embodiment, a system for the filtration of gray water can comprise a filtration unit. The filtration unit can comprise a housing comprising a removable cap, an inlet port, a retentate output port and a filtrate output port, the housing further comprising a filter disposed along at least a portion of an inner wall of the housing. The filtration unit can further comprise a rotor coupled to a rotational drive means, and configured to rotate within the housing. The filtration unit can further comprise a gap between the housing and the rotor, such that rotation of the rotor within the housing generates Taylor vortices within the gap.

[0009] In another embodiment, gray water can be filtered by collecting gray water and transporting the gray water into a filtration device. The filtration device can comprise a conical housing comprising a filter, a rotor coupled to a rotational drive means, and configured to rotate within the housing, and a gap between the housing and the rotor, such that rotation of the rotor within the housing generates Taylor vortices within the gap, such Taylor vortices being sufficient to reduce filter clogging during filtration. The gray water can then be filtered while rotating the rotor within the housing, and transported to a fixture, reservoir, or system configured to utilize or store the filtered gray water.

[0010] In another embodiment, a filtration device can comprise a conical housing comprising a removable cap, an inlet port, a retentate output port and a filtrate output port, the housing further comprising a filter disposed along at least a portion of an inner wall of the housing; a motor configured to rotate a drive shaft; a conical rotor coupled to the drive shaft, and configured to rotate within the conical housing; and a gap between the housing and the rotor, such that rotation of the rotor within the housing generates Taylor vortices within the gap.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIGURE 1 illustrates a schematic diagram of an embodiment of a gray water filtration system.

[0012] FIGURE 2 illustrates an inner view of an embodiment of the housing containing the rotor and filter.

[0013] FIGURE 3 illustrates an outer view of an embodiment of the housing containing the rotor and filter.

[0014] FIGURES 4A and B illustrate outer and inner viewpoints of an embodiment of the filtration device.

[0015] FIGURES 5A-E illustrate different viewpoints of an embodiment of a housing for the filtration device.

[0016] FIGURES 6A-C illustrate different viewpoints of an embodiment of a cap.

[0017] FIGURES 7A-C illustrate different viewpoints of an embodiment of a small retention ring.

[0018] FIGURES 8A and B illustrate different viewpoints of an embodiment of a large retention ring.

[0019] FIGURES 9A-F illustrate different viewpoints of an embodiment of a rotor.

[0020] FIGURES 10A-F illustrate different viewpoints of an embodiment of a motor mount.

[0021] FIGURE 11 illustrates an embodiment of the filter with a conical shape.

[0022] FIGURE 12 illustrates a spread out schematic of a portion of the conical filter.

DETAILED DESCRIPTION

[0023] Embodiments of the present disclosure provide a gray water filtration device containing a Taylor vorticity-filtration device. Taylor vortices, also referred to herein as Taylor vorticity, can increase the mass transfer through a filter by one or two orders of magnitude. This is useful where it is desirable to remove a component of a fluid by size separation from a feed fluid. In particular, the filtration device can use Taylor vortices to filter and/or clean used water so that it can be put back to use in a home or other area.

[0024] The terms “approximately”, “about”, and “substantially” as used herein represent an amount close to the stated amount that still performs a desired function or achieves a desired result. For example, the terms “approximately”, “about”, and “substantially” may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, or within less than 0.01% of the stated amount.

[0025] The term “conical” as used herein is a broad term and includes its ordinary dictionary definition. In some embodiments, conical means that the radius varies along an axis.

[0026] Filtration can be used in the treatment of gray water. The term “gray water,” as used herein, is a broad term and includes its ordinary dictionary meaning. In some embodiments, gray water may include used water from bathroom sinks, showers and tubs, or from roof run-off from rain, for example.

[0027] In general, embodiments of the present disclosure comprise a Taylor-vorticity filtration device for filtration of gray water, and methods of filtering the gray water using the device. Embodiments of a Taylor vorticity-filtration device can be used to filter and recycle gray water from, for example, households and businesses. The filtration device could also be used to filter gray water from apartment complexes, or larger city blocks.

[0028] In some embodiments, the filtration device can comprise a filter element which filters gray water with the assistance of the Taylor vorticity-filtration. The filtered gray water can then be pumped back into the household or business for use in activities such as, for example, irrigation, toilet flushing, and some general washing.

[0029] Taylor vortices can be induced in the gap between coaxially arranged cylindrical members when the inner member is rotated relative to the outer member. Taylor-Couette filtration devices generate strong vorticity as a result of centrifugal flow instability ("Taylor instability"), which serves to mix the filtered material concentrated along the filter back into the fluid to be processed. Typically, a cylindrical filter is rotated within a stationary outer housing. It has been observed that membrane fouling due to concentration polarization is very slow compared to dead-end or tangential filtration. Indeed, filtration performance may be improved by approximately one hundred fold.

[0030] A Taylor number is a dimensionless number that relates centrifugal forces to viscous forces. When inducing fluid flow through a gap between a spinning rotor and a stationary case, at some rotational speed, centrifugal forces become powerful enough to cause vorticity in the gap. There are various formulas for the Taylor number. For example, from page 500 of Boundary Layer Theory by H. Schlichting 6^{th} ed., 1968 (McGraw-Hill), hereby incorporated by reference in its entirety:

$$\text{Taylor number} = \frac{(\text{velocity of the rotor}) \times (\text{gap}) \times (\text{gap/radius of rotor})^{1/2}}{\text{Kinematic viscosity}}$$

Where the kinematic viscosity of water is 1.0 centiStoke, 1×10^{-6} m^2/sec, 1×10^{-2} cm^2/sec, or 1 mm^2/sec.

[0031] In some embodiments, vorticity can begin when the Taylor number exceeds, for example, 30, 35, 40, 45, or 50. In some embodiments, vorticity may begin when the Taylor number exceeds 41.3.

[0032] In some applications of filtration utilizing T-V technology, there is a desire to keep the device operating for extended periods, such as, for example, multiple years. In some filtration applications, where the device is operated long enough, the filtration media may become clogged by components of the input fluid being processed. If the value of the processed fluid cannot justify a completely disposable T-V technology device, then for financial reasons, the T-V technology as described above may not be a viable option.

[0033] In certain applications, the filter unit may need to be replaced for various reasons, but replacement costs of the device are preferably low. This may occur in applications where the device is used for extended periods and where the feed fluid contains substances that will eventually clog the membrane. One example is in processing gray water for basic use such as a source of water for toilets, or for irrigation.

[0034] Common practice in the industry is to discard gray water. With the growing cost of water, and even sometimes the unavailability of water regardless of cost, there is a desire to provide methods to process this gray water so it may be used for other purposes, such as for flushing toilets and irrigating landscapes. Systems to do this could range in size, for example, appropriate for individual households, neighboring housing groups, apartments, commercial buildings, and factories small to large.

[0035] **FIGURE 1** shows a schematic diagram of an embodiment of a gray water filtration system. Gray water from, for example, a sink, shower or roof drainage **102**, can be collected and directed through a coarse pre-filter **104** and then on to a first holding reservoir **106**. The pre-filter **104** can remove large particles and debris such as, for example, toothpaste tube caps, hair, broken teeth, or the like. The pre-filter **104** can also use T-V filtration to remove some of the debris from the gray water prior to a subsequent filtering. Any number of pre-filters **104** can be used, for example subsequently smaller and smaller filters can be used to slowly remove generally large sized particles.

[0036] The reservoir **106** can be sized to collect gray water for a given period of time. For example, in some embodiments, the reservoir **106** can be sized to hold a day, a week, or a month's worth of gray water. In some embodiments, the reservoir **106** can be generally small and hold minimal water and merely act as a holding container for a brief time between filtrations. From reservoir **106**, the gray water can be transported to a T-V filtration device **108**, which is further described below. The device **108** can separate components larger than a certain size, for example about 50 or 100 μm, as determined by the particular filter media employed. The filter size is not limiting. A plurality of T-V filtration devices **108** can be used with subsequently smaller sized filter media to progressively filter the gray water. After filtering, the gray water can then be transported to a second reservoir **110**. In some embodiments, the waste **112** can be discarded from the

T-V filtration device **108.** In some embodiments, the waste **112** can be discarded from the second reservoir **110** or during transportation from the T-V filtration device **108** to the second reservoir **110**. In other embodiments, the waste **112** can be discarded prior to the gray water entering the T-V filtration device **108**. After removal of the concentrated waste **112**, the filtered gray water can be transported to devices or systems, such as for example, toilets **114**, where gray water can be used for flushing instead of fresh water. The filtered gray water can also be directed to an irrigation system **116**. The gray water can be directed to any desired location and the location and use is not limiting.

[0037] **FIGURE 1** further illustrates an embodiment of a gray water filtration system using multiple sensors. In some embodiments, sensor **118** and sensor **120** can monitor the level of water in the two reservoirs, **106** and **110** respectively. Sensor **122** can monitor the pressure, such as trans-membrane pressure, in the filtration unit **108** to prevent over or under pressurization. Preferably, the pressure can be maintained between about 10 and 200 mm Hg above the water pressure of the system if there was no device 108 in place. In some embodiments, the pressure is maintained at about 100 mm Hg. In some embodiments, the pressure can vary during operation. Accordingly, pressure is not particularly limiting. Sensor **124** can monitor the pressure of the outflow filtered gray water being directed into a home. In other embodiments, a lower or higher number of sensors may be used. The sensors can be used to monitor properties of the gray water such as, for example, pressure, filtration success, volume, viscosity, conductivity, opacity, microbe contamination, biological materials, ionic strength, pH, etc, any properties of aqueous solutions for which sensing technology exists can be monitored.

[0038] The embodiment of **FIGURE 1** also illustrates multiple pumps in the gray water filtration system. In some embodiments, two pumps can be used to transfer gray water from reservoir **106** to the T-V filtration device **108** (pump **126**) and from the T-V filtration device **108** to the second reservoir 110 (pump **128**). Pump **130** can be used to move the gray water from reservoir **110** out for use, such as in toilets **114** or out to the landscape through irrigation system **116**. In other embodiments, a lower or higher number of pumps may be used. The pressure of the pumps is also not limiting. In some embodiments, gravity, either alone or in combination with one or more pumps, can be used move water within the system, as well as into and out of the system.

[0039] **FIGURE 1** further illustrates a motor **132**. The motor **132** can be used to drive the rotor in the filtration unit **108**, as further described below. In some embodiments, an electronic controller **134** can be used. In embodiments with an electronic controller, the electronic controller **134** can receive inputs from the various sensors and control the pumps and the motors in the system. The electronic controller **134** is not limiting and can be, for example, a computer system, code for a computer program, a physical remote control, or other devices capable of sending and receiving signals. The electronic controller **134** can be, for example, connected wirelessly and may contain an antenna in some embodiments. In other embodiments, the controller **134** can be wire connected to the system, including the pumps, motor, and/or sensors. In some embodiments, the controller **134** can be used to actuate valves throughout the filtration unit filtration system, such as, for example, in the filtration device **108** and the reservoir **110**. In some embodiments, the controller **134** can control optional pumps to distribute filtered gray water among, for example, toilet fixtures **114** and irrigation systems **116**. In some embodiments, the controller **134** can be programmed to prioritize filtered gray water allocation among end uses. For example, the controller **134** can prioritize filling the toilets **114** prior to sending gray water to the irrigation system **116**, or vice versa. In some embodiments, the controller **134** can be programmed to supplement the filtered gray water with an amount of fresh water sufficient to meet an end user's demands.

