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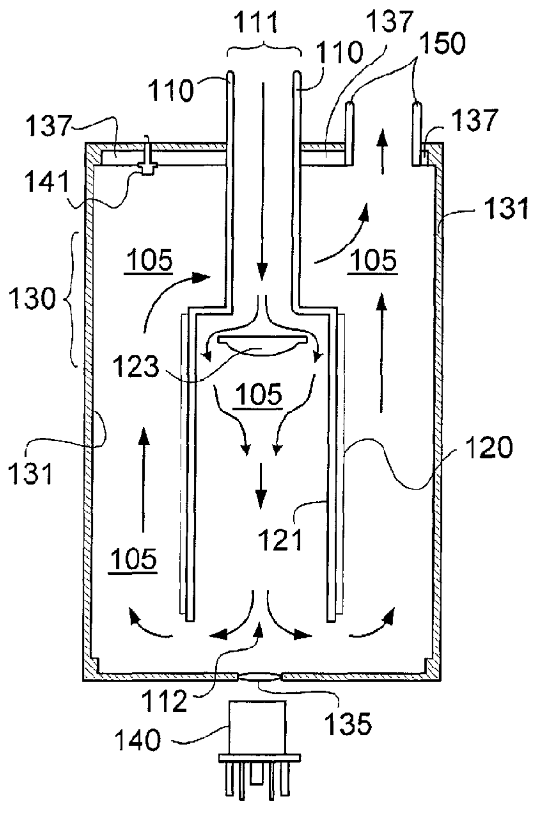
(54) Title: ULTRAVIOLET DISINFECTING APPARATUS



(57) Abstract: Ultraviolet radiation is used to disinfect air (105) in a flow tube (110), where the flow tube (110) includes total reflecting features (120) on a portion of its external surface and said ultraviolet radiation propagates through a portion of the flow tube via total internal reflection.

WO 03/039604 A3

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Ultraviolet Disinfecting Apparatus

The disclosures of US Patent Application Serial No. 10/268567, filed October 9, 2002, and US Provisional Patent Application Serial No. 60/336381, filed November 2, 2001, are both hereby incorporated by reference.

This invention relates to an air purification system using intense ultraviolet irradiation to break down chemical bonds in toxic compounds and to de-activate pathogens. The method can also be applied to any mass transport, including the purification of water or other fluids containing naturally occurring toxins or those resulting from biological and chemical agents used in warfare.

Previously proposed UV disinfecting systems are typically water disinfecting systems where the water is exposed to UV radiation such that the radiation passes through the water, strikes a reflecting surface and then again passes through the water after reflection. The reflecting surfaces, typically polished stainless steel, absorb a significant amount of radiation. Air disinfection systems, such as that described by Halloran (US Patent 3,744,216) employ extended-arc low pressure mercury germicidal lamps within an airstream. Companies such as American Ultraviolet and Steril-Aire manufacture systems that use these lamps within duct of a heating, ventilating, and air conditioning (HVAC) system, providing germicidal action.

In Whitehead, US 4,260,220, a square cross-section hollow tube waveguide is constructed, operating under the principle of total internal reflection (TIR). Each wall section has a planar inner surface and an outer surface having 90° angle longitudinal corrugations. The walls are constructed of transparent dielectric material, such as acrylic or optically clear glass. The Whitehead device is used to transport visible light.

A square cross section light waveguide is known in the art to maximum flux homogeneity in a short distance according to Pritchard (US Patent 3,170,980). These devices are typically employed in projection systems between a the light source and an imaging device such as for example is

2002363320 06 Jan 2006

described in Magarill (US Patent 5,625,738).

Common to previously proposed UV disinfection systems is overdosage of ultraviolet (UV) radiation to the air being disinfected, which necessarily increases the size, weight, and power of the resulting equipment. There is a long-felt need to improve the efficiency of such systems and also to provide a portable efficient UV disinfecting system for air.

According to one aspect of the present invention, there is provided a system to disinfect air using ultraviolet radiation (UV), the system comprising:

an air inlet tube comprising an entrance end, a distally opposing exit end, an internal surface in contact with the air, and an external surface;

total internal reflecting features disposed upon at least a portion of a surface of the air inlet tube;

an air containment vessel disposed around the air inlet tube;

an ultraviolet window in the containment vessel, the window allowing ultraviolet radiation to enter the air inlet tube at its exit end but preventing passage therethrough of air;

an ultraviolet lamp providing ultraviolet radiation that passes through the window and impinges on the inner surface of the air inlet tube; and

an air outlet extending from the air containment vessel.

The air inlet tube may itself is constructed of a non-UV-absorbing material, such as UV-grade fused silica glass for example. Advantageously, the use of light-pipe technology, which is based on total internal reflection (TIR), ensures that all the input UV radiation is dissipated in the air.

