

Ultraviolet Disinfecting Apparatus

2 RELATED APPLICATIONS

This application is a continuation-in-part of the US Patent Application
4 Serial No. 10/268567, filed October 9, 2002, and relies on the disclosure of US
Provisional Patent Application Serial No. 60/336381, filed November 2, 2001,
6 both of which are incorporated by reference.

BACKGROUND OF THE INVENTION

8 Technical Field

This invention relates to an air purification system using intense ultraviolet
10 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
12 purification of water or other fluids containing naturally occurring toxins or those
resulting from biological and chemical agents used in warfare.

14 Background Art

Prior art UV disinfecting systems are typically water disinfecting systems
16 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
18 water after reflection. The reflecting surfaces, typically polished stainless steel,
absorb a significant amount of radiation. Air disinfection systems, such as that
20 described by Halloran (US Patent 3,744,216) employ extended-arc low pressure
mercury germicidal lamps within an airstream. Companies such as American
22 Ultraviolet and Steril-Aire manufacture systems that use these lamps within duct
of a heating, ventilating, and air conditioning (HVAC) system, providing
24 germicidal action.

In Whitehead, US 4,260,220, a square cross-section hollow tube
26 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
2 90° angle longitudinal corrugations. The walls are constructed of transparent
dielectric material, such as acrylic or optically clear glass. The Whitehead device
4 is used to transport visible light.

A square cross section light waveguide is known in the art to maximum
6 flux homogeneity in a short distance according to Pritchard (US Patent
3,170,980). These devices are typically employed in projection systems
8 between a the light source and an imaging device such as for example is
described in Magarill (US Patent 5,625,738).

10 Common to the prior art UV disinfection systems is overdosage of
ultraviolet (UV) radiation to the air being disinfected, which necessarily increases
12 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
14 UV disinfecting system for air.

SUMMARY OF THE INVENTION

16 My invention is an apparatus and method for disinfecting air that channels
air through one end of a hollow totally internally reflecting light conduit or
18 waveguide and couples ultraviolet (UV) energy from a high intensity lamp
through the conduit or waveguide from the other end. The waveguide itself is
20 constructed of a non-UV-absorbing material, such as UV-grade fused silica
glass. Advantageously, the use of light-pipe technology, which is based on total
22 internal reflection (TIR), ensures that all the input UV radiation is dissipated in
the air.

24 BRIEF DESCRIPTION OF DRAWINGS

Brief Description of the Several Views of the Drawing

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

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

2 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
4 internal reflection (TIR).

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

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

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

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 numerical
12 order.

	1	incidence angle (refraction at fluid inlet tube internal surface)
14	2	internal reflection angle (reflection at fluid inlet tube external surface)
16	5	fluid (to be disinfected)
	10	fluid inlet tube
18	11	entrance end (fluid inlet tube)
	12	exit end (fluid inlet tube)
20	13	internal surface (fluid inlet tube)
	14	external surface (fluid inlet tube)
22	15	concentric gap (between inlet tube and optical cladding tube)
24	20	optical cladding tube

	30	fluid containment vessel
2	31	ultraviolet mirror (fluid containment vessel internal surface)
	32	air gap (fluid containment vessel)
4	33	inner tube (of fluid containment vessel)
	35	ultraviolet inlet aperture
6	36	lower ultraviolet window surface
	37	upper ultraviolet window surface
8	40	high intensity ultraviolet lamp
	50	fluid outlet tube
10	71	first UV light ray (exiting lower ultraviolet window surface)
	72	second UV light ray (exiting fluid)
12	73	third UV light ray (entering fluid inlet tube internal surface)
	74	fourth UV light ray (exiting fluid inlet tube internal surface)
14	75	fifth UV light ray (entering fluid)
	100	light pipe (formed from fluid, fluid inlet tube, and concentric gap)
16		
	101	air inlet fan
18	102	air filter
	103	catalytic filter
20	104	air outlet fan
	105	air (to be disinfected)
22	110	air inlet tube
	111	entrance end (air inlet tube)
24	112	exit end (air inlet tube)
	113	internal surface (fluid inlet tube)
26	114	external surface (fluid inlet tube)
	120	total internal reflecting features (of air inlet tube)
28	121	internal surface (of total internal reflecting features)

	123	deflector mirror
2	130	air containment vessel
	131	ultraviolet mirror (air containment vessel internal surface)
4	135	ultraviolet inlet aperture
	137	ultraviolet window surface
6	140	high intensity ultraviolet lamp
	141	ultraviolet sensor
8	150	fluid outlet tube
	101	air inlet fan
10	102	air filter
	103	catalytic filter
12	104	air outlet fan
	200	controller (for disinfecting system)

14 DESCRIPTION OF THE INVENTION

Mode(s) for Carrying Out the Invention

16 Referring first to FIG. 1, the basic construction of an ultraviolet (UV) water
disinfecting device in accordance with my invention is shown, including a fluid
18 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**,
20 a fluid containment vessel **30**, a fluid outlet tube **50**, and a high intensity UV lamp
40, such as a flashlamp.

22 Referring next to FIG. 2, the fluid containment vessel **30** includes an
internal surface configured as an ultraviolet mirror **31**; for example, the fluid
24 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
26 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
2 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**,
4 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
6 end of the fluid containment vessel **30**.