[0040] The components described above need not all be used. In certain embodiments, some of these components can be removed, depending on the placement of the reservoirs and the final destination of the gray water. In other embodiments, additional components can be used. In some embodiments, gravity may be used to replace the pumps. For example, in a home containing a basement, waste gray water can flow to reservoir **106** by gravity, without using a pump. In other embodiments, a third reservoir (not illustrated), possibly with a smaller volume than the other reservoirs, could accept waste gray water from a sink, shower, or rainwater **102** prior to the first filter **104**. An additional pump could then pump the gray water from the third reservoir to reservoir **106**, which could be located on the same level as a home's toilets and shower. In some embodiments, the filtration system could be located in an attic space, or in any other part of the house.

[0041] **FIGURE 2** illustrates an embodiment of a filtration device **200** using T-V technology. In some embodiments, the shape of the rotor **202** and the housing **204** can be a conical configuration. In such configurations, the filtration device can be manufactured for ease of installation of the filtration device, further described below. In one embodiment, the housing **204** can be approximately 6 inches long with an inside diameter **201** of approximately 1.5 inches at one end, and an inside diameter **203** of approximately 2.5 inches at the opposite end. In other embodiments, the housing **204** can be other desired lengths such as, for example, approximately 12 inches, 1 foot, 5 feet, etc. In some embodiments, the diameters of the housing **204** can be approximately 0.5 inches, 5 inches, 10 inches, 1 foot, 2 feet, etc. The size of the housing **204** is not limiting. The rotor can be supported axially on either end by a drive axle **206**. On the end with the smaller diameter **201** of the housing **204**, the drive axle **206** can be supported by a conventional roller bearing **208** fixed to the housing **204**. On the end with the larger diameter **203** of the housing **204**, the drive axle **206** can be supported by a seal **210** and roller bearing **212** fixed in a housing cap **214**. The seal **210** can prevent fluid from leaking around the axle **206**. The axle **206** can extend through the housing cap **214** and can connect to a motor used to spin the rotor **202** inside the housing **204**. The housing **204** and housing cap **214** can contain multiple fluid ports, as shown in **FIGURE 2**, although the number of fluid ports is not limiting. An inlet port **216** on the smaller diameter end **201** can be located for the waste gray water to enter the filtration device **200**. A retentate output port **218** on the larger diameter end **203** can be located where a small percentage, for example approximately 5%, of concentrated retentate can be output from the device **200**. A filtered gray water output port **220** can be located between the smaller diameter end **201** and the larger diameter end **203** and configured so the filtered gray water can be output from the device **200**.

[0042] The taper angle of the rotor **202** and the inside of the housing **204** can be equal. In the embodiment of **FIGURE 2**, the taper angle is approximately 4.76 degrees. In other embodiments, the taper angle can be approximately 3 degrees, 4 degrees, 5 degrees, 6 degrees, 7 degrees, etc. The taper angle is not limiting. In some embodiments, the taper angle can change. With the 4.76 degree taper angle, the gap **222** between the rotor **202** and a filter assembly **224** can be approximately 0.050 inches. In other embodiments, the gap **222** can be approximately 0.010 inches, 0.1 inches, 0.2 inches, 1 inch, etc. The size of the gap **222** is not limiting. In some embodiments, the size of the gap **222** can change. The filter assembly **224** can comprise a filter and a substrate, as described below. However, other angles and gap distances can be used and are not limiting. Because the diameter of the filtration device **200** changes at any point along the axis of the rotor **202**, the shear rate and Taylor number change as well. In some embodiments, there may be advantages in having the shear rate increase and the Taylor number decrease as the gray water travels from the inlet port **216** to the output port **220**, or vice versa. In other embodiments, there may be reason to adjust the gap **222** as the diameter changes so that the ratio of the shear rate to the Taylor number remains relatively constant. Retaining a constant Taylor number can be done by making the taper angle of the rotor **202** different from the taper angle of the housing **204**.

[0043] An advantage of the conical shape of both rotor **202** and housing **204** is that the gap **222** can be changed simply by moving the rotor **202** relative to the housing **204**. This could be accomplished by re-positioning the drive axle **206**, towards the smaller diameter end **201** or the larger diameter end **203**. In some embodiments, the fluid can travel from the inlet port **216** to the outlet ports **218/220**, wherein the radius of the housing **204** and rotor **202** increases during the travel. If the gap **222** is kept constant, increasing the radius can increase the vorticity but decrease the shear rate.

[0044] The rotor **202** can be configured such that it produces pressure differentials resulting in the flow of fluid from input to output ends of the housing **204**. The nature of the tapered rotor **202** can cause some pressure differential between the input **216** and output ports **218/220**. Greatly increased pressure differentials can be made with a device called an "impeller". An impeller can comprise a rotating element inside a chamber to increase flow of a fluid. The impeller is attached to the rotor and thus is driven to rotate with the rotor by the motor. **FIGURE 2** shows an example location where an impeller **226** could be located in some embodiments. In embodiments using an impeller **226**, an approximately 248 ml/min flow at approximately 2650 rpm can be created. In other embodiments, the impeller **226** can create approximately a 100ml/min flow, a 200ml/min flow, a 300ml/min flow, etc. In other embodiments, the impeller can be run at approximately 1000 rpm, 2000rpm, 3000rpm, etc. The flow and the rpm of the impeller are not limiting. In some embodiments an impeller can be rotated at 1800, 2650, 2750, or

3200 rpm to achieve a filtrate flow rate of 106, 142, 156, and 190 ml/min respectively, and a retentate flow rate of 42, 82, 94, and 128 ml/min respectively.

[0045] As shown in **FIGURE 2**, the housing can be made in two sections. One section, referred to as the housing cap **214**, can include the seal **210** and bearing **212** for the larger diameter end of the rotor **202**. The second section of the housing can comprise the rest of the housing **204**. The housing cap **214** can be screwed in place to the housing **204**. An O-ring seal **228** can provide a fluid tight junction between the cap **214** and the housing **204**.

[0046] The embodiment shown in **FIGURE 2** can provide a convenient way to change the filter assembly **224**, or filtration media/substrate assembly. In some embodiments, the cap **214** can be unscrewed and removed. The filtration media/substrate assembly **224** can then be removed from the housing **204**. In some embodiments, the cap **214** can be unscrewed and the housing **204** can be removed, wherein the filtration media/substrate assembly **224** can be removed from the housing **204**. Once the used filtration media/substrate assembly **224** is removed, a replacement assembly can be pushed into the housing **204** and snapped in place. Circumferential seals can engage with the circumferential grooves **230** in the housing **204**. Then the housing **204** can be screwed back onto the cap **214**, or the cap **214** can be screwed back onto the housing **204**, thus allowing the system to be started up again. In some embodiments, the controller **134** (illustrated in **FIGURE 1**) can use readings from pumps **126**, and **128**, and sensor **122** to determine when the filtration assembly **224** should be changed, and the controller **134** can be configured to alert a user with an audible or visual alarm. As described above, filtration media/substrate assembly **224** can be removed from the housing **204**, replaced, and disposed.

[0047] In some embodiments, the filtration assembly **224** can be placed on the inside wall of the stationary housing **204** surrounding the rotor **202**. Advantageously, rotary seals can be eliminated. In this embodiment, the filter assembly **224** can be held stationary, and the exit path for the filtrate is a stationary port in the case which is located downstream from the filter assembly **224**.

[0048] **FIGURE 3** illustrates an outer viewpoint of the T-V filtration device **200**, showing the location of the ports **216**, **218**, and **220**. **FIGURE 3** further illustrates a cutout portion of the housing **204**, for viewing of the rotor **202**.

[0049] **FIGURE 4A** illustrates an outside perspective of an embodiment of a T-V filtration device **400**. The device **400** can have an outer housing **402** that surrounds an internal filtration system. As shown, the housing **402** can be generally conical in shape. The housing **402** can be capped at one end by an end cap **404**. In some embodiments, the end cap **404** can be attached to a motor mount **406**. The end cap **404** can be attached to the motor mount **406** through the use of, for example, screws or welding, though the attachment means is not limiting. In some embodiments, the housing **402** can be surrounded by an attachment ring **408**. The attachment ring **408** can be tightened and loosened so that the end cap **404** can be removed and attached for changing of the filtration system inside the housing **402**. Further, the housing **402** can have a plurality of input/output ports **410/412**. The housing **402** can also be configured to support a drive axle **420**.

[0050] **FIGURE 4B** illustrates a cut-out perspective of the T-V filtration device **400**. As shown, inside the housing **402** described with respect to **FIGURE 4A** is a rotor **414,** described with respect to **FIGURES 9A-F**. There can be a gap between the rotor **414** and the housing **402**. The pair of retainer rings **416/418** is described with respect to **FIGURES 7A-C** and **8A-B**, respectively. Further, the housing **402** can be closed with an end cap **404**, described with respect to **FIGURES 6A-C**. Further, the device **400** can have a motor mount to attach a motor to the end cap **404**, described with respect to **FIGURES 10A-F**.

[0051] **FIGURES 5A-E** illustrate an embodiment of housing **402 of FIGURE 4**. **FIGURE 5A** illustrates a barrel viewpoint of the housing **402**. As shown, in some embodiments the housing **402** can contain at least one ring **502**. Ring **502** is one example for providing strength to the housing 402 to support the filtrate outlet port 412 and other support means can be used. **FIGURE 5B** illustrates a side view of the outside of the housing **402**. The housing **402** can be generally conical, and sized to contain the rotor **414** and any filtration media. The housing **402** can also have an attachment feature **506** that can be used to secure the end cap **404** onto the housing **402**, as further described below. **FIGURE 5E** illustrates a close up of the attachment piece **506**. In some embodiments, the housing **402** can be manufactured with an open front end, and a front portion **508,** shown in **FIGURE 5D**, containing the input port **410** and the drive axle **420**. As shown in **FIGURE 5C**, the front portion **508** could be integrated into the housing **402** so that they are one piece. The housing **402** can be manufacture with, for example, stainless steel or aluminum, however the material is not limiting.

[0052] **FIGURES 6A-C** illustrate different perspectives of an embodiment of the end cap **404 of FIGURE 4**. The end cap **404** can be sized and configured to fit within the housing **402** of the filtration device **400**. In some embodiments, the end cap **404** can be screwed directly into the housing **402**. In some embodiments, an attachment ring **406** can be used to hold the cap in place. In some embodiments, the end cap **404** can have an outer edge **602** along the circumference of the end cap **404**. The outer edge **602** can be configured to be inserted into a slot in the housing **402** so that the end cap **404** can be retained within the housing **402**. In some embodiments, the outer edge **602** extends partially around the circumference of the end cap **404**, or, in other embodiments, multiple outer edges **602** can be used. As shown in **FIGURE 6A**, the end cap **404** can contain at least one screw hole **604**, which can allow for attachment of a motor mount **406**. Additionally, the end cap **404** can contain a drive-axle hole **606** configured to receive a drive axle **420** Further, the end cap **404** can have a retentate output port **608**. In some embodiments, the end cap **404** can have a raised portion **610** to fit a motor. The end cap **404** can be made from, for example, stainless steel or aluminum, although the material is not limiting.

[0053] **FIGURES 7A-C** show an embodiment of a small retainer ring **416 of FIGURE 4**. The small retainer ring **416** can be configured to surround the smaller portion of the conical shaped rotor **414**. The retainer ring **416** has ridges **702** that fit within grooves formed in the housing **402** so that the ring **416** locks in place within the housing. The ring **416** can be formed from, for example, plastic or metal. In some embodiments, the small retainer ring **416** can be made of, for example, GE Plastics' ULTEM® 1000, although the material is not limiting.

