ClorDiSys

Application Note #12

Ultraviolet Light Disinfection Data Sheet

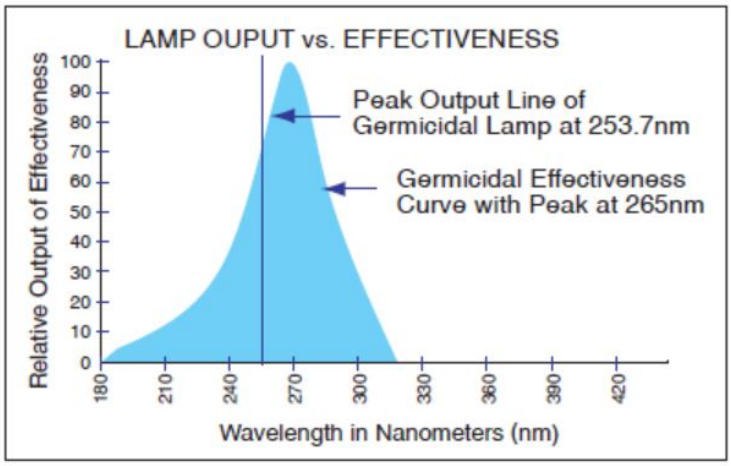
Ultraviolet light (UV) has been used for disinfection since the mid-20th century, with beginnings even earlier when sunlight was investigated for bactericidal effects in the mid-19th century. It's used for drinking and wastewater treatment, air disinfection, the treatment of fruit and vegetable juices, as well as a myriad of home devices for disinfecting everything from toothbrushes to tablet computers. Within research facilities, UV has been an option when purchasing biological safety cabinets for years and can also be used within ductwork.

UV technology has advanced in recent years to become more reliable. Ballasts being used today are able to maintain the power output of UV bulbs for far longer than in the past. UV bulbs now have rated lifespans in the thousands-of-hours. This has allowed UV systems to become more viable for wide ranging use.

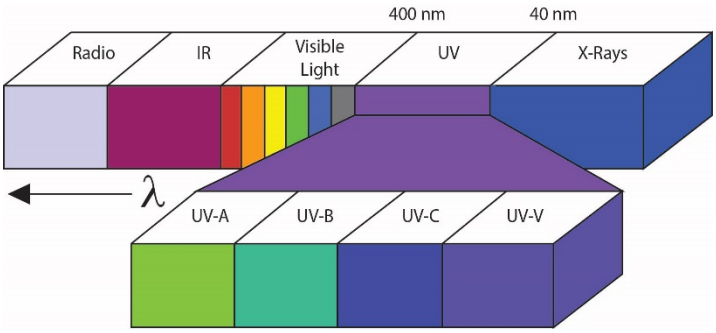
The use of UV has recently grown within the healthcare industry as an invaluable option for preventing the spread of hospital acquired infections, providing disinfection of room surfaces in addition to existing cleaning methods. Since the pandemic of COVID-19 caused by the novel coronavirus SARS-CoV-2, more consumers are interested in purchasing ultraviolet light products to disinfect surfaces in the home, office, transit, and other commercial spaces. The use of ultraviolet light for surface disinfection within an array of facilities has started to increase due to its ease of use, short dosage times, and broad efficacy.

How Does UV Work?

Ultraviolet light exists within the spectrum of light between 10 and 400 nm. The germicidal range of UV is within the 100-280nm wavelengths, known as UV-C, with the peak wavelength for germicidal activity being 265 nm. This range of UV light is absorbed by the DNA and RNA of microorganisms, which causes changes in the DNA and RNA structure, rendering the microorganisms incapable of replicating. A cell that can't reproduce is considered dead; since it is unable to multiply to infectious numbers within a host. This is why UV disinfection is sometimes called ultraviolet germicidal irradiation (UVGI).



ClorDiSys' UV systems use low-pressure, mercury-arc germicidal lamps which are designed to produce the highest amounts of UV radiation - where 90% of energy is typically generated at 254nm. This radiation is very close to the peak of the germicidal effectiveness curve of 265nm, the most lethal wavelength to microorganisms.



