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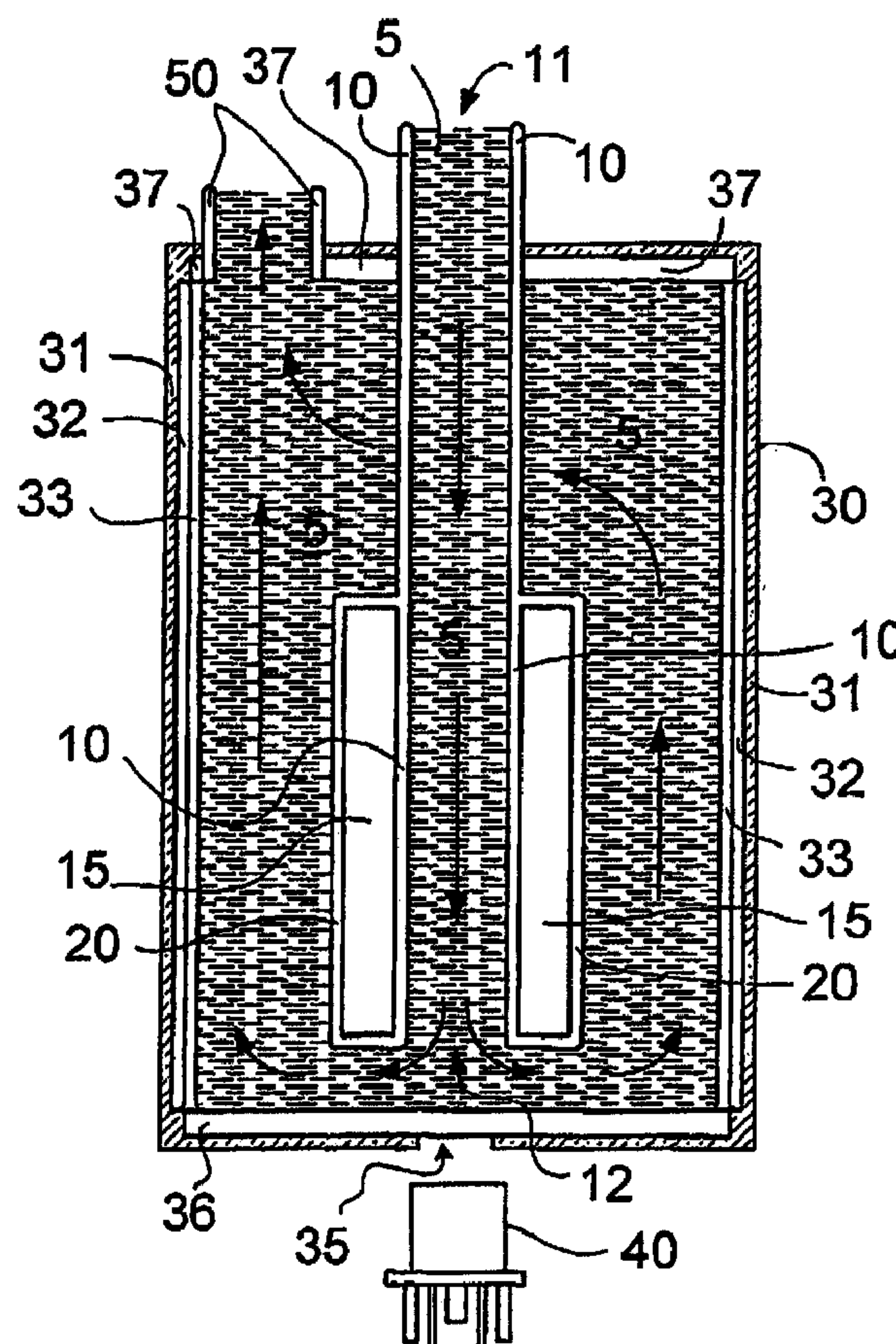
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(54) Title: APPARATUS FOR DISINFECTING WATER USING ULTRAVIOLET RADIATION



(57) **Abrégé/Abstract:**

Ultraviolet radiation is used to disinfect water (5) in a flow tube, where the flow tube (10) acts a fluid filled light guide for the ultraviolet radiation and the ultraviolet radiation propagates through the flow tube via total internal reflection.