The present invention will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

FIG. 1 depicts an apparatus for disinfecting water using ultraviolet radiation (UV).

FIG. 2 depicts a sectional view of the UV disinfecting apparatus of FIG. 1.

FIG. 3 depicts a light pipe irradiation zone within the UV disinfecting apparatus of FIG. 1, showing how the ultraviolet radiation is contained using total internal reflection (TIR).

FIG. 4 depicts an apparatus for disinfecting air using ultraviolet radiation (UV) in accordance with one illustrative embodiment of the present invention.

FIG. 5 depicts a sectional view of the UV disinfecting apparatus of FIG. 4.

FIG. 6 depicts a block diagram of an air handling system that incorporates my inventive UV disinfecting apparatus.

The following is a list of the major elements in the drawings in numerical order.

1	incidence angle (refraction at fluid inlet tube internal surface)
2	internal reflection angle (reflection at fluid inlet tube external surface)
5	fluid (to be disinfected)
10	fluid inlet tube
11	entrance end (fluid inlet tube)
12	exit end (fluid inlet tube)
13	internal surface (fluid inlet tube)
14	external surface (fluid inlet tube)
15	concentric gap (between inlet tube and optical cladding tube)
20	optical cladding tube

30	fluid containment vessel
31	ultraviolet mirror (fluid containment vessel internal surface)
32	air gap (fluid containment vessel)
33	inner tube (of fluid containment vessel)
35	ultraviolet inlet aperture
36	lower ultraviolet window surface
37	upper ultraviolet window surface
40	high intensity ultraviolet lamp
50	fluid outlet tube
71	first UV light ray (exiting lower ultraviolet window surface)
72	second UV light ray (exiting fluid)
73	third UV light ray (entering fluid inlet tube internal surface)
74	fourth UV light ray (exiting fluid inlet tube internal surface)
75	fifth UV light ray (entering fluid)
100	light pipe (formed from fluid, fluid inlet tube, and concentric gap)
101	air inlet fan
102	air filter
103	catalytic filter
104	air outlet fan
105	air (to be disinfected)
110	air inlet tube
111	entrance end (air inlet tube)
112	exit end (air inlet tube)
113	internal surface (fluid inlet tube)
114	external surface (fluid inlet tube)
120	total internal reflecting features (of air inlet tube)
121	internal surface (of total internal reflecting features)

123	deflector mirror
130	air containment vessel
131	ultraviolet mirror (air containment vessel internal surface)
135	ultraviolet inlet aperture
137	ultraviolet window surface
140	high intensity ultraviolet lamp
141	ultraviolet sensor
150	fluid outlet tube
101	air inlet fan
102	air filter
103	catalytic filter
104	air outlet fan
200	controller (for disinfecting system)

Referring first to FIG. 1, the basic construction of an ultraviolet (UV) water disinfecting device is shown, including a fluid inlet tube **10** that acts as a central light pipe, an optical cladding tube **20** around the lower portion of fluid inlet tube **10** and defining therewith a concentric gap **15**, a fluid containment vessel **30**, a fluid outlet tube **50**, and a high intensity UV lamp **40**, such as a flashlamp.

Referring next to FIG. 2, the fluid containment vessel **30** includes an internal surface configured as an ultraviolet mirror **31**; for example, the fluid containment vessel may be constructed from aluminum and the internal surface may be polished aluminum. A fluid **5** to be disinfected, such as water, enters the fluid inlet tube **10** through an entrance end **11**. The fluid inlet tube **10** may be manufactured, for example from UV-grade fused silica.

The fluid **5** travels through the fluid inlet tube **10** towards the high intensity UV lamp **40** and exits the fluid inlet tube **10** at the exit end **12**. The fluid **5** flow then is redirected by an ultraviolet (UV) transmissive window lower surface **36**, which forms a portion of the lower end of fluid containment vessel **30**. Next, the fluid **5** flow is redirected to the fluid outlet tube **50**, which is located in the upper end of the fluid containment vessel **30**.

The fluid **5** is contained within the fluid containment vessel **30**. The fluid containment vessel **30** includes an inner tube **33**, which may be constructed from UV-grade fused silica, contained within an outer aluminum shell with a reflective interior surface defining a UV mirror **31**, with a gap **32**, such as an air gap, between the outer shell and the inner tube **33**. Then ends of the outer tube **30** are closed off with the lower ultraviolet window surface **36** and an ultraviolet window upper surface **37**.

The preferred orientation of the ultraviolet (UV) water disinfecting device is vertical, so that the fluid **5** flow approximates plug-flow, and the position of the fluid outlet tube **50** is at or near the highest point, allowing for quick and efficient removal of undesirable air bubbles. Air bubbles present in the fluid **5** can form scattering sites for the UV radiation thereby degrading system efficiency. These UV scattering sites result in UV radiation being directed at less than optimum angles causing reflections from the fluid containment vessel internal surface, the ultraviolet mirror **31** that is approximately 86% reflective when composed of aluminum tube. Without these UV scattering sites, the ultraviolet radiation is dissipated mostly within the fluid **5**, because all reflections are near loss-less because of the total internal reflection (TIR) operation of a light pipe.