[0054] **FIGURES 8A** and **8B** show an embodiment of a large retainer ring **418 of FIGURE 4**. The retainer ring **418** can be configured to surround the larger portion of the conical shaped rotor **414**. The retainer ring **418** can have a fitted edge **802** that can fit within a recess formed in the housing **402**. The ring **418** can be formed from, for example, plastic or metal. In some embodiments, the large retainer ring **418** can be made of, for example, GE Plastics' ULTEM® 1000, although the material is not limiting.

[0055] Rings **416/418** are configured to give support the filter **1150** and the substrate **1152**, described in detail below. Rings **416/418** can contain O-rings, such as those shown as **1154** in **FIGURE 11**. The rings **416/418** can be located within the housing **402** and can remain stationary. In some embodiments, a filter and/or substrate, as further described below, can be attached to the retainer rings **416/418**. In some embodiments, retainer rings may not be used at all, and the rotor **414** can be configured to fit directly into the housing **402**.

[0056] **FIGURES 9A-F** illustrate an embodiment of rotor, such as rotor **414** or **202**, although all non-limiting references will be made with respect to rotor **414**. The rotor **414** can be conical in shape and sized to fit within the housing **402**. In some embodiments, the rotor **414** can comprise a narrowed portion **902** at one end of the rotor, a conical portion **904** in the middle, and a cylindrical portion **906** at the opposite end of the narrowed portion **902**. In some embodiments, the narrowed portion **902** can be generally cylindrical, instead of conical, and configured to fit within the small retainer ring **416**. The narrowed portion **902** can have a smaller diameter than the conical portion **904**, creating a step-down feature **908** as shown in **FIGURE 9E**. On the other end of the rotor **414**, the conical portion **904** could form into the cylindrical portion **906**. Like the narrowed portion **902**, the cylindrical portion **906** can contain a similar step-up feature, or can be smoothly integrated with the conical portion **904**. The cylindrical portion **906** can have a generally cylindrical shape, and can be configured to fit within the large retainer ring **418**. The rotor **416** can further have a drive axle hole **910** through the center of the rotor for a drive axle to pass through. In some embodiments, the rotor **414** can be made of, for example, DuPont™ DELRIN® or aluminum, though the material is not limiting.

[0057] **FIGURES 10A-F** show different viewpoints of an embodiment of motor mount **406 of FIGURE 4**. The motor mount **406** can be used to attach the filtration device **200** to a motor. As previously described, the motor mount **406** can be attached to the end cap **404**. Screw holes **1002** can be drilled into the mount **406** so that the mount **406** and end cap **404** can be attached to one another. In some embodiments, the mount **406** can have a generally U-shaped hole **1004** cut out of opposite sides of the mount **406**. In some embodiments, motor mount **406** can be manufactured as a single piece. In some embodiments, motor mount **406** can be two halves attached together through, for example, screwing or welding. The motor mount **406** can be manufactured with, for example, stainless steel or aluminum, however the material is not limiting.

[0058] **FIGURE 11** illustrates the filter/filtration media assembly **224** fabricated in the approximate shape of a cone. Filter media **1150** can be located on the inside surface of the cone while a substrate **1152** can be located on the outside surface of the cone. A substrate **1152** can be used when the filter **1150** is not rigid enough to maintain a set shape, such as a cone of fixed dimensions. In some embodiments, the filter media **1150** and the substrate **1152** are fixed together. In addition, media can rest on the substrate surface **1152** that allows flow of the filtrate with minimal resistance to an exit port. In some embodiments, Genesee Scientific 57-106 NITEX® Nylon (50 micron mesh) can be used as the filter **1150** and Genesee Scientific 57-101 NITEX® Nylon (630 micron mesh) can be used as the substrate surface **1152**. In such embodiments, the 630 micron mesh, which can act as the substrate **1152**, has enough rigidity to maintain the conical shape, and it acts as a protective outer layer for the inner layer of 50 micron mesh filter, which can act as the filter **1150**. However, other filters and substrates can be used and the material is not limiting. In some embodiments, ends of the filtration media cone can be made with circumferential seals **1154** that can slip into shallow circumferential ridges **230** in the housing **204** (illustrated in **FIGURE 2**). These seals **1154** can isolate the filtered gray water on the outside surface of the filter assembly **224** (illustrated in **FIGURE 2**) with the unfiltered gray water in the inside surface, facing the rotor **202**. In some embodiments, the circumferential seals **1154** can be given increased physical integrity if stainless steel wires are embedded into them. The stainless steel wires can also aid the leak proof connection between the filter **1150** and retainer rings **216/218**. In some embodiments, the seals **1154** can be attached to the retainer rings **416/418** (illustrated in **FIGURES 6** and **7**). In some embodiments, the filter **1150** can be attached to a rotor.

[0059] The filter **1150** and substrate **1152** can be attached to the rings **216/218**, and these four components can make up the insertable/removable filter/filtration media assembly **224**. In some embodiments, the circumferential seals **1154** can produce a fluid tight seal against the housing **402** so that filtrate does not escape into the gap and so that retentate or input fluid does not enter the filtrate.

[0060] **FIGURE 12** illustrates an embodiment of the filtration media **1150** in an unwrapped position. In some embodiments, the filtration media **1150** can be approximately 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15 inches in length, preferably about 7.25 inches in length, as defined by the distance between the media **1150** at the front of the housing **204** and the back of the housing **204**. The filtration media **1150** can have a curvature of about 0.5, 1, 1.5, 2, 2.5, 3, 3.5, or 4 inches. The filtration media **1150** can be approximately 0.001 to 0.1 inches thick, for example about 0.005, 0.01, or 0.05 inches thick.. However, other dimensions can be used. For example, a much larger filtration media **350** can be used to collect a large amount of gray water from an apartment complex as compared to an individual house. In one embodiment, the filtration media **1150** can be approximately 6 inches long with a diameter of approximately 1.5 inches at one end, and a diameter of approximately 2.5 inches at the opposite end. In other embodiments, the filtration media **1150** can be other desired lengths such as, for example, approximately 12 inches, 1 foot, 5 feet, etc. In some embodiments, the diameters of filtration media **1150** can be approximately 0.5 inches, 5 inches, 10 inches, 1 foot, 2 feet, etc. The filtration media **1150** can be sized to fit in the housing **402**.

[0061] In some embodiments, the rotor and housing may not be a cone shape. The rotor and housing may be shaped to produce a gap between the rotor and housing, or filter, that varies in a non-linear fashion along the axis from inlet to outlet port, and the shape is not limiting.

Examples

[0062] The following examples are provided to demonstrate the benefits of embodiments of a filtration system as described above. These examples are discussed for illustrative purposes and should not be construed to limit the scope of the disclosed embodiments.

Example 1

[0063] A filtration media of 40 micron POREX® media's was used in an embodiment of the filtration device.

[0064] The 40 micron filtration media had ample strength, and therefore a substrate layer was not used. The filtration device was operated with an inlet flow of about 100 ml/min, and the rotor was spun at about 2600rpm. A solution of 90 g sunscreen, 60 g skin moisturizer, 195 g toothpaste, 60 g deodorant, 300 g clay, 42 g vegetable oil, 432 g shampoo, and 900 g laundry detergent was prepared for filtering (hereinafter "Gray Water Test Solution"). About 4 liters of Gray Water Test Solution was inputted into the filtration device. The filtrate flow was set to about 90 ml/min and trans-membrane pressure ("TMP") was stable from about -2 to 13 mm Hg.

[0065] In some embodiments, different filtration media can be used. For example, nylon, polyester, cellulose acetate, polycarbonate, polypropylene, polytetrafluorethylene (PTFE), regenerated cellulose, or polyethersulphone (PES) could be used. Filtration media from, for example, STERLITECH or MILLIPORE can be used. In some embodiments, media that absorbs certain contaminants can be used. For example, Pall Corporation ULTRABIND™ could be used to bind proteins. Further, a positively or negatively charged membrane could be used to bind the opposite charge molecule. In any embodiment, the contaminants could be washed out. For example, a chemical wash or an acid/base wash could be used.

<u>Example 2</u>

[0066] A filtration media of 50 micron nylon fiber (GENESEE 57-106 nylon mesh) was used in an embodiment of the filtration device. A substrate of 630 micron mesh (GENESSE 57-101) was used as a substrate where the filter media was surrounded by the substrate. Approximately 4 gallons of Gray Water Test Solution was used. The motor was set to spin the rotor at approximately 1800rpm Approximately 1200 ml/min of Gray Water Test Solution was inputted into the filtration device. Flow from the retentate port was set at about 100 ml/min with a pump. In some embodiments, a peristaltic pump can be used. The trans-membrane pressure measured varied from about 65 to about 93 mm Hg. Approximately 14 gallons were processed in about 49 minutes. There was no perceived rise in trans-membrane pressure, showing that the filter media was not being clogged by components of the Gray Water Test Solution.

<u>Further Examples</u>

[0067] Further testing was also performed on the filtration device. For example, 4oz of Bentonite Clay was added to the Gray Water Test Solution with similar positive results, where the clay was removed during filtration. Further, 50 g OPS Diagnostics' 100 micron silica beads in 6 L of water was added to the Gray Water Test

Solution, with the results showing that the filtration device was secure, as no beads were found in the filtrate.

[0068] The filter media described above was also replaced with 20 micron INDUSTRIAL NETTING WS0020 media and the rotor was rotated at a speed of about 200 rpm. The filtration device was trans-membrane pressure stable between about 123 and 95 mm Hg during about 112 minutes of running with the Gray Water Test Solution.

Taylor Number and Shear Rate

[0069] Table I below illustrates calculations for both the Taylor number and shear rate for an embodiment of a filtration device as described above. All units are in inches unless otherwise defined.

TABLE I

Housing Inner Diameter	Housing Circum.	Housing Length	Gap	Revolutions per minute (revs/min)	Revolutions per second (revs/sec)	Velocity at rotor (mm/sec)	Taylor Number	Shear Rate (1/sec)
1.58	4.96372	7.22	0.001	2000	33.3	4200	4	165373
1.58	4.96372	7.22	0.005	2000	33.3	4200	42	33075
1.58	4.96372	7.22	0.01	2000	33.3	4200	120	16537
1.58	4.96372	7.22	0.015	2000	33.3	4200	221	11025
1.58	4.96372	7.22	0.02	2000	33.3	4200	340	8269
1.58	4.96372	7.22	0.024	2000	33.3	4200	446	6891
1.58	4.96372	7.22	0.03	2000	33.3	4200	624	5512
1.58	4.96372	7.22	0.0305	2000	33.3	4200	639	5422
1.58	4.96372	7.22	0.035	2000	33.3	4200	786	4725
1.58	4.96372	7.22	0.04	2000	33.3	4200	960	4134
1.58	4.96372	7.22	0.045	2000	33.3	4200	1146	3675
2.87	8.82788	7.22	0.001	2000	33.3	7630	5	300393
2.87	8.82788	7.22	0.005	2000	33.3	7630	57	60079
2.87	8.82788	7.22	0.01	2000	33.3	7630	162	30039
2.87	8.82788	7.22	0.015	2000	33.3	7630	297	20026
2.87	8.82788	7.22	0.02	2000	33.3	7630	458	15020
2.87	8.82788	7.22	0.024	2000	33.3	7630	602	12516

2.87	8.82788	7.22	0.025	2001	33,4	7630	640	12016
2.87	8.82788	7.22	0.03	2000	33.3	7630	841	10013
2.87	8.82788	7.22	0.035	2000	33.3	7630	1059	8583
2.87	8.82788	7.22	0.04	2000	33.3	7630	1294	7510
2.87	8.82788	7.22	0.045	2000	33.3	7630	1544	6675

[0070] For reference, a device used for filtering blood, such as a PLASMACELL device operating at optical conditions has a Taylor number of about 639 and a shear rate of about 7850 1/sec. The diameter of the rotor and case of the blood filtering device is generally cylindrical. However, the diameter of the rotor and case of embodiments of the device described above is not constant, but varies between the inlet (inner diameter equals about 1.58 in) and the outlet (about 2.87 in). When the rotor spins at about 2000 RPM, a gap of about 0.0305 inches can provide a Taylor number equal to the PLASMACELL device. At the outlet, a gap of about 0.025 inches can provide a Taylor number of about 640, close to the Taylor number for the PLASMACELL device of about 639. Thus, to reproduce the PLASMACELL device, the gap could change from about 0.0305 inches at the inlet to about 0.025 inches at the outlet. Additionally, the shear rate for the PLASMACELL is about 7850 1/sec. At the inlet above, it is about 5422 1/sec. and at the outlet about 12022 1/sec.