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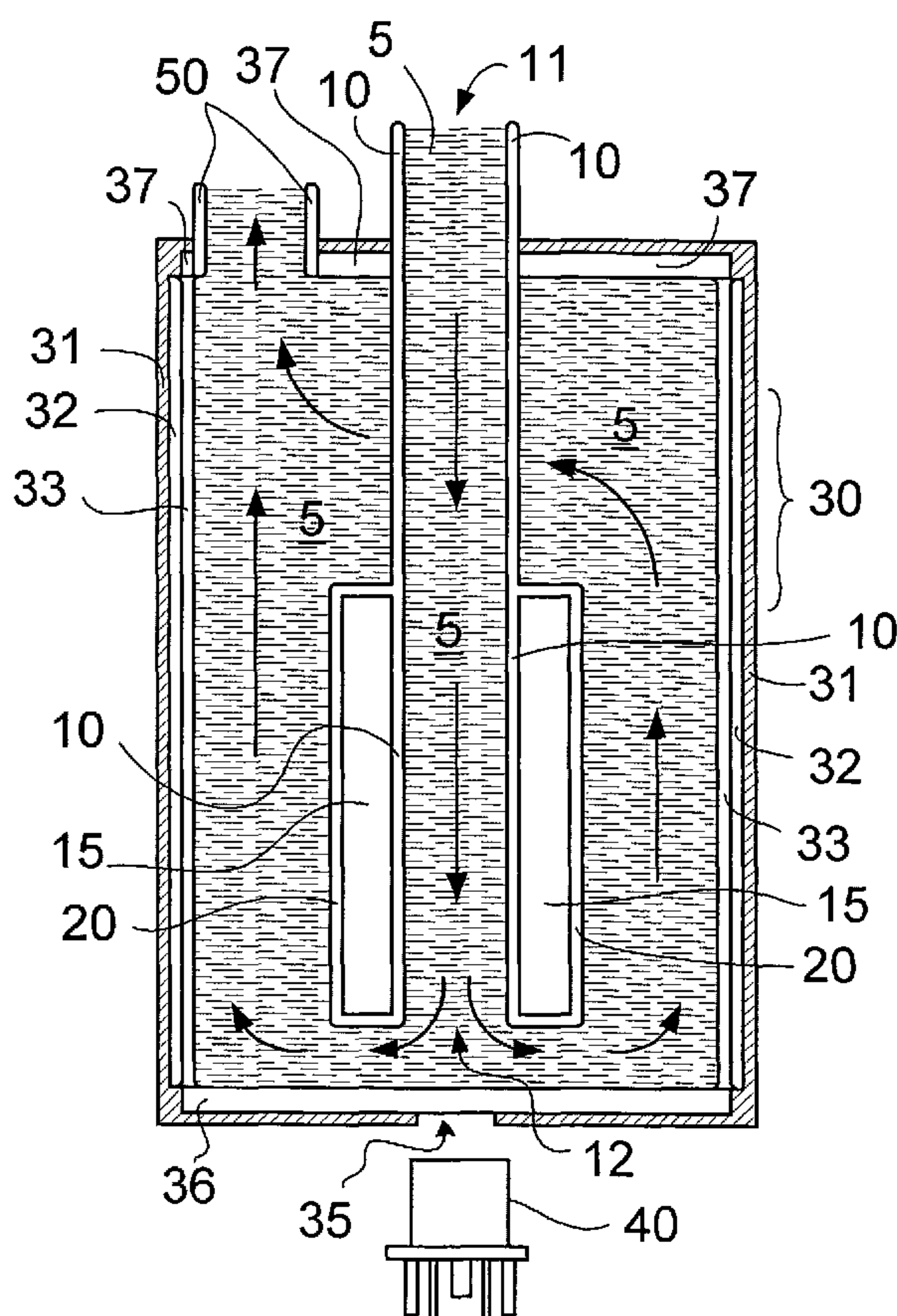
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(54) Title: APPARATUS FOR DISINFECTING WATER USING ULTRAVIOLET RADIATION

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Apparatus for Disinfecting Water Using Ultraviolet Radiation

BACKGROUND OF THE INVENTION

Technical Field

This invention relates to a water 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 air. These systems can be applied to purify fluids containing naturally occurring toxins or those resulting from biological and chemical agents used in warfare.