Referring next to FIG. 3, a light pipe **100** region is formed from the fluid **5**, such as water, the fluid inlet tube **10**, such as a UV-grade fused silica tube, and the concentric gap **15**, such as an air gap or a vacuum gap. The concentric gap **15** is hydraulically isolated from the fluid **5**, in order to allow the light pipe **100** to operate. Light pipe operation is based on the refractive index of the concentric gap being less than the refractive index of the fluid **5**. The refractive indices of fused silica and water in the UV region of the light spectrum are shown in Table 1 below.

Fused Silica UV Grade (SiO2)		Water	
Wavelength (nm)	Refractive Index	Wavelength (nm)	Refractive Index
170	1.615	172	1.568
185	1.575	185	1.549
200	1.550	200	1.543
214	1.534	215	1.513
280	1.494	280	1.492
302	1.487	305	1.475
436	1.467	450	1.344
546	1.460	550	1.336
656	1.456	650	1.331

Table 1 - Refractive Indices of Fused Silica and Water

As shown in Table 1, water has about the same refractive index as UV grade fused silica glass in the ultraviolet (UV) portion of the light spectrum.

Ultraviolet (UV) radiation is transmitted from the high intensity ultraviolet lamp **40**, passes through the ultraviolet inlet aperture **35**, and enters the lower ultraviolet window surface **36** as shown in FIG. 2. It is desirable to minimize the distance between lamp **40** and aperture **35** to preclude UV absorption by fluid-borne or surface contaminants. In certain embodiments, aperture **35** is fashioned with one or more lens elements (to enhance the optical coupling efficiency. A first UV light ray **71** exits lower ultraviolet window surface, is bent by refraction, and enters the fluid **5**, defining a second UV light ray **72**. The second UV light ray **72** impinges upon the internal surface **13** of the fluid inlet tube **10**, which is in contact with the fluid **5**, at an incidence angle 1□where incidence angle **1** is measured with reference to the surface normal of internal surface **13**. As the second UV light ray **72** enters a sidewall of the fluid inlet tube

10, it is bent by refraction and redirected at a new internal reflection angle **2**, defining a third UV light ray **73**.

The value of angle **2**, as defined by Snell's Law, is a function of incident angle **1** and the refractive indices of the fluid **5** and the material, such as UV-grade silica, from which the fluid inlet tube **10** is constructed. The third UV light ray **73** continues through the fluid inlet tube **10** material and impinges upon the external surface **14** of the fluid inlet tube that is in contact with the concentric gap **15**. The third UV light ray **73** is reflected back into the sidewall of the fluid inlet tube **10**, defining a fourth UV light ray **74** when the refractive indices of the fluid inlet tube **10** material and the concentric gap **15** meet total internal reflection conditions as defined by Snell's Law. The refractive index of the concentric gap **15** is defined by the material contained in the concentric gap or by the refractive index of a vacuum if no material is contained within the concentric gap **15**.

A light pipe **100** region, as defined by an initial optical trajectory from UV light source **40**, exists for at least part of the length of the fluid inlet tube **10**. Therefore, it is required that the incidence angle **2** be limited to a predetermined range in accordance with the refractive indices of the fluid **5**, the material from which the fluid inlet tube **10** is constructed, and the concentric gap **15**. Preferably, the fluid inlet tube **10** is constructed from UV-grade silica glass, the fluid **5** to be disinfected is water, and the concentric gap **15** contains dry air.

An embodiment of the present invention suitable for disinfecting air is shown in FIGS. 4-6. Referring first to FIG. 4, an air containment vessel **130** includes an internal surface configured as an ultraviolet mirror **131**; for example, the air containment vessel may be constructed from aluminium and the internal surface may be polished aluminium. The air **105** to be disinfected enters the TIR light conduit **110** through an entrance end **111**. The light conduit **110** may be manufactured, for example from UV-grade fused silica, especially grades that are highly transmissive in the germicidal wavelengths of 200nm ~ 300nm, such as Hereaus Suprasil.