[0071] A shear rate of about 12022 1/sec. may destroy blood cells in blood filtration, but this may be complementary to increased filtration when processing gray water. The gap and shape of the rotor can be adjusted to benefit higher filtration rates. For example, it may be beneficial to have a higher shear rate and or Taylor number at the output of the housing, as the retentate concentration is higher there (as filtrate has been removed starting at the inlet). Higher retentate concentration means a higher tendency to occlude the filter with a concentration polarization layer of retentate. Higher shear rate and or a higher Taylor number may reduce filter clogging by reducing this concentration polarization.

[0072] Another feature of the filtration device described above is that a slight shift in the axial position of the rotor in the case will change the gap. A drive motor could be mounted in such a way that it can be moved on the axis of the rotor. Should a pressure sensor measure a rising trans-membrane pressure, position control means can be used. For example, the motor can be moved closer to the filtration device, which would decrease the gap, increase the shear rate, and decrease the Taylor number. Conversely, if the motor is moved away from the filtration device described above, the rotor moves toward the outlet port, increasing the gap, decreasing the shear rate and increasing the Taylor number.

[0073] In some embodiments, the filtration device can produce Taylor numbers ranging from about 1 to 1500, such as about 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 300, 400, 500, 1000, 1100, 1200, 1300, and 1400. In some embodiments, the filtration device can produce a shear rate ranging from about 5000 to 300000 1/s, such as about 6000, 7000, 8000, 9000, 10000, 15000, 20000, 25000, 30000, 35000, 40000, 45000, 50000, and 100000 (1/sec). Preferably, the filtration device can produce a Taylor number of about 52 at the inlet and a shear rate of about 33,075 1/sec. A gap of 0.005 at the outlet can produce a shear rate of 60,079 1/sec. Other gaps can be used to produce different shear rates as well.

Example Usage of the Filtration System in a Home

[0074] In some embodiments, a reservoir can be sized to complement a household's use of water. Contemporary toilets use approximately 1.6 gallons per flush. Generally, at least 16 gallons of water per person per day can be used for flushing toilets. Therefore, a family of four may use about 64 gallons per day of gray water to operate their toilets. Additionally, typical bathroom sinks put out about 2.5 gallons per minute. Typical bathroom showers put out about 3.3 gallons per minute. A ten minute shower and two minute shave can generate about 38 gallons of gray water. Therefore, a family of four can generate about 152 gallons of gray water just getting ready to face the day, providing ample waste gray water for toilet flushing. While a reservoir can be sized to receive and hold any volume of water, any excess waste gray water can be diverted to the sewer, or it can be filtered and used for irrigation. Embodiments of a filtration device described above can be sized and configured to provide at least two times this amount of filtered gray water, assuming the filtration device operates continuously, 24 hours/day. The throughput capacity of the filtration device is at least about 330 ml/min, or about 132.5 gallons per day. In other embodiments, the capacity of the filtration device can be about 100 ml/min, 200 ml/min, 300 ml/min, 400 ml/min, etc. The capacity of the filtration device is not limiting.

[0075] In typical households, there are busy times (mornings and evenings) when most of the waste water may be created. Therefore, the reservoirs can be sized and configured to be able to handle the busy times during the day. During the quiet times, the filtration device can continue to operate to process the gray water. Advantageously, by using reservoirs to store filtered gray water, particularly sized to hold water from a full day or more, the throughput needs of the filtration device can be reduced, thus reducing its size and cost. In exchange, the filtration device can run more or less continuously between the busy times, storing up the volumes needed for toilets.

[0076] The examples listed above describe using a filtration device for a single household. However, the filtration device, as well as the other components, can be sized and configured to handle much larger or much smaller buildings, as well as groups of buildings. The filtration system could come in various sizes with various capacities, which are not limiting. Any number of filtration devices, sensors, reservoirs, pumps, etc., can be used in any number of combinations to provide filtered gray water to a community.

[0077] Those skilled in the art will appreciate that numerous changes and modifications may be made to the preferred embodiments of the disclosure and that such changes and modifications may be made without departing from the spirit of the disclosure disclosed herein. It is therefore intended that the appended claims cover all such equivalent variations as may fall within the true spirit and scope of the disclosure.

WHAT IS CLAIMED IS:

1. A system for the filtration of gray water, comprising:

a filtration unit comprising:

a housing comprising a removable cap, an inlet port, a retentate output port and a filtrate output port, the housing further comprising a filter disposed along at least a portion of an inner wall of the housing;

a rotor coupled to a rotational drive means, and configured to rotate within the housing; and

a gap between the housing and the rotor, such that rotation of the rotor within the housing generates Taylor vortices within the gap.

2. The system of Claim 1, further comprising:

an inlet conduit that fluidly couples a source of gray water to the inlet port of the housing; and

an outlet conduit that fluidly couples the filtrate output port of the housing to a fixture, reservoir, or system configured to utilize or store the filtered gray water.

3. The system of Claim 1, wherein the housing and rotor are conical.

4. The system of Claim 1, wherein the filtration unit further comprises an impeller.

5. The system of Claim 1, wherein the filtration unit is configured to output filtered gray water of a rate of at least about 330 ml/min.

6. The system of Claim 1, further comprising a plurality of reservoirs, with at least one reservoir feeding into the inlet conduit and at least one reservoir accepting gray water from the outlet conduit.

7. The system of Claim 1, further comprising at least one sensor, wherein the sensor is configured to read volume and pressure levels in the reservoirs.

8. The system of Claim 7, further comprising at least one pump, wherein the pump is configured to pass water to and from the filtration unit.

9. The system of Claim 8, wherein a controller is configured to control the at least one pump and at least one sensor

10. The system of Claim 1, wherein the filter is configured to be removed after removing the removable cap.

11. The system of Claim 2, further comprising at least one sensor operably coupled to at least one of the outlet conduit, fixture, reservoir, or system configured to utilize or store the filtered gray water, wherein the at least one sensor monitors a property of the filtered gray water.

12. The system of Claim 11, wherein the property is selected from the group consisting of pressure, filtration success, volume, viscosity, conductivity, opacity, microbe contamination, biological materials, ionic strength, and pH.

13. A method for the filtration of gray water, comprising:

collecting gray water;

transporting the gray water into a filtration device, comprising a housing comprising a filter; a rotor coupled to a rotational drive means, and configured to rotate within the housing; a gap between the housing and the rotor, such that rotation of the rotor within the housing generates Taylor vortices within the gap, such Taylor vortices being sufficient to reduce filter clogging during filtration;

filtering the gray water while rotating the rotor within the housing; and

transporting the filtered gray water to a fixture, reservoir, or system configured to utilize or store the filtered gray water.

14. The method of Claim 13, wherein the rotor and housing are conical.

15. The method of Claim 13, wherein transporting the collected gray water is facilitated by gravity.

16. The method of Claim 13, wherein transporting the collected gray water comprises pumping the gray water.

17. The method of Claim 13, further comprising transporting the collected gray water to a reservoir prior to transporting the gray water into the filtration device.

18. The method of Claim 13, further comprising monitoring a property of the filtered gray water.

19. The method of Claim 13, further comprising using controller-actuated valves with optional pumps to distribute the filtered gray water among one or more toilet fixtures and irrigation conduits.

20. The method of Claim 19, wherein the controller is programmed to prioritize filtered gray water allocation among end uses.

21. The method of Claim 19, wherein the controller is programmed to supplement the filtered gray water with an amount of fresh water sufficient to meet an end use demand.

22. A filtration device, comprising:

a conical housing comprising a removable cap, an inlet port, a retentate output port and a filtrate output port, the housing further comprising a filter disposed along at least a portion of an inner wall of the housing;

a motor configured to rotate a drive shaft;

a conical rotor coupled to the drive shaft, and configured to rotate within the conical housing;

a gap between the housing and the rotor, such that rotation of the rotor within the housing generates Taylor vortices within the gap and a shear rate.

23. The filtration device of Claim 22, wherein the filtration device further comprises an impeller.

24. The filtration device of Claim 22, wherein the conical rotor comprises a taper angle of about 3-7 degrees.

25. The filtration device of Claim 24, wherein the taper angle is approximately 4.76 degrees.

26. The filtration device of Claim 22, wherein the gap is approximately 0.010-1 inch.

27. The filtration device of Claim 26, wherein the gap is approximately 0.050 inches.

28. The filtration device of Claim 22, wherein the Taylor vorticity has a Taylor number of greater than about 41.3 and the shear rate is greater than about 5,000 1/s.