What is UV Effective Against?

UV has been proven effective against a broad spectrum of microorganisms. Viruses contain RNA or DNA and are thus susceptible to irradiation. Bacteria and fungi both contain DNA and are similarly vulnerable to UV light. Spores are also susceptible to UV. With the longstanding use of UV for disinfection, there is a plethora of information regarding dosages necessary to inactivate different microorganisms. Bacteria are generally easier to inactivate than viruses, with fungi and spores being even harder to inactivate with UV. **Please see Appendix 2 for a list of microorganisms against which UV-C is effective.**

Safety

As UV-C provides radiation, it is not safe to be in the room while disinfection is taking place. UV-C is classified as "reasonably anticipated to be a human carcinogen" by the National Toxicology Program. It presents a hazard to skin and eyes, so direct exposure to UV-C is always to be avoided. UV-C is blocked by a number of materials, including glass (but not quartz glass) and most clear plastics, so it is possible to safely observe a UV-C system if you are looking through a window.

The process is environmentally friendly in that there are no dangerous or toxic chemicals that require specialized storage or handling. Since no chemicals are added to the air/water, there are no process byproducts to be concerned with. The UV bulbs do not require special handling or disposal either, making the system a green alternative to chemical disinfectants. UV-C provides residue free disinfection, so there is no concern over dangerous residues that need to be wiped down or neutralized after the disinfection occurs.

There has been concern with regard to the residual odors that have been noted after rooms are disinfected with ultraviolet light. Sometimes this smell is associated with ozone, a harmful gas. In reality, this odor is due to UV-C reacting with human dead skin cells and hair from dust in the room.
Up to 80% of airborne dust in homes, offices, and other indoor environments is made up of dead human skin and hair. Skin and hair cells consist of keratin, a protein, while hair also contains cysteine, an amino acid. When high energy UV-C light hits keratin/cysteine molecules, it has enough power to break their internal chemical bonds creating smaller, sulfur-containing compounds that fall into the categories of thiols. The human nose is extremely sensitive to thiols and can detect them at concentrations as low as 1 part per billion. Concentrations of thiol molecules after a UV-C disinfection are negligible when compared to the published acceptable exposure limit. This means that any odor present after a UV-C disinfection is not dangerous, making the room immediately safe to enter after a UV-C disinfection has been performed.

Benefits

While there are definite limitations to UV-C disinfection technologies, there are many benefits as well. Disinfection times are fast, with a typical disinfection cycle lasting about 15 minutes. This allows for extremely fast turnover times for rooms or other spaces being disinfected. Due to its simplicity, UV-C disinfection is extremely easy to understand. All surfaces within a certain distance will observe an assured level of disinfection in a certain amount of time as long as the light is not blocked from shining on that surface. It becomes very easy to plan the use of a UV-C disinfection system when the parameters and limitations are easily established and understood.

There is no need to establish air flow patterns with UV-C as you would with a fogging system. Nor is there a need to isolate rooms from HVAC systems or seal doors. This, along with the lack of chemical mixture, makes the preparation time quick to setup and start a UV-C disinfection cycle.

The cost to run UV systems is very low, as systems are powered by regular wall outlets. With that, a typical UV-C treatment costs under two cents. UV systems also require little maintenance and upkeep due to their simplistic nature. UV bulbs last thousands of hours at their peak output, limiting the need for routine consumable change out and maintenance.

Drawbacks

While UV is effective at inactivating a wide range of microorganisms, there are limitations for its use. As it involves light waves, UV operates in a "line-of-sight" fashion, only irradiating surfaces within its sightlines. Surfaces can be blocked from the light if objects are in the way, much like a beach umbrella offering protection from the sun. These areas that become blocked from the UV light are commonly referred to as shadow areas. Surfaces in these shadow areas do not receive adequate disinfection as UV light does not have the ability to reflect well. Shadow areas can be addressed by moving the UV light source to a second position to accommodate disinfection of the surfaces blocked from first disinfection cycle. UV light also does not penetrate well into organic materials, so for best results, UV-C should be used after a standard cleaning of the room to remove any organic materials from surfaces.