Refer now to FIG. 5, air inlet tube **110** transitions into a section including total internal reflecting (TIR) features **120** that extend from the exit end **110** closest to lamp **140**, some distance toward the entrance end **111**. This allows some UV light to leak out of air inlet tube **110** and distribute throughout air containment vessel **130**. In one embodiment, the TIR features **120** are a plurality of prism light guides, similar to those taught for visible light in Whitehead (US Patent 4,260,220), which describes the solid angle through which TIR can be maintained for an air waveguide. For example, the uncollimated UV energy from a short-arc xenon flash lamp without auxiliary optics can be totally contained via TIR out to a conical half angle of about 27 degrees. UV rays beyond this angle will necessarily leak through the TIR features **120** into the air **105** until it strikes another surface, such as UV mirror **131**. Advantageously, air containment vessel **130** maximizes the overall system efficacy by containing the UV, allowing it more opportunity to interact with the air stream. Air containment vessel **130** can also have a square cross section, such as for maximum UV beam homogeneity, or other shape as required.

The air **105** travels through the air inlet tube **110** towards the high intensity UV lamp **140** and exits the light conduit **110** at the exit end **112**. The air **105** flow strikes and is diverted around optional deflector mirror **123**, which also functions optically to minimize the amount of UV radiation escaping air containment vessel **130**.

For embodiments that do not include mirror **123**, a portion of UV radiation from the lamp will exit the section of inlet tube **110** having TIR features **120**, and enter the upper portion of containment vessel **130**. Only that fraction of UV radiation from the lamp that is highly collimated will reach inlet aperture **111**. These rays can be further deflected back into containment vessel **130** by introducing, for example, a right angle fitting at the inlet aperture **111**.

Continuing to refer to airflow path **105**, the air then strikes an ultraviolet (UV) window **135**, which forms a portion of the lower end of air containment vessel **130**. As discussed earlier, in certain embodiments, window **135** comprises one or more lens elements. The TIR structure, for the embodiments that are primarily designed to disinfect air, have more limited containment angles than the embodiments that are primarily designed to disinfect water. For the embodiments designed to disinfect air, some degree of optical collimation is advantageous, although the principle of etendue requires a larger cross section for the TIR region **120** of tube **110**.

Finally, the air **105** flow is redirected to the air outlet **150**, which is located in the upper end of the air containment vessel **130**. Advantageously, while the air **105** is travelling outside of the TIR section, it receives additional UV irradiation that has been trapped by UV mirror **131**, and thus forms a practical embodiment of a high efficiency UV irradation system. Alternatively, the UV exiting the lamp can be collimated with the ~ 27 degree conical half angle, and injected into a very long TIR guiding structure, thereby achieving extremely high efficacy (i.e. the amount of disinfection per electrical watt).

In a preferred embodiment, a UV sensor **141** is used as a feedback element to ensure that proper irradiance levels are being applied. Apprise Technology (Duluth, MN), under the trade name UV Clean, produces a suitable UV sensor that can handle continuous and pulsed UV sources. The UV sensor **141** is located with a view into vessel **130**, but without direct view of UV lamp **140**. Advantageously, this position enables the sensor to measure the integrated cavity irradiance, and is not prone to variations in the lamp's output distribution. Since the air stream is filtered, cleaning of the sensor's input aperture is minimized. In certain embodiments, such as those where the provision of disinfected air life-critical, redundant UV sources and sensors are employed.

Referring now to FIG. 6, an ultraviolet air disinfecting system that uses my inventive UV disinfecting apparatus, is schematically depicted. Air to be disinfected enters, for example, through inlet fan **101** and passes through air filter **102** to remove contaminants that would degrade the system efficacy by absorbing UV. The filtered air **105** to be disinfected next flows into air containment vessel **30** where it is irradiated by high intensity ultraviolet (UV) lamp **140**. After being irradiated, the air flows from the air containment vessel **130**, through optional catalytic filter **103**, which converts ozone back into breathable oxygen and finally exits through air outlet fan **104**. Feedback from sensors are fed into controller **200** which then can regulate the amount of UV introduced into vessel **130**, and the flow rate via inlet fan **101** and outlet fan **104**. Additionally, for those embodiments that use a pulsed lamp as UV source **40**, controller **200** varies the pulse repetition rate. In further embodiments controller **200** can also provide alarm warnings, for example, when sensor **141** detects abnormally low UV irradiation in chamber **130**, perhaps signaling the need for the lamp to be replaced.

The following is a list of the acronyms used in the specification in alphabetical order.

HEPA	high efficiency particulate air (filter)
HVAC	heating, venting, and air conditioning
TIR	total internal reflection
UV	ultraviolet

Alternate embodiments may be devised without departing from the spirit or the scope of the invention. For example, this same system can be adapted for a dual-use application, whereby multiple fluids (e.g. air and water) can be purified.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

The reference to any prior art in this specification is not, and should not be taken as, an acknowledgment or any form of suggestion that that prior art forms part of the common general knowledge in Australia.