29. The filtration device of Claim 28, wherein the Taylor number is about 640 and the shear rate is about 33,000 1/s.

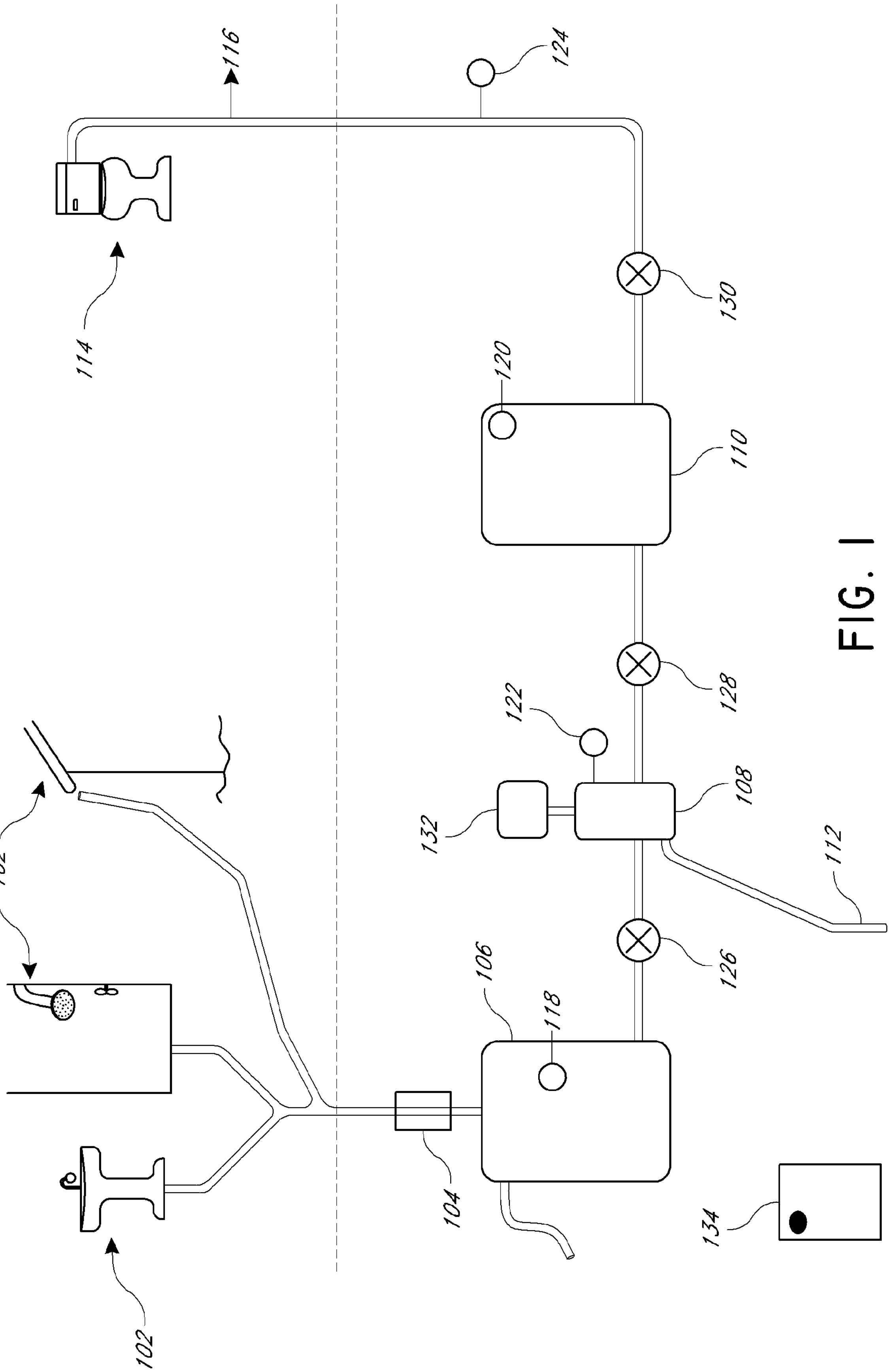
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FIG. 1

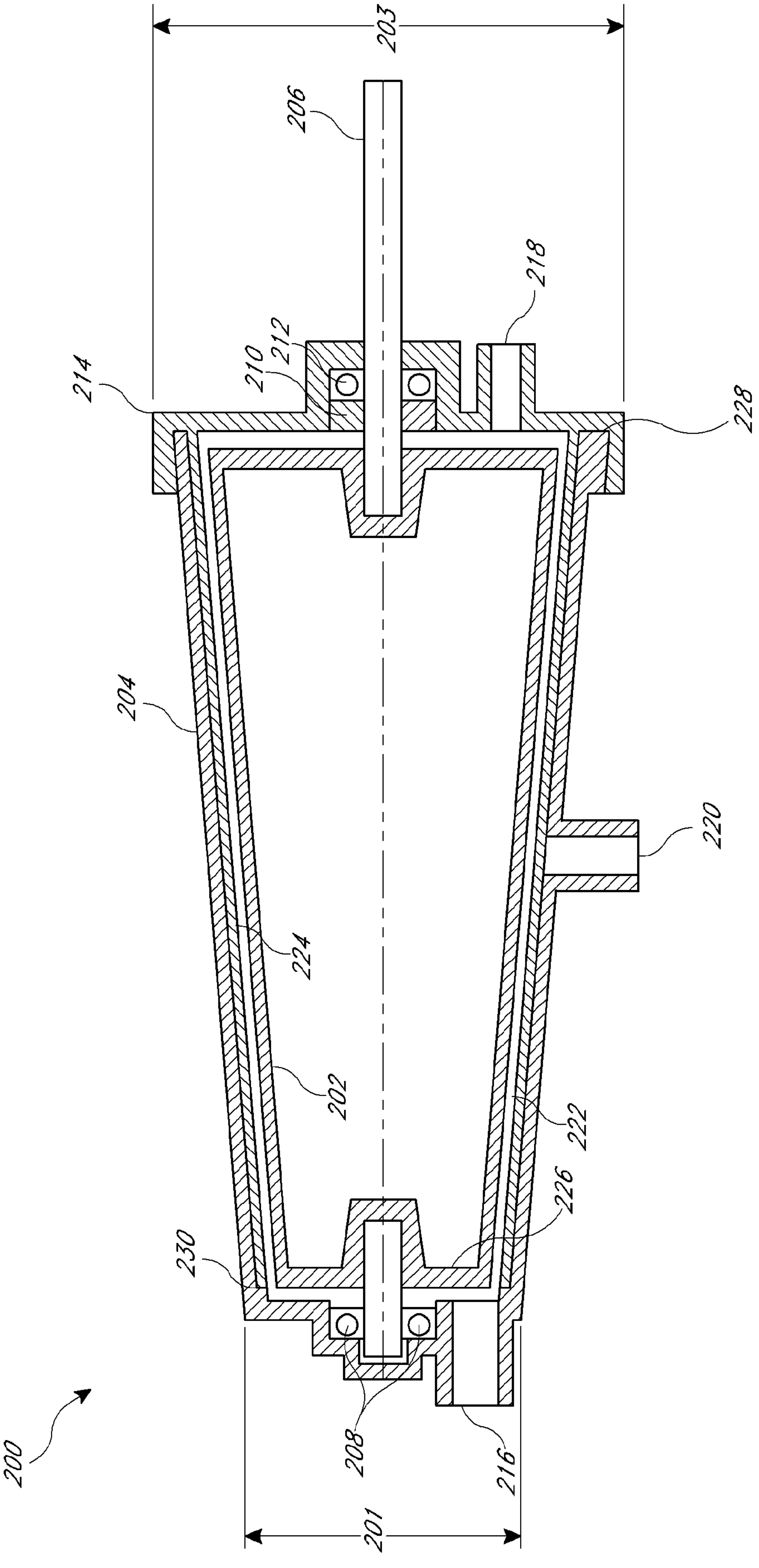
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FIG. 2