Background Art

The first application of an ultra violet (UV) low-pressure mercury vapor discharge lamp to disinfect water was in Marseilles, France in 1901. However, it was not until 1955 that UV disinfection became widely applied in Europe for potable water. In that year UV disinfection equipment was installed in Switzerland, Austria and Norway. Following the discovery of the formation of halogenated hydrocarbons during chlorination, UV disinfection since became popular in most European countries.

US Patent 1,196,481, issued August 29, 1916 described the use of a mercury vapor lamp to generate sufficient ultraviolet light (mostly 254-nm wavelength) to purify water. This basic approach, built upon the UV efficacy of extended-arc continuous-duty mercury based lamps, has been refined over the years, such as in Ellner US Patent 3,182,193 issued May 4, 1965, Maarschalkerweerd US Patent 4,482,809 issued November 13, 1984, Moyher US Patent 5,069,782 issued December 3, 1991, Tiede US Patent 5,393,419 issued February 28, 1995, and Anderson US Patent 6,099,799 issued August 8, 2000. Much of the latter art improved upon aspects related to commercial viability, such as improving UV dosage uniformity through the

use of baffles, UV-transparent coils, and controlled turbulence; increasing
2 UV intensity for higher flow rates by increasing the number of lamps in a
given volume; and improving maintenance through the use of Teflon
4 coatings, wiper mechanisms, and adding turbulence.

Prior art UV water disinfecting systems expose the water to UV
6 radiation such that the radiation passes through the water, strikes a
reflecting surface and then passes through the water after reflection. The
8 reflecting surfaces absorb a significant amount of radiation. There is a long-
felt need to improve the efficiency of such systems.

10 SUMMARY OF THE INVENTION

My invention is an apparatus and method for disinfecting water, or
12 other fluid, that channels water through one end of a tube and couples
ultraviolet (UV) energy from a high intensity lamp through the tube from the
14 other end. The water, or other fluid, acts like the core of a liquid light pipe,
with an air gap surrounding the tube acting as a low index cladding. The
16 tube itself is constructed of a non-UV-absorbing material, such as UV-grade
fused silica glass. Advantageously, the use of light-pipe technology, which is
18 based on total internal reflection (TIR), ensures that all the input UV radiation
is dissipated in the water. Preferably, the tube is polygonal in cross-section,
20 which is known in the art to maximize light flux uniformity within a light pipe.

Embodiments of my invention with multiple zones efficiently handle a
22 wide range of water absorption coefficients, all at the highest practical
efficiency. In accordance with an aspect of my invention one of three zones
24 is defined by a concentric UV-grade tubing concentrically around only a
portion of the tube through which the water flows and others of these zones
26 are defined between these tubes and the enclosing outer tube.

BRIEF DESCRIPTION OF DRAWINGS

Brief Description of the Several Views of the Drawing

2 FIG. 1 depicts an apparatus for disinfecting water using ultraviolet
radiation (UV) in accordance with one illustrative embodiment of my
4 invention.