2002363320 06 Jan 2006

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A system to disinfect air using ultraviolet radiation (UV), said system comprising:

an air inlet tube comprising an entrance end, a distally opposing exit end, an internal surface in contact with said air, and an external surface;

total internal reflecting features disposed upon at least a portion of a surface of said air inlet tube;

an air containment vessel disposed around said air inlet tube;

an ultraviolet window in said containment vessel, said window allowing ultraviolet radiation to enter said air inlet tube at its exit end but preventing passage therethrough of air;

an ultraviolet lamp providing ultraviolet radiation that passes through said window and impinges on the inner surface of said air inlet tube; and

an air outlet extending from said air containment vessel.

2. The system of claim 1 wherein said air inlet tube is constructed of UV-grade silica glass.

3. The system of claim 1 wherein said total internal reflecting features comprise a plurality of prism light guides extending along said external surface of said air inlet tube.

4. The system of claim 1 further comprising alarm means including a UV sensor extending into said air containment vessel as a feedback mechanism.

5. The system of claim 1 further comprising a catalytic filter in the air path from said air outlet to convert ozone to oxygen.

6. The system of claim 5 further comprising an air filter for removing contaminants before entry into said air inlet tube entrance of the air to be disinfected.

7. The system of claim 1 further comprising a deflector mirror positioned in the path of the air in said air inlet tube.

8. A system to disinfect air using ultraviolet radiation (UV) substantially as hereinbefore described with reference to the accompanying drawings.

Dated this 4th day of January, 2006

Honeywell International, Inc.

by DAVIES COLLISON CAVE
Patent Attorneys for the applicant(s)

FIG. 1

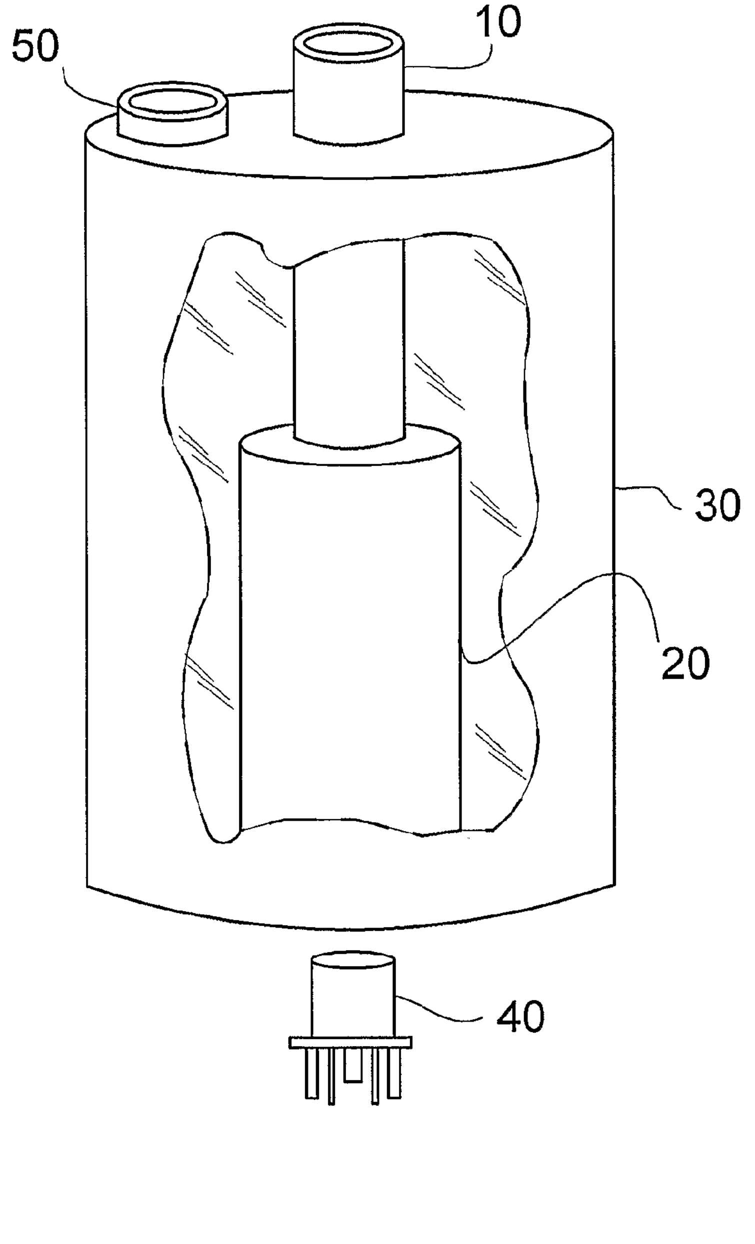
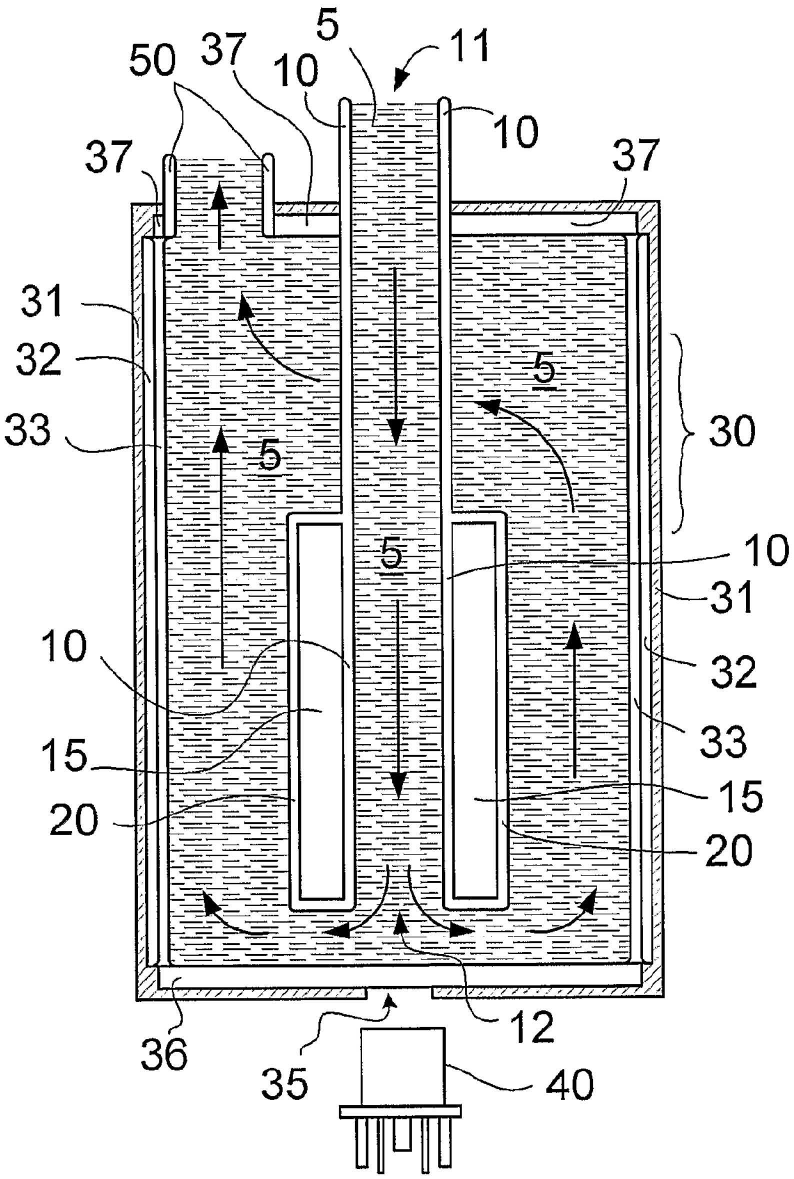