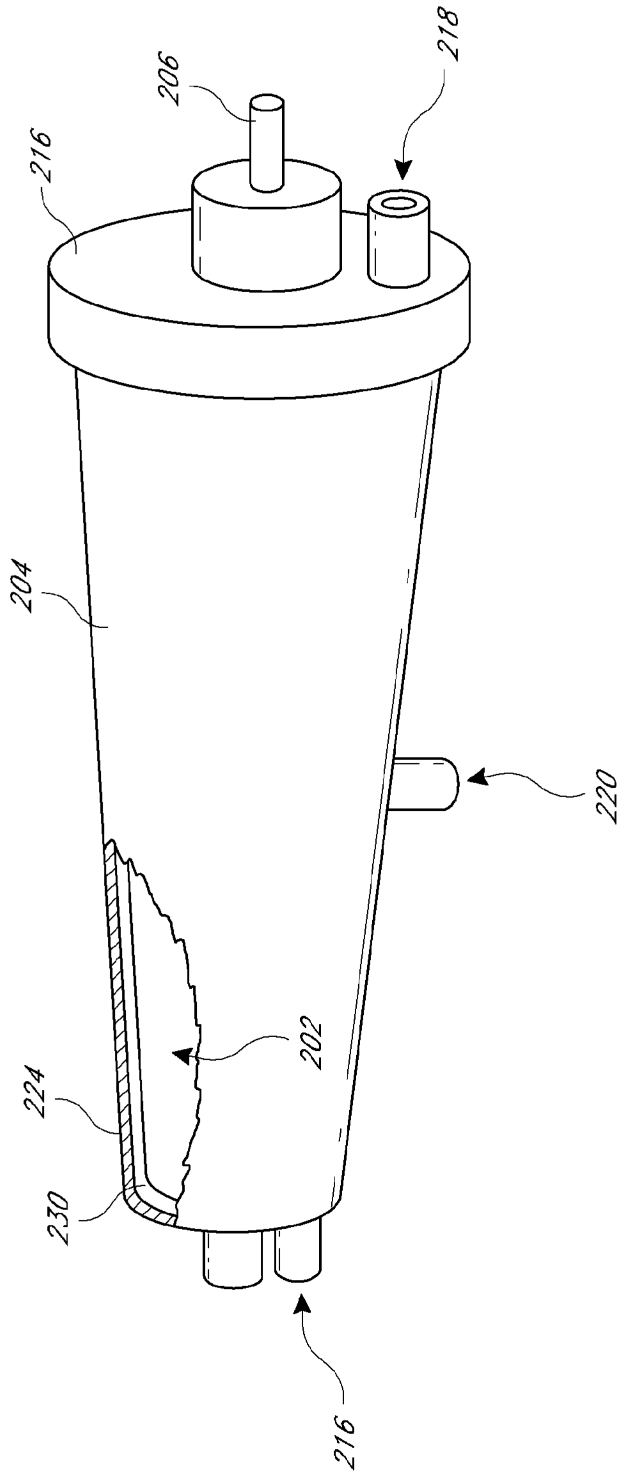

FIG. 3

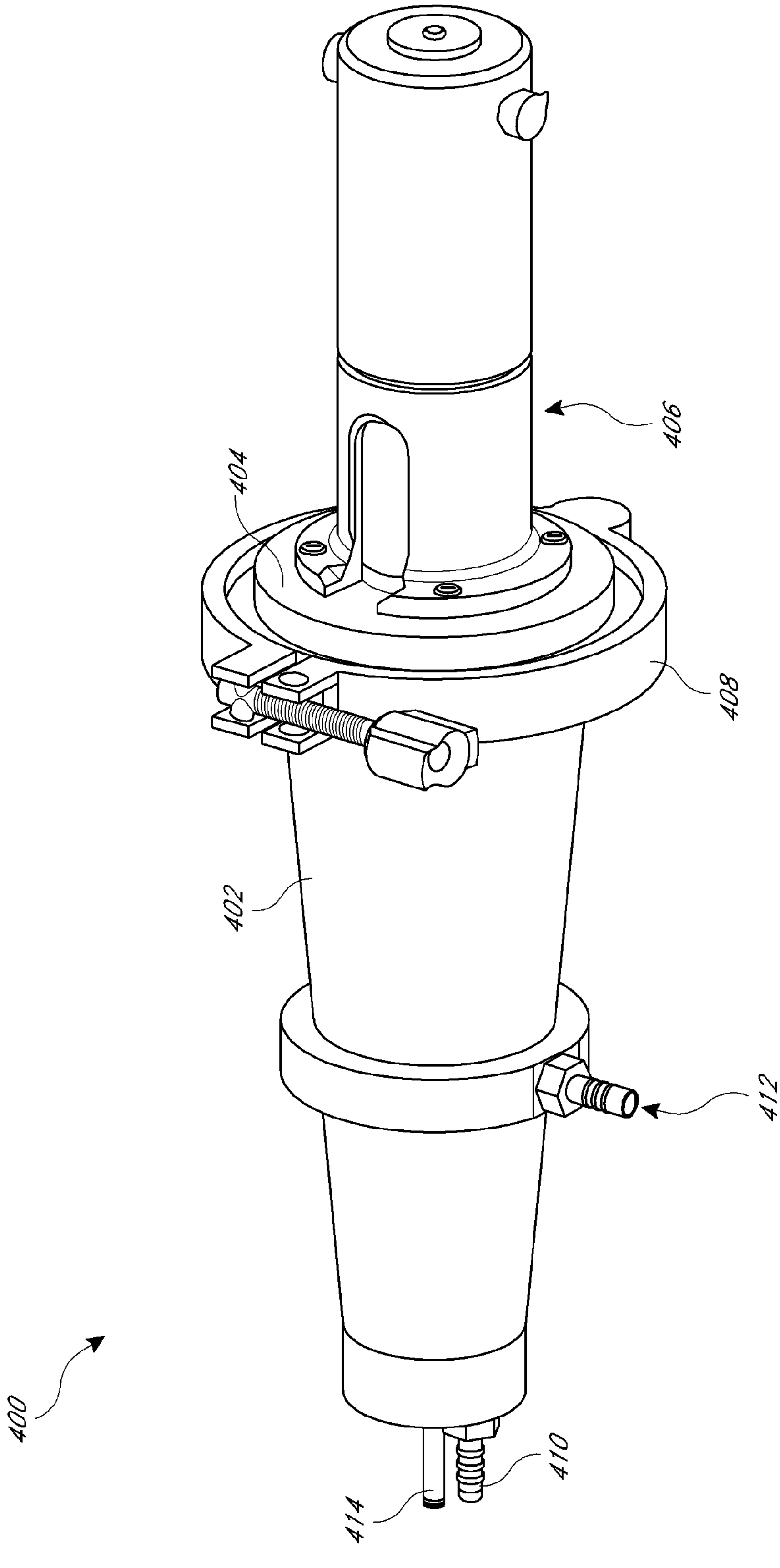

FIG. 4A

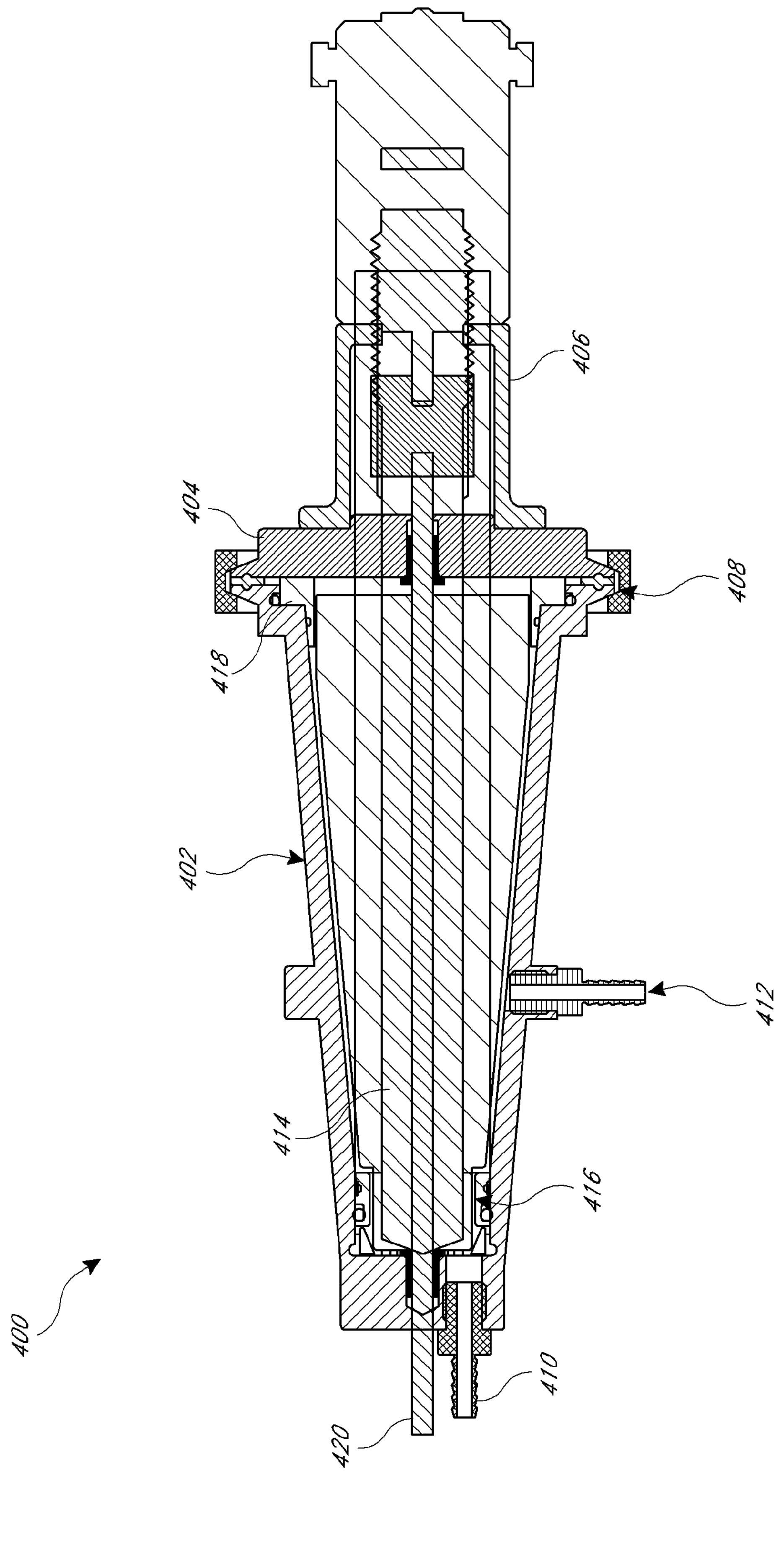

FIG. 4B

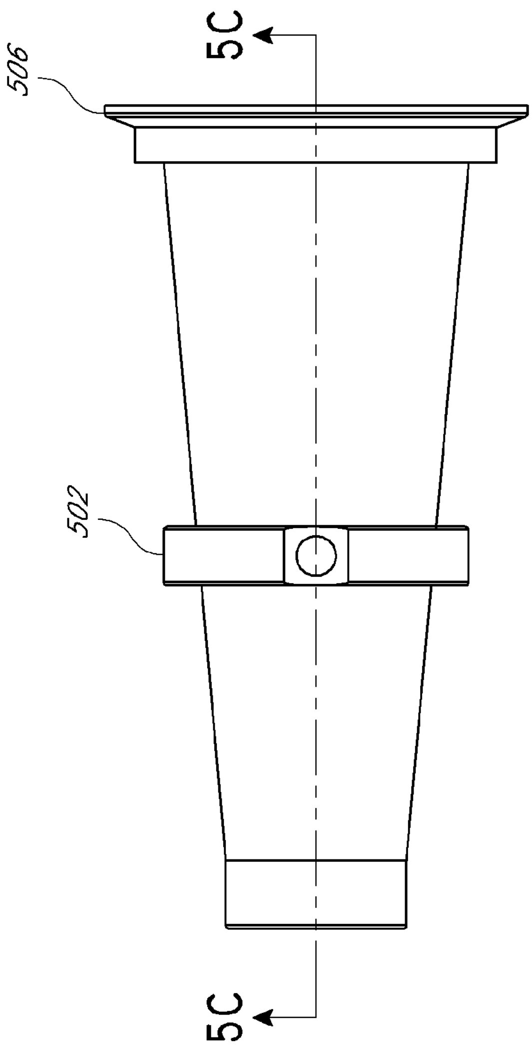

FIG. 5B

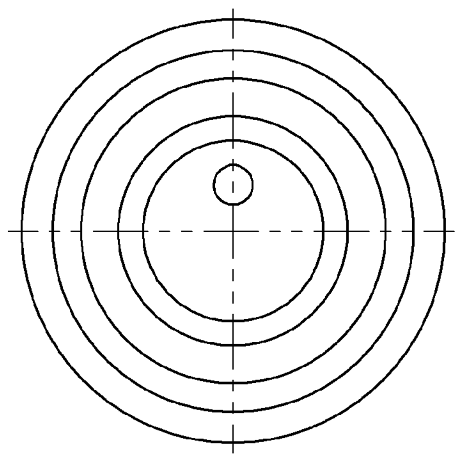

FIG. 5A

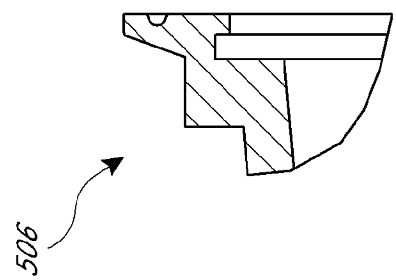

FIG. 5E

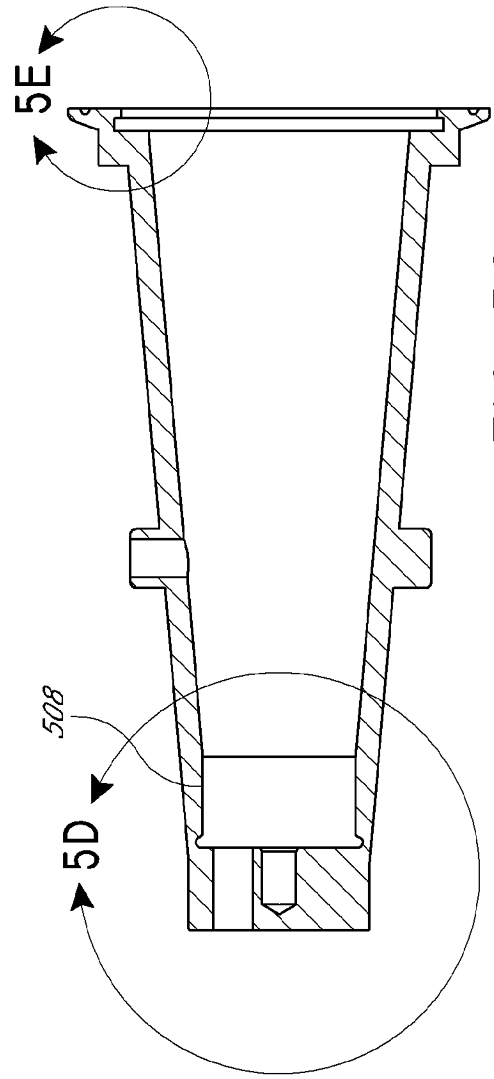

FIG. 5C

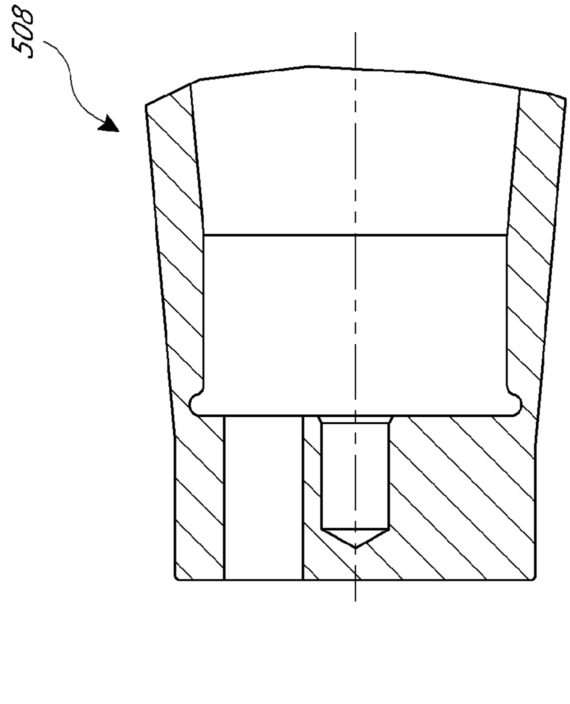

FIG. 5D

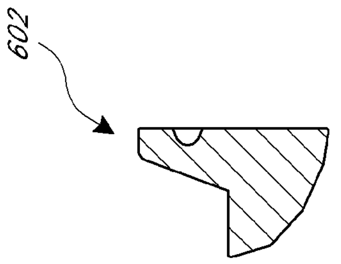

FIG. 6C

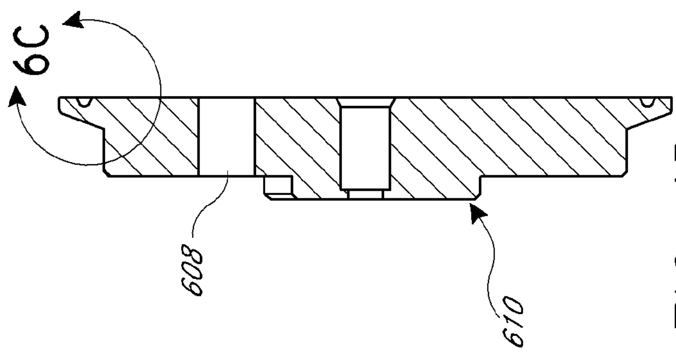

FIG. 6B