Distance also plays a factor into the efficacy of UV light. The strength of the UV-C light decreases the further away it gets from the light source, following the inverse square law. This means that at twice the distance, the UV-C will have ¼ of its power that was present at the original reference point. This relationship limits how far a single source of UV light is effective before it is too weak to provide adequate disinfection. Most systems deal with this by quantifying their UV-C output at a given distance, and using that distance to generate treatment times. Sensors are available which can measure the UV-C output of the UV systems at any location, such that adequate treatment times can be interpreted.

Applications

UV light can safely be used for a variety of disinfection applications. Systems are available to disinfect rooms and high traffic areas with common touchpoints, ambulances and other emergency service vehicles, ductwork, tools or equipment inside a disinfection chamber, continuous pass-through conveyors, and many more. It has long been available for biological safety cabinet disinfection and home water treatment as well. It provides a chemical free method of disinfecting soundproofing materials and sensitive electronics that are traditionally chemically incompatible.

Appendix 1 – Historical Use of UV Light for Disinfection

For the past 100 years science has recognized the bactericide effects of the ultraviolet area of the electromagnetic spectrum. Below are some key contributions over the years:

1855 Arloing and Daclaux demonstrated sunlight killed Bacillus anthracis and Tyrothrix scaber

1877 Downes and Blunt reported bacteria were inactivated by sunlight – violet blue spectrum most effective

1889 Widmark confirmed UV rays from arc lamps were responsible for inactivation

1892 Geisler used a prism and heliostat to show sunlight and electric arc lamps are lethal to Bacillus Typhosus

1903 Banard and Morgan determined UV spectrum 226-328 nm is biocidal

1932 Ehris and Noethling isolated biocidal spectrum to 253.7 nm

1957 Riley proves effectiveness for Tb control

1994 CDC acknowledges UV effectiveness for Tb control

1999 WHO recommends UVGI for Tb control

2014 UV-C used as part of the terminal cleaning procedure within the Nebraska Biocontainment Unit upon ebola patient discharge

2020 UV-C Disinfection recommended for the disinfection of N95 masks and other PPE during SARS-CoV-2 pandemic.

Appendix 2 – Ultraviolet Light Exposure Dosage

The degree of inactivation by ultraviolet radiation is directly related to the UV dose applied. The UV dose is the product of UV intensity [I] (expressed as energy per unit surface area) and exposure time [T]. Therefore: DOSE = I x T

This dose is commonly expressed as millijoule per square centimeter (mJ/cm^2).

The reduction of micro-organisms is classified using a logarithmic scale. A single log reduction is a 90% reduction of organisms. A two log reduction is a 99% reduction of organisms, followed by a three log reduction (99.9%), etc. The UV-C exposure dosage needed for each level of reduction is shown in the table along with the published reference where the data came from.

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UV Dose (mJ/cm²) for Various Reduction Levels

