JFHB Journal of Food Health and Bioenvironmental Science

Journal of Food Health and