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

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

10 List of Reference Numbers for the Major Elements in the Drawing

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

	5	fluid (to be disinfected)
14	10	fluid inlet tube
	11	entrance end (fluid inlet tube)
16	12	exit end (fluid inlet tube)
	13	internal surface (fluid inlet tube)
18	14	external surface (fluid inlet tube)
	15	concentric gap (between inlet tube and optical cladding 20 tube)
	20	optical cladding tube
22	30	fluid containment vessel
	31	ultraviolet mirror (fluid containment vessel internal 24 surface)

	32	air gap (fluid containment vessel)
2	33	inner tube (of fluid containment vessel)
	35	ultraviolet inlet aperture
4	36	lower ultraviolet window surface
	37	upper ultraviolet window surface
6	40	high intensity ultraviolet lamp
	50	fluid outlet tube
8	71	first UV light ray (exiting lower ultraviolet window surface)
10	72	second UV light ray (exiting fluid)
	73	third UV light ray (entering fluid inlet tube internal surface)
12		
	74	fourth UV light ray (exiting fluid inlet tube internal surface)
14		
	75	fifth UV light ray (entering fluid)
16	100	light pipe (formed from fluid, fluid inlet tube, and concentric gap)
18	1	incidence angle (refraction at fluid inlet tube internal surface)
20	2	internal reflection angle (reflection at fluid inlet tube external surface)

22 DESCRIPTION OF THE INVENTION

Mode(s) for Carrying Out the Invention

24 Referring first to FIG. 1, the basic construction of an ultraviolet (UV)
water disinfecting device in accordance with my invention is shown, including
26 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
2 concentric gap 15, a fluid containment vessel 30, a fluid outlet tube 50, and a
high intensity UV lamp 40, such as a flashlamp.

4 Referring next to FIG. 2, the fluid containment vessel 30 includes an
internal surface configured as an ultraviolet mirror 31; for example, the fluid
6 containment vessel may be constructed from aluminum and the internal
surface may be polished aluminum. A fluid 5 to be disinfected, such as
8 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.

10 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
12 fluid 5 flow then strikes an ultraviolet (UV) window lower surface 36, which
forms a portion of the lower end of fluid containment vessel 30. Next, the
14 fluid 5 flow is redirected to the fluid outlet tube 50, which is located in the
upper end of the fluid containment vessel 30.

16 The fluid 5 is contained within the fluid containment vessel 30. The
fluid containment vessel 30 includes an inner tube 33, which may be
18 constructed from UV-grade fused silica, contained within an outer aluminum
shell with a reflective interior surface defining a UV mirror 31, with an air gap
20 32 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
22 ultraviolet window upper surface 37.

The preferred orientation of the ultraviolet (UV) water disinfecting
24 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
26 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
28 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
 2 approximately 86% reflective when composed of aluminum tube. Without
 these UV scattering sites, the ultraviolet radiation is dissipated mostly within
 4 the fluid 5, because all reflections are near loss-less because of the total
 internal reflection (TIR) operation of a light pipe.

6 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
 8 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
 10 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.
 12 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 (SiO ₂)		Water	
Wavelength (nm)	Refractive Index	Wavelength (nm)	Refractive Index
170	1.615	172	1.568
185	1.575	185	1.492
200	1.550	200	1.452
214	1.534	215	1.427
280	1.494	280	1.379
302	1.487	305	1.370
436	1.467	450	1.344
546	1.460	550	1.336
656	1.456	650	1.331

14 **Table 1 - Refractive Indices of Fused Silica and Water**

As shown in Table 1, water has a lower refractive index than
 16 UV grade Silica glass in the ultraviolet (UV) portion of the light spectrum.

Ultraviolet (UV) radiation is transmitted from the high intensity
2 ultraviolet lamp 40, passes through the ultraviolet inlet aperture 35, and
enters the lower ultraviolet window surface 36 as shown in FIG. 2. A first UV
4 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
6 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
8 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
10 bent by refraction and redirected at a new internal reflection angle 2 , defining
a third UV light ray 73.

12 The value of angle 2 is a function of incident angle 1 and the
refractive indices of the fluid 5 and the material, such as UV-grade silica,
14 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
16 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
18 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
20 certain 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
22 or by the refractive index of a vacuum if no material is contained within the
concentric gap 15.

24 It is a feature of my invention that a light pipe 100 region exists for at
least part of the length of the fluid inlet tube 10. Therefore, it is required that
26 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
28 tube 10 is constructed, and the concentric gap 15. In a preferred
embodiment of my invention, the fluid inlet tube 10 is constructed from UV-
30 grade silica glass, the fluid 5 to be disinfected is water, and the concentric
gap 15 contains a vacuum.