Spore	90%	99%	99.9%	99.99%	99.999%	99.9999%	Reference
Bacillus anthracis spores – Anthrax spores	24.32	48.64	72.96	97.28			UV-Light.co.UK
Bacillus magaterium sp. spores	2.73	5.46	8.19	10.92			UV-Light.co.UK
Bacillus subtilis ATCC6633(spores	36	48.6	61	78			Chang et al. 1985
Clostridioides difficile (C. diff) spores	6.0	12.0	18.0	24.0			UV-Light.co.UK
Bacterium							
Aeromonas salmonicida	1.5	2.7	3.1	5.9			Liltved and Landfald 1996
Aeromonas hydrophila ATCC7966	1.1	2.6	3.9	5	6.7	8.6	Wilson et al. 1992
Bacillus anthracis – Anthrax	4.52	9.04	13.56	18.08			UV-Light.co.UK
Bacillus magaterium sp. (veg.)	1.3	2.6	3.9	5.2			UV-Light.co.UK
Bacillus paratyphusus	3.2	6.4	9.6	12.8			UV-Light.co.UK
Bacillus subtilis	5.8	11.6	17.4	23.2			UV-Light.co.UK
Campylobacter jejuni ATCC 43429	1.6	3.4	4	4.6	5.9		Wilson et al. 1992
Citrobacter diversus	5	7	9	11.5	13		Giese and Darby 2000
Citrobacter freundii	5	9	13				Giese and Darby 2000
Clostridium tetani	13.0	22.0					Light Sources Inc. 2014
Corynebacterium diphtheriae	3.37	6.74	10.11	13.48			UV-Light.co.UK
Ebertelia typhosa	2.14	4.28	6.42	8.56			UV-Light.co.UK
Escherichia coli O157:H7 CCUG 29193	3.5	4.7	5.5	7			Sommer et al. 2000
Escherichia coli O157:H7	<2	<2	2.5	4	8	17	Yaun et al. 2003
Halobacterium elongate ATCC33173	0.4	0.7	1				Martin et al. 2000
Halobacterium salinarum ATCC43214	12	15	17.5	20			Martin et al. 2000
Klebsiella pneumoniae	12	15	17.5	20			Giese and Darby 2000
Klebsiella terrigena ATCC33257	4.6	6.7	8.9	11			Wilson et al. 1992
Legionella pneumophila ATCC33152	1.9	3.8	5.8	7.7	9.6		Oguma et al.2004
Leptospiracanicola – infectious Jaundice	3.15	6.3	9.45	12.6			UV-Light.co.UK
Micrococcus candidus	6.05	12.1	18.15	24.2			UV-Light.co.UK
Micrococcus sphaeroides	1.0	2.0	3.0	4.0			UV-Light.co.UK
Mycobacterium tuberculosis	6.2	12.4	18.6	24.8			UV-Light.co.UK
MRSA	3.2	6.4	9.6	12.8			UV-Light.co.UK
Neisseria catarrhalis	4.4	8.8	13.2	17.6			UV-Light.co.UK
Phytomonas tumefaciens	4.4	8.8	13.2	17.6			UV-Light.co.UK
Proteus vulgaris	3.0	6.0	9.0	12.0			UV-Light.co.UK
Pseudomonas stutzeri	100	150	195	230			Joux et al. 1999
Pseudomonas aeruginosa	5.5	11.0	16.5	22.0			UV-Light.co.UK
Pseudomonas fluorescens	3.5	7.0	10.5	14.0			UV-Light.co.UK
Salmonella anatum (from human feces)	7.5	12	15				Tosa and Hirata 1998
Salmonella derby (from human feces)	3.5	7.5					Tosa and Hirata 1998
Salmonella enteritidis	4.0	8.0	12.0	16.0			UV-Light.co.UK
Salmonella infantis (from human feces)	2	4	6				Tosa and Hirata 1998
Salmonela paratyphi – Enteric fever	3.2	6.4	9.6	12.8			UV-Light.co.UK
Salmonella typhosa – Typhoid fever	2.15	4.3	6.45	8.6			UV-Light.co.UK