FIG. 2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40

FIG. 3

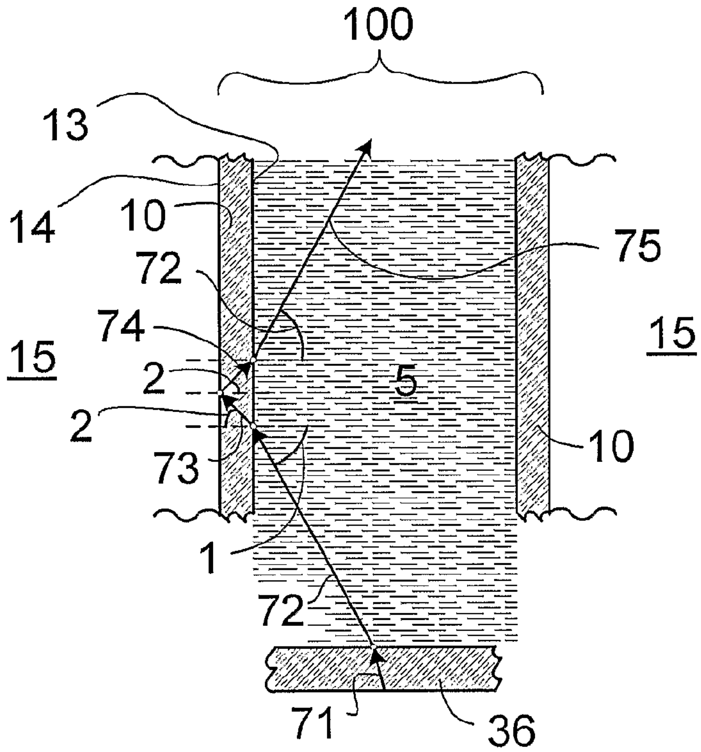


FIG. 4

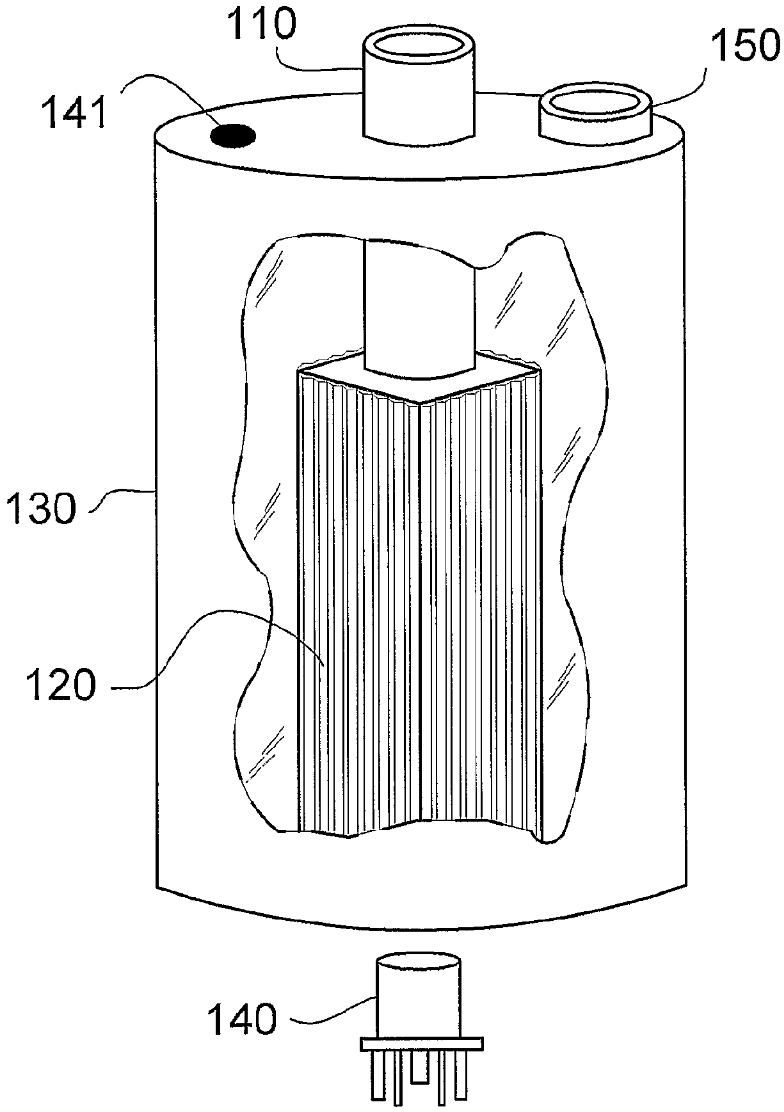
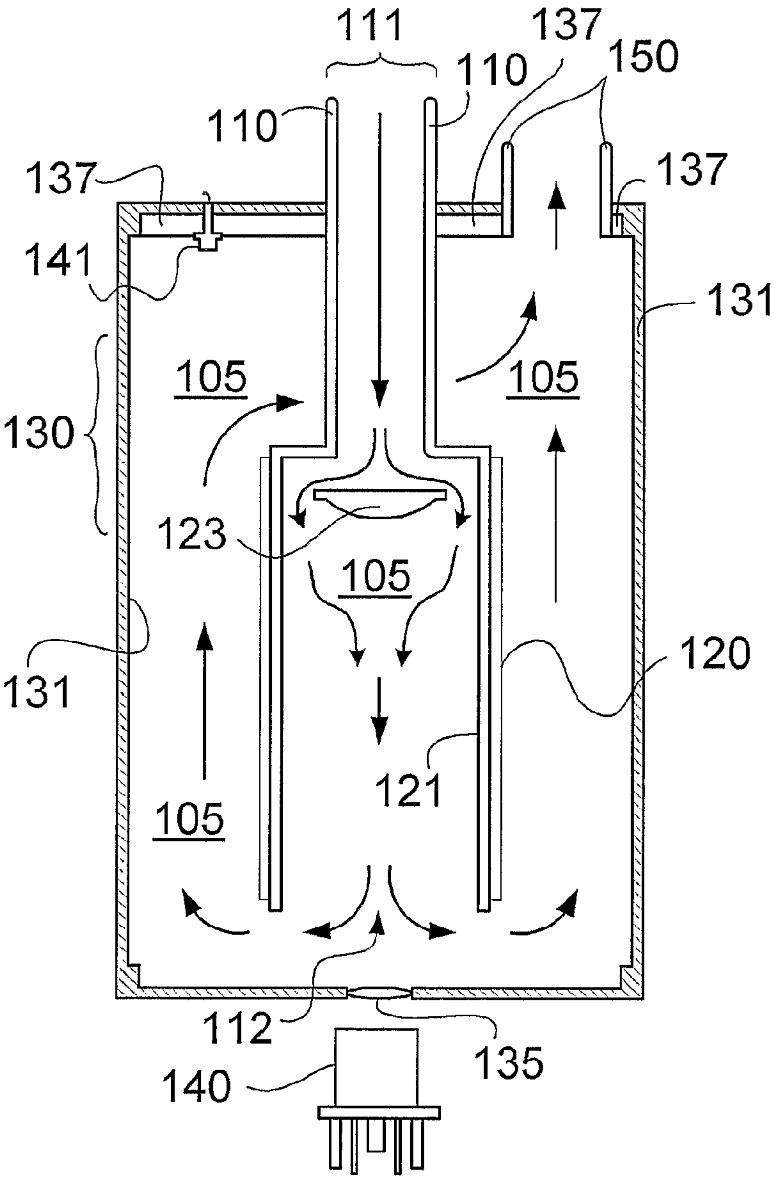