Alternate Embodiments

2 Alternate embodiments may be devised without departing from the
spirit or the scope of the invention. For example, the methods described
4 herein can be applied not only to water flow, but also to other fluids that
require purification such as breathable air.

6

* * * * *

CLAIMS**What is claimed is:**

1. A system to disinfect water using ultraviolet radiation (UV), said system comprising:
 - (a) a fluid inlet tube (10), for carrying a fluid (5) to be disinfected, said fluid having a first refractive index, said fluid inlet tube constructed from a material having a second refractive index and comprising an entrance end (11), a distally opposing exit end (12), an internal surface (13) in contact with said fluid, and an external surface (14);
 - (b) an optical cladding tube (20) disposed around the external surface of the fluid inlet tube defining a concentric gap (15) between said fluid inlet tube and said optical cladding tube, wherein said concentric gap has a third refractive index;
 - (c) a fluid containment vessel (30) around said fluid inlet tube and said optical cladding tube wherein a portion of said fluid inlet tube extends from said fluid containment vessel and said concentric gap is hydraulically isolated from said fluid containment vessel;
 - (d) an ultraviolet inlet aperture (35) disposed on and forming a portion of said fluid containment vessel;
 - (e) a high intensity ultraviolet lamp (40) providing ultraviolet radiation that passes through said ultraviolet inlet aperture and impinges upon said internal surface of said fluid inlet tube at a predetermined range of incidence angles;

wherein said predetermined range of incidence angles is limited in accordance with said first, second and third refractive indices such that the inlet tube acts as a light pipe wherein

substantially all of the ultraviolet radiation is propagated through said inlet tube via total internal reflection; and

- (f) a fluid outlet tube (50) extending from said fluid containment vessel.
2. The system of claim 1 wherein the concentric gap contains a vacuum.
 3. The system of claim 1 wherein the concentric gap contains a gas selected from the group consisting of: dry air, nitrogen, and argon.
 4. The system of claim 1 wherein the concentric gap contains a clear solid selected from the group consisting of: glass, Plexiglas, and acrylic.
 5. The system of claim 1 wherein said fluid to be disinfected is potable water.
 6. The system of claim 1 wherein said fluid to be disinfected is breathable air.
 7. The system of claim 1 wherein said fluid inlet tube and said optical cladding tube each have a polygonal cross-section.
 8. The system of claim 1 wherein a portion of said fluid inlet tube located within said fluid containment vessel extends past an end of said optical cladding tube.

9. An apparatus for purifying a fluid using ultraviolet (UV) energy, said apparatus comprising:

5 a tube through which the fluid to be purified flows, said tube comprising a non-UV absorbing material;

means encompassing at least a portion of said tube and having a lower refractive index than said fluid so as to create a light pipe;

a source of UV; and

10 a window surface through which the UV energy from said source is coupled into said fluid within said tube, whereby said UV energy is contained within and along the length of said light pipe via total internal reflection.

10. The apparatus of claim 9 wherein said means comprises means defining a gap and encompassing a lower portion of said tube.

15 11. The apparatus of claim 10 wherein said gap encloses air.

12. The apparatus of claim 10 wherein said gap encloses a vacuum.

20 13. The apparatus of claim 9 further comprising a metallic reflector surrounding said tube, said metallic reflector causing UV energy scattered by air bubbles within said fluid to be directed back into said fluid within said tube.

14. The apparatus of claim 13 wherein said metallic reflector comprises aluminum.

25 15. The apparatus of claim 9 wherein said tube comprises UV-grade quartz.