UV Dose (mJ/cm²) for Various Reduction Levels

Bacteria	90%	99%	99.9%	99.99%	99.999%	99.9999%	Reference
Salmonella typhimurium	8.0	16.0	24.0	32.0			UV-Light.co.UK
Sarcina lutea	19.7	39.4	59.1	78.8			UV-Light.co.UK
Serratia marcescens	2.42	4.84	7.26	9.68			UV-Light.co.UK
Shigella dyseteriae – Dysentery	2.2	4.4	6.6	8.8			UV-Light.co.UK
Shigella flexneri – Dysentery	1.7	3.4	5.1	6.8			UV-Light.co.UK
Shigella paradysenteriae	1.68	3.3	5.04	6.72			UV-Light.co.UK
Shigella sonnei ATCC9290	3.2	4.9	6.5	8.2			Chang et al. 1985
Spirillum rubrum	4.4	8.8	13.2	17.6			UV-Light.co.UK
Staphylococcus albus	1.84	3.68	5.52	7.36			UV-Light.co.UK
Staphylococcus aureus	2.6	5.2	7.8	10.4			UV-Light.co.UK
Staphylococcus hemolyticus	2.16	4.32	6.48	8.64			UV-Light.co.UK
Staphylococcus lactis	6.15	12.3	18.45	24.6			UV-Light.co.UK
Streptococcus faecalis ATCC29212	6.6	8.8	9.9	11.2			Chang et al. 1985
Streptococcus viridans	2.0	4.0	6.0	8.0			UV-Light.co.UK
Vibrio anguillarum	0.5	1.2	1.5	2			Liltved and Landfald 1996
Vibrio comma – Cholera	3.375	6.75	10.125	13.5			UV-Light.co.UK
Vibrio natriegens	37.5	75	100	130	150		Joux et al. 1999
Yersinia enterocolitica ATCC27729	1.7	2.8	3.7	4.6			Wilson et al. 1992
Yersinia ruckeri	1	2	3	5			Liltved and Landfald 1996
Yeasts							
Brewers yeast	3.3	6.6	9.9	13.2			UV-Light.co.UK
Common yeast cake	6.0	12.0	18.0	24.0			UV-Light.co.UK
Saccharomyces carevisiae	6.0	12.0	18.0	24.0			UV-Light.co.UK
Saccharomyces ellipsoideus	6.0	12.0	18.0	24.0			UV-Light.co.UK
Saccharomyces spores	8.0	16.0	24.0	32.0			UV-Light.co.UK
Molds							
Aspergillius flavus	60.0	120.0	180.0	240.0			UV-Light.co.UK
Aspergillius glaucus	44.0	88.0	132.0	176.0			UV-Light.co.UK
Aspergillius niger	132.0	264.0	396.0	528.0			UV-Light.co.UK
Mucor racemosus A	17.0	34.0	51.0	68.0			UV-Light.co.UK
Mucor racemosus B	17.0	34.0	51.0	68.0			UV-Light.co.UK
Oospora lactis	5.0	10.0	15.0	20.0			UV-Light.co.UK
Penicillium digitatum	44.0	88.0	132.0	176.0			UV-Light.co.UK
Penicillium expansum	13.0	26.0	39.0	52.0			UV-Light.co.UK
Penicillium roqueforti	13.0	26.0	39.0	52.0			UV-Light.co.UK
Rhisopus nigricans	111.0	222.0	333.0	444.0			UV-Light.co.UK
Protozoan							
Chlorella Vulgaris	13.0	26.0	39.0	52.0			UV-Light.co.UK
Cryptosporidium hominis	3	5.8					Johnson et al. 2005
Cryptosporidium parvum	2.4	<5	5.2	9.5			Craik et al. 2001
Cryptosporidium parvum, oocysts, tissue culture assay	1.3	2.3	3.2				Shin et al. 2000
Encephalitozoon cuniculi,microsporidia	4	9	13				Marshall et al. 2003
Encephalitozoon hellem,microsporidia	8	12	18				Marshall et al. 2003
Encephalitozoon intestinalis,microsporidia	<3	3	<6	6			Huffman et al. 2002

UV Dose (mJ/cm²) for Various Reduction Levels							
Protozoan	90%	99%	99.9%	99.99%	99.999%	99.9999%	Reference
Giardia lamblia	<10	~10	<20				Campbell et al. 2002
Giardia muris	<10	<10	<25	~60			Belosevic et al. 2001
Nematode Eggs	45.0	90.0	135.0	180.0			UV-Light.co.UK
Paramecium	11.0	22.0	33.0	44.0			UV-Light.co.UK

The following table shows the required UV-C exposure dosages necessary for various log reductions of viruses.