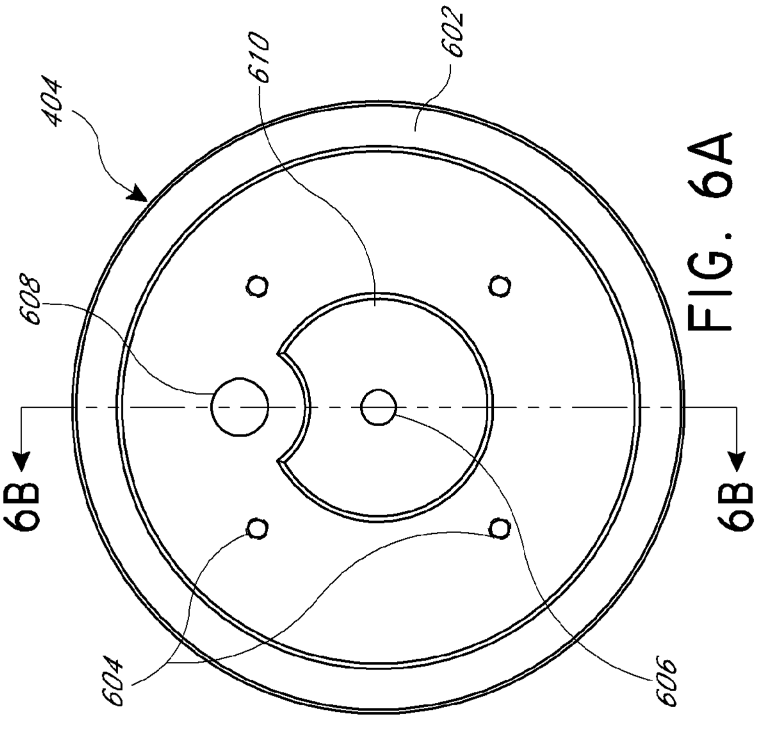

FIG. 6A

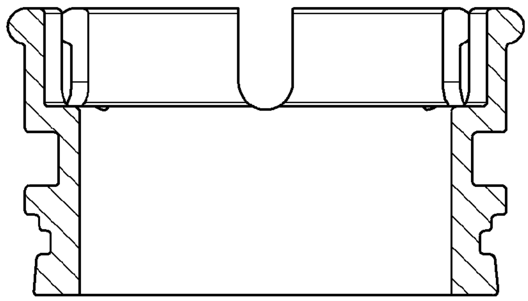

FIG. 7C

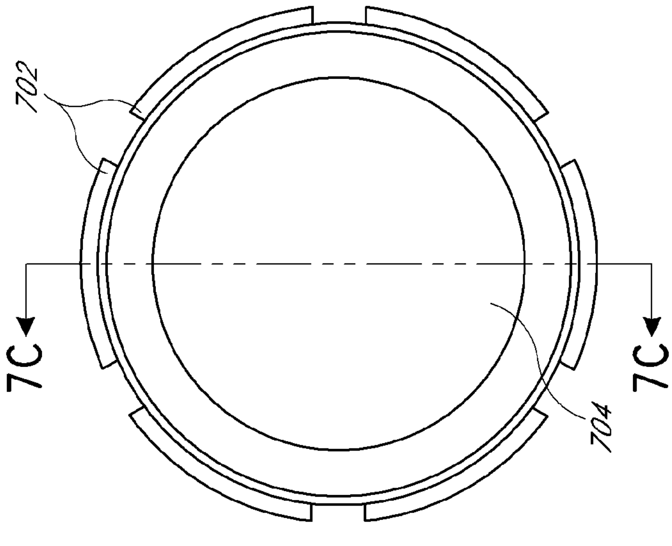

FIG. 7B

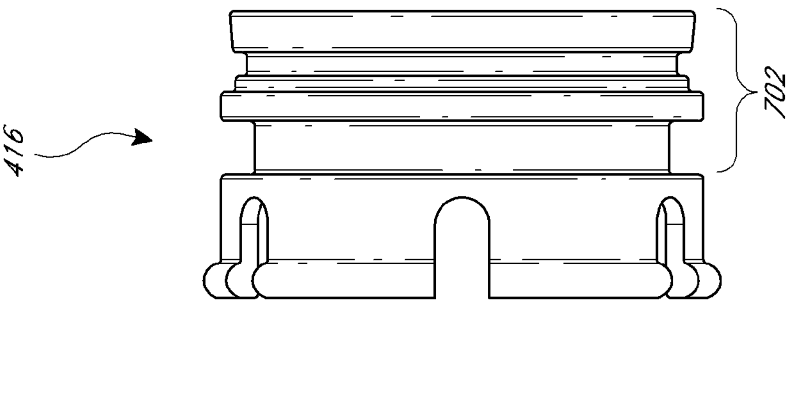

FIG. 7A

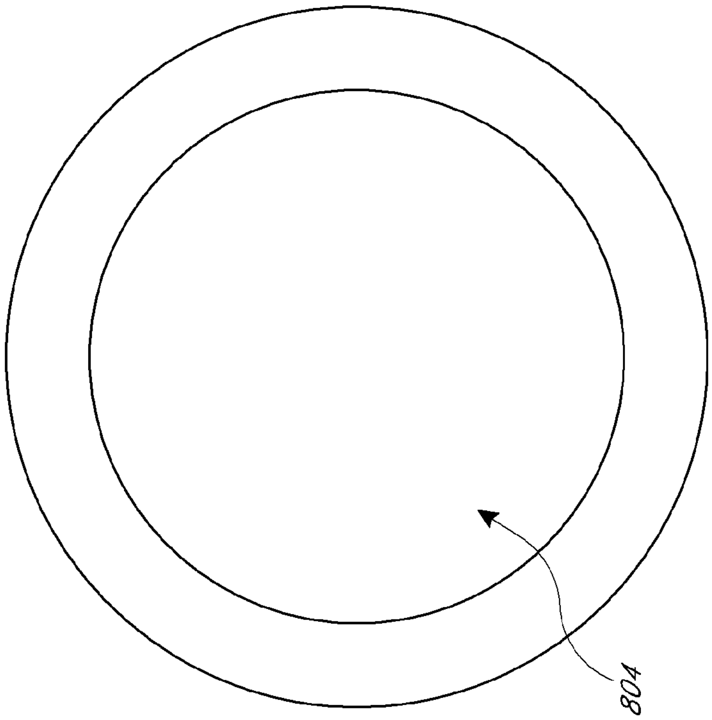

FIG. 8B

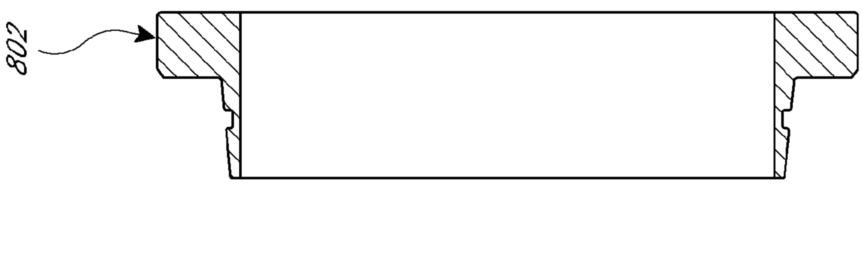

FIG. 8A

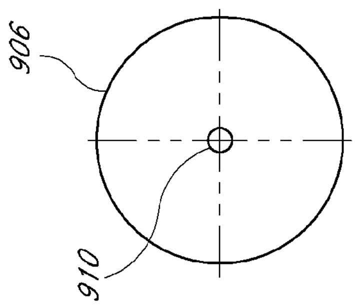

FIG. 9C

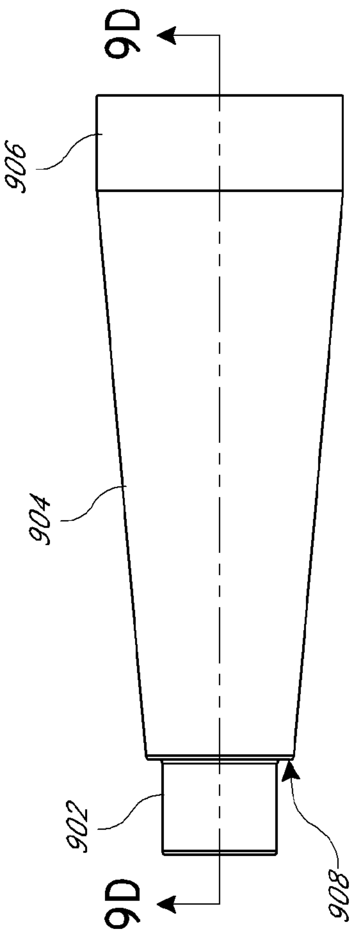

FIG. 9B

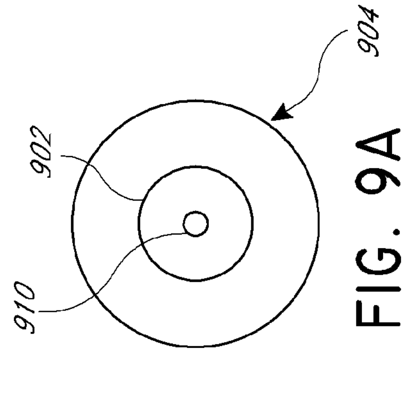

FIG. 9A

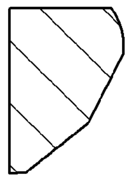

FIG. 9F