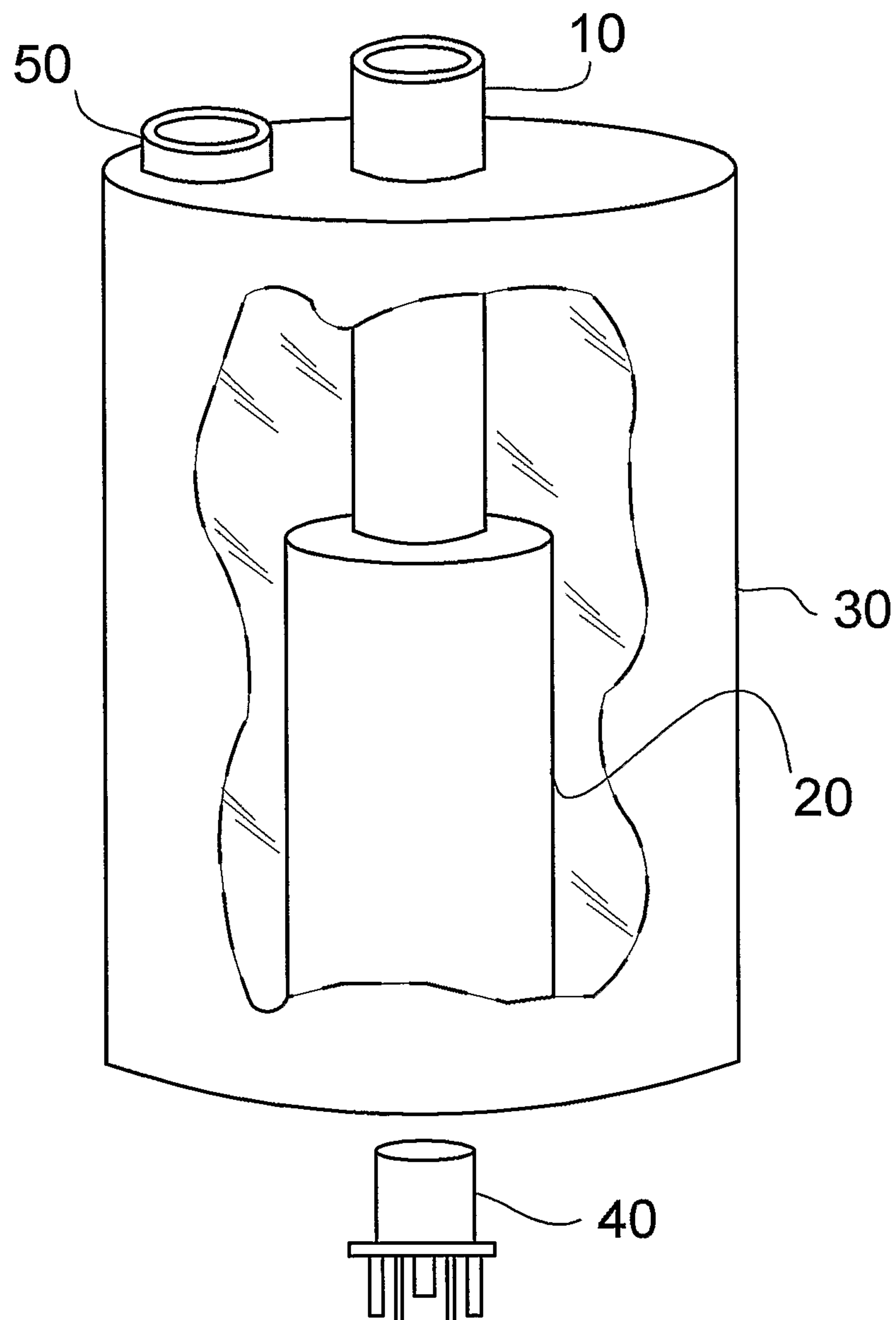
16. The apparatus of claim 9 wherein said tube has a polygonal cross sectional shape.