The fluid **5** is contained within the fluid containment vessel **30**. The fluid
8 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
10 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**
12 are closed off with the lower ultraviolet window surface **36** and an ultraviolet
window upper surface **37**.

14 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
16 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
18 scattering sites for the UV radiation thereby degrading system efficiency. These
UV scattering sites result in UV radiation being directed at less than optimum
20 angles causing reflections from the fluid containment vessel internal surface, the
ultraviolet mirror **31** that is approximately 86% reflective when composed of
22 aluminum tube. Without these UV scattering sites, the ultraviolet radiation is
dissipated mostly within the fluid **5**, because all reflections are near loss-less
24 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**,
26 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
28 **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
30 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 (SiO ₂)		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**,
2 defining a third UV light ray **73**.

The value of angle **2**, as defined by Snell's Law, is a function of incident
4 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
6 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
8 **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
10 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
12 **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**.

14 It is a feature of my invention that a light pipe **100** region, as defined by an
initial optical trajectory from UV light source **40**, exists for at least part of the
16 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
18 the fluid **5**, the material from which the fluid inlet tube **10** is constructed, and the
concentric gap **15**. In a preferred embodiment of my invention, the fluid inlet
20 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.

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

Refer now to FIG. 5, air inlet tube **110** transitions into a section including
2 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
4 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
6 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
8 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
10 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
12 **105** until it strikes another surface, such as UV mirror **131**. Advantageously, air
containment vessel **130** maximizes the overall system efficacy by containing the
14 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
16 beam homogeneity, or other shape as required.

The air **105** travels through the air inlet tube **110** towards the high
18 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
20 functions optically to minimize the amount of UV radiation escaping air
containment vessel **130**.

22 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
24 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**.
26 These rays can be further deflected back into containment vessel **130** by
introducing, for example, a right angle fitting at the inlet aperture **111**.

28 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
30 vessel **130**. As discussed earlier, in certain embodiments, window **135**

comprises one or more lens elements. The TIR structure, for the embodiments
2 that are primarily designed to disinfect air, have more limited containment angles
than the embodiments that are primarily designed to disinfect water. For the
4 embodiments designed to disinfect air, some degree of optical collimation is
advantageous, although the principle of etendue requires a larger cross section
6 for the TIR region **120** of tube **110**.

Finally, the air **105** flow is redirected to the air outlet **150**, which is located
8 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
10 irradiation that has been trapped by UV mirror **131**, and thus forms a practical
embodiment of a high efficiency UV irradiation system. Alternatively, the UV
12 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
14 efficacy (i.e. the amount of disinfection per electrical watt).

In a preferred embodiment, a UV sensor **141** is used as a feedback
16 element to ensure that proper irradiance levels are being applied. Apprise
Technology (Duluth, MN), under the trade name UV Clean, produces a suitable
18 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
20 **140**. Advantageously, this position enables the sensor to measure the
integrated cavity irradiance, and is not prone to variations in the lamp's output
22 distribution. Since the air stream is filtered, cleaning of the sensor's input
aperture is minimized. In certain embodiments, such as those where the
24 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
26 inventive UV disinfecting apparatus, is schematically depicted. Air to be
disinfected enters, for example, through inlet fan **101** and passes through air
28 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
30

containment vessel **30** where it is irradiated by high intensity ultraviolet (UV)
2 lamp **140**. After being irradiated, the air flows from the air containment vessel
130, through optional catalytic filter **103**, which converts ozone back into
4 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
6 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**,
8 controller **200** varies the pulse repetition rate. In further embodiments controller
200 can also provide alarm warnings, for example, when sensor **141** detects
10 abnormally low UV irradiation in chamber **130**, perhaps signaling the need for
the lamp to be replaced.

12 **List of Acronyms used in the Specification**

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

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

Alternate Embodiments

20 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
22 a dual-use application, whereby multiple fluids (e.g. air and water) can be
purified.

24 * * * * *

CLAIMS

What is claimed is:

1. A system to disinfect prefiltered air using ultraviolet radiation
(UV), said system comprising:
 - (a) an air inlet tube (110) comprising an entrance end (111), a distally opposing exit end (112), an internal surface (121) in contact with said air, and an external surface;
 - (b) total internal reflecting features disposed upon at least a portion of the external surface of said air inlet tube;
 - (c) an air containment vessel (130) disposed around said air inlet tube;
 - (d) an ultraviolet inlet aperture (135) optically penetrating said air containment vessel;
 - (e) a high intensity ultraviolet lamp (40) providing ultraviolet radiation that passes through said ultraviolet inlet aperture and impinges upon the internal surface of said air inlet tube; and
 - (f) an air outlet (150) extending from said air containment vessel.
2. The system of claim 1 wherein said air inlet tube is constructed from UV-grade silica glass.
3. The system of claim 1 wherein the light conduit comprises a plurality of prism light guides.

- 2 4. The system of claim 1 further comprising a UV sensor (141) as a
 feedback mechanism
- 2 5. The system of claim 1 wherein ozone generation is suppressed
 by use of a lamp employing UV absorbing glass
- 2 6. The system of claim 1, further comprising a catalytic filter (103) to
 convert ozone into oxygen.