FIG. 5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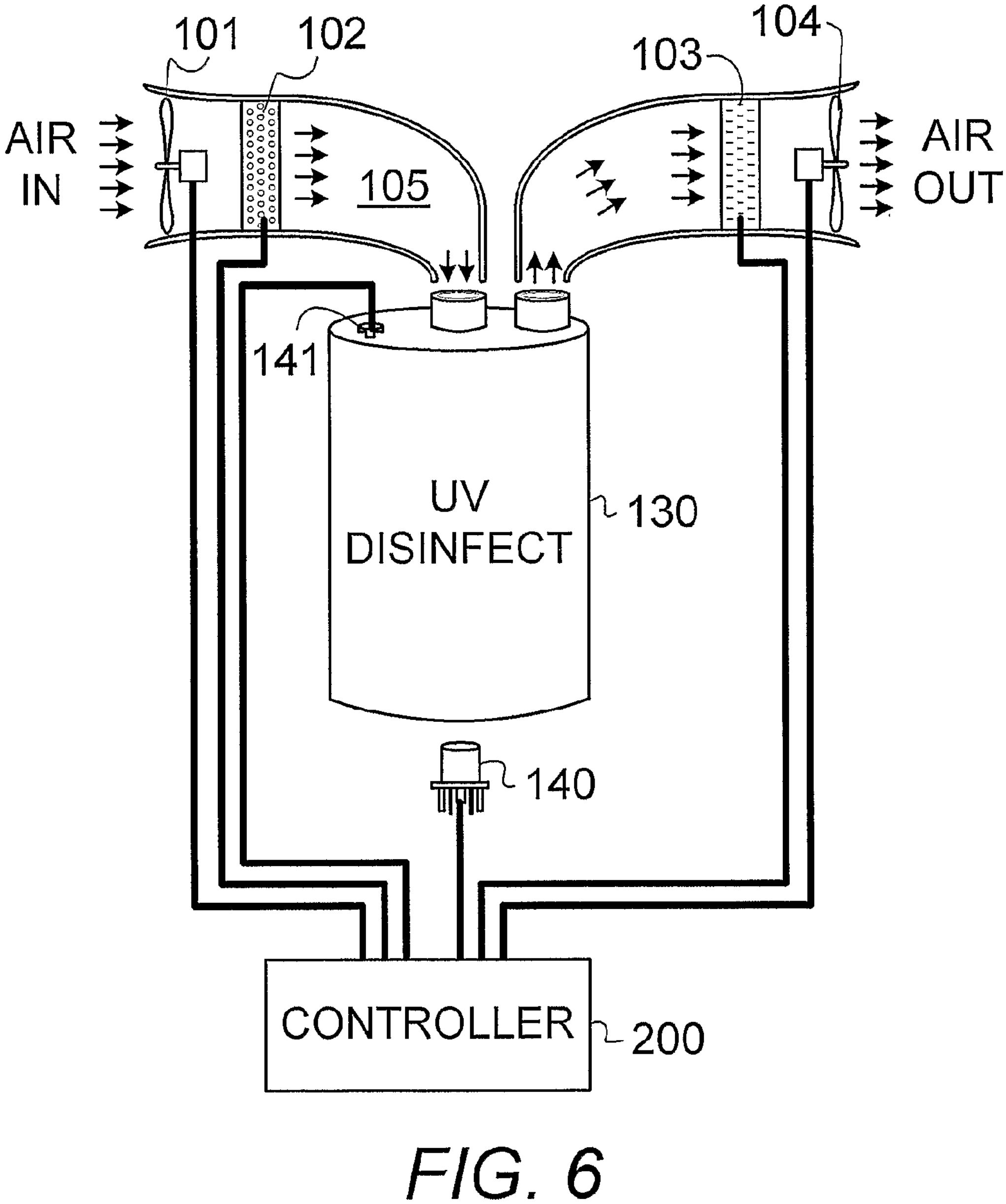
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UV DISINFECT
130
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CONTROLLER
200

FIG. 6