17. An apparatus for disinfecting a fluid, said apparatus comprising:

30 a chamber having reflective walls, a bottom, at least one inlet and one outlet, wherein the fluid enters the chamber through the inlet and exits through the outlet, and an optically transmissive window integrated into the bottom; and

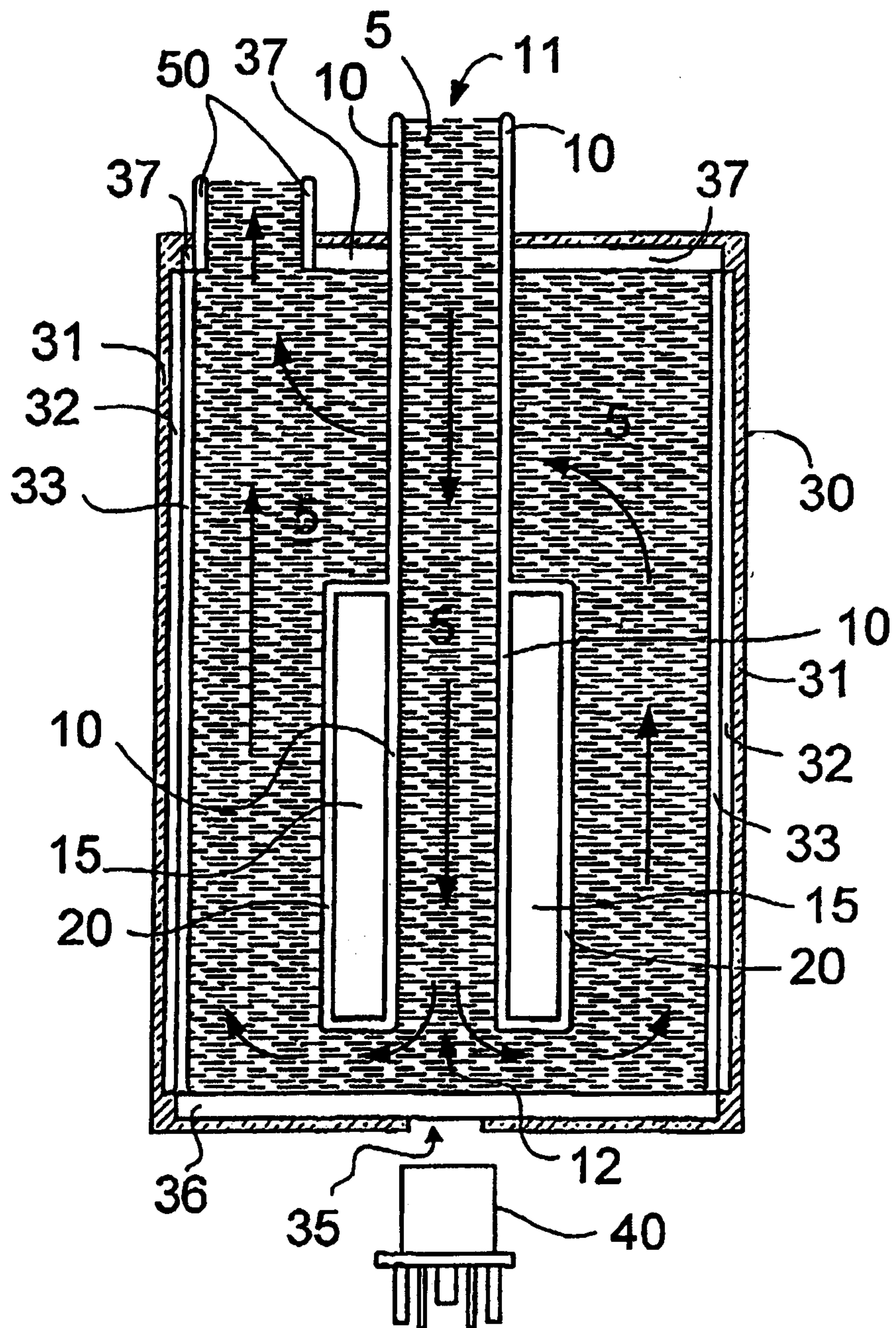
a high intensity source of ultraviolet (UV) light positioned adjacent said window and outside said chamber for transmitting UV radiation throughout said chamber substantially via total reflection off of an inside surface of said reflective walls.

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FIG. 1

2/3

FIG. 2



3/3

FIG. 3