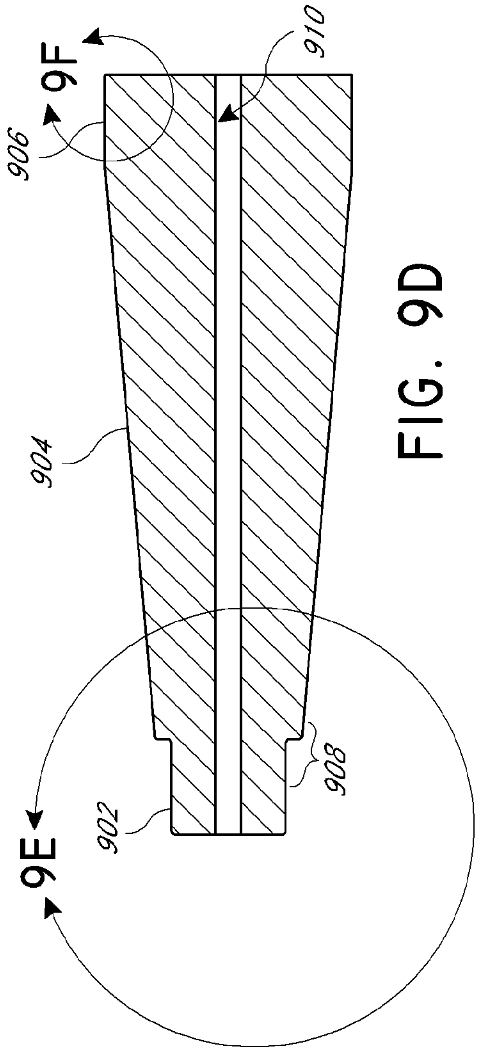

FIG. 9D

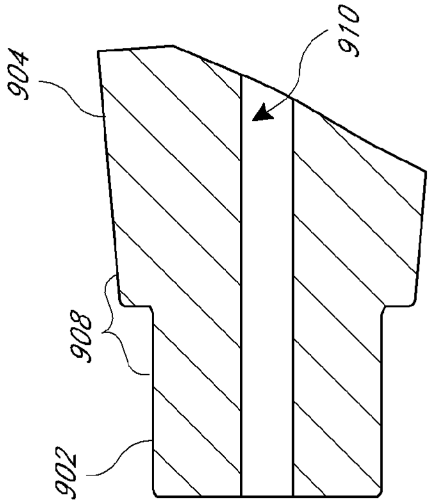

FIG. 9E

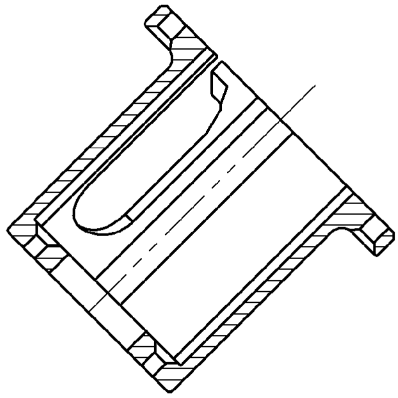

FIG. 10D

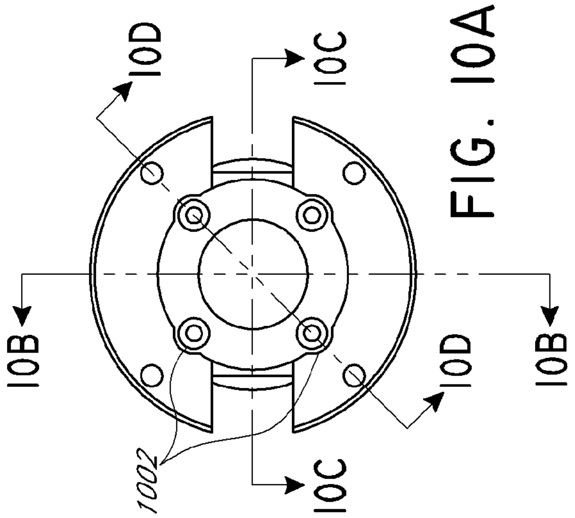

FIG. 10A

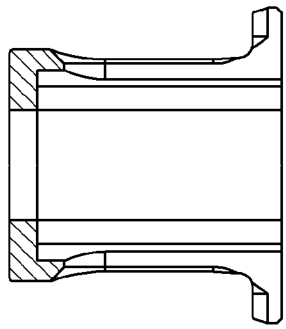

FIG. 10C

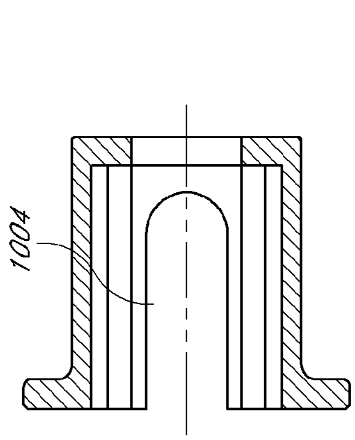

FIG. 10B

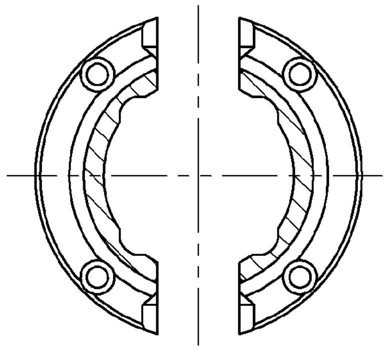

FIG. 10F

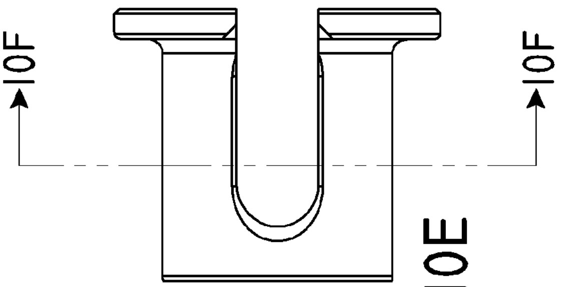

FIG. 10E

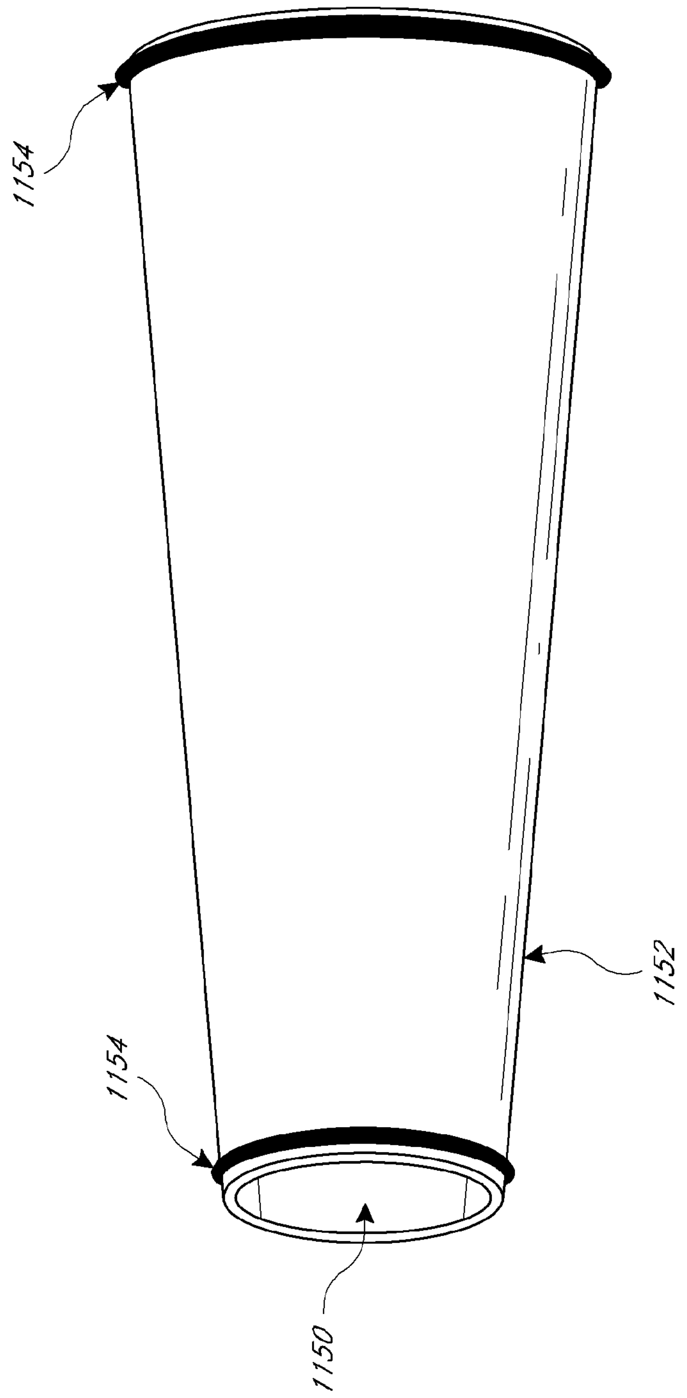

FIG. 11

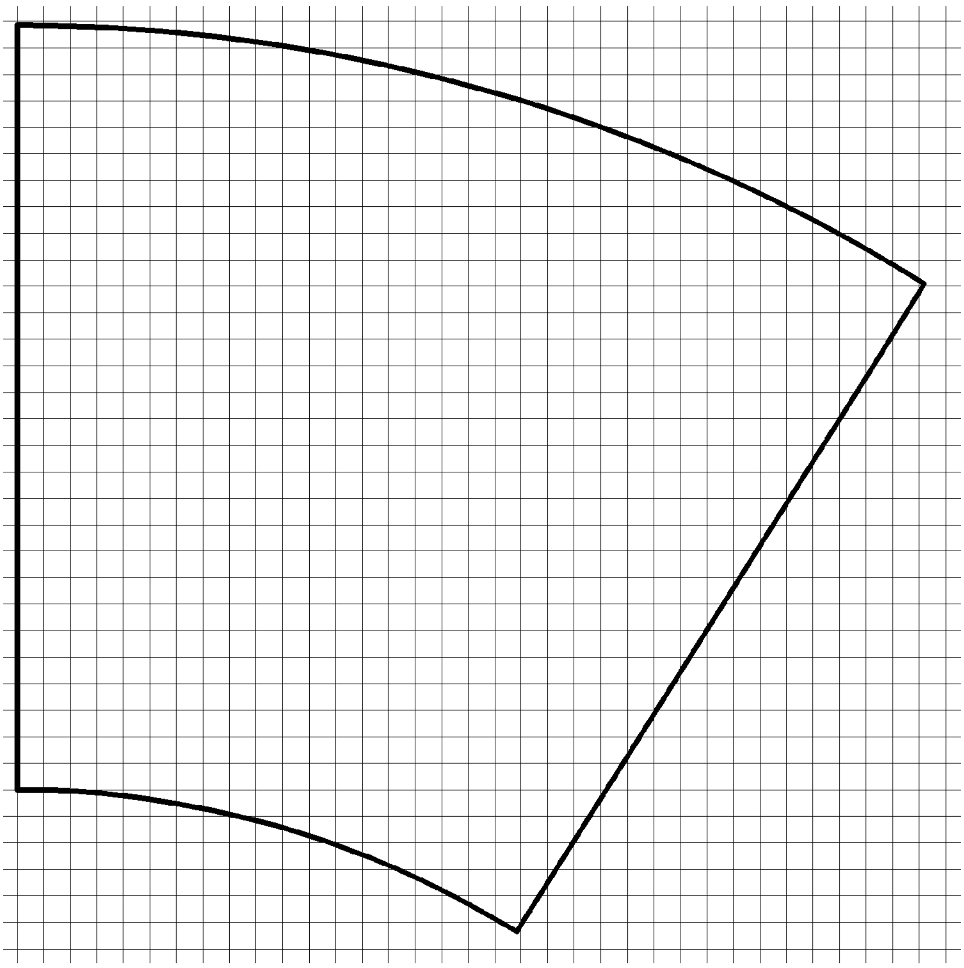

FIG. 12