UV Dose (mJ/cm²) for Various Reduction Levels								
Virus	Host	90%	99%	99.9%	99.99%	99.999%	99.9999%	Reference
Adenovirus type 15	A549 cell line (ATCC CCL-	40	80	122	165	210		Thompson et al. 2003
Adenovirus type 2	PLC / PRF / 5	40	78	119	160	195	235	Gerba et al. 2002
B40-8 (Phage)	B. Fragilis	11	17	23	29	35	41	Sommer et al. 2001
Bacteriophage – E. Coli		2.6	5.2	7.8	104.0			UV-Light.co.UK
Calicivirus canine	MDCK cell line	7	15	22	30	36		Husman et al. 2004
Calicivirus feline	CRFK cell line	5	15	23	30	39		Thurston-Enriquez et al. 2003
Coxsackievirus B3	BGM cell line	8	16	24.5	32.5			Gerba et al. 2002
Coxsackievirus B5	BGM cell line	9.5	18	27	36			Gerba et al. 2002
Echovirus I	BGM cell line	8	16.5	25	33			Gerba et al. 2002
Echovirus II	BGM cell line	7	14	20.5	28			Gerba et al. 2002
Hepatitis A HM175	FRhK-4 cell	5.1	13.7	22	29.6			Wilson et al. 1992
Infectious Hepatitis		5.8	11.6	17.4	232.0			UV-Light.co.UK
Influenza		3.4	6.8	10.2	136.0			UV-Light.co.UK
MS2 (Phage)	*E. coli*		45	75	100	125	155	Thompson et al. 2003
Norovirus		10	16	22	26	30		Lee et al. 2008
Parvovirus		2.2	4.6					Cornelis et al. 1982
PHI X 174 (Phage)	*E. coli* WG 5	3	5	7.5	10	12.5	15	Sommer et al. 2001
Poliovirus – Poliomyelitis		3.15	6.3	9.45	126.0			UV-Light.co.UK
Poliovirus 1	CaCo2 cell-line (ATCC HTB37)	7	17	28	37			Thompson et al. 2003
PRD-1 (Phage)	S. typhimurium	9.9	17.2	23.5	30.1			Meng and Gerba 1996
Reovirus Type 1 Lang strain	N/A	16	36					Harris et al. 1987
Reovirus-3	Mouse L-60	11.2	22.4					Rauth 1965
Rotavirus	MA104 cells	20	80	140	200			Caballero et al. 2004
Rotavirus SA-11	MA-104 cell	9.1	19	26	36	48		Wilson et al. 1992
SARS-CoV-2	N/A		5				22	Boston University. 2020
Staphylococcus aureus phage A	*Staphylococcus aureus* 994	8	17	25	36	47		Sommer et al. 1989
Tobacco mosaic	N/A	240.0	440.0					Light Sources Inc. 2014

Appendix 3 – Persistence of Bacteria (As compiled via a Google Search)

Persistence of Clinically Relevant Bacteria on Dry Inanimate Surfaces[1]	
Organism	**Persistence**
Acinetobacter spp.	3 days to 5 months
Bordetella pertussis	3-5 days
Campylobacter jejuni	Up to 6 days
Clostridium difficile (spores)	5 months
Chlamydia pneumoniae	Up to 30 hours
Chlamydia psittaci	15 days
Corynebacterium diphtheria	7 days – 6 months
Corynebacterium pseudotuberculosis	1-8 days
Escherichia coli	1.5 hours – 16 months
Enterococcus spp. including VRE and VSE	5 days – 4 months
Haemophilus influenza	12 days
Helicobacter pylori	Up to 90 minutes
Klebsiella spp.	2 hours – 30 months
Listeria spp.	1 day – 4 months
Mycobacterium bovis	Up to 2 months
Mycobacterium tuberculosis	1 day – 4 months
Neisseria gonorrhoeae	1-3 days
Proteus vulgaris	1-2 days
Pseudomonas aeruginosa	6 hours – 16 months; 5 weeks on dry floor
Salmonella typhi	6 hours – 4 weeks
Salmonella typhimurium	10 days – 4.2 years
Salmonella spp.	1 day
Serratia marcescens	3 days – 2 months; 5 weeks on dry floor
Shigella spp.	2 days – 5 months
Staphylococcus aureus, including MRSA	7 days – 7 months
Streptococcus pneumoniae	1-20 days
Streptococcus pyogenes	3 days – 6.5 months
Vibrio cholera	1-7 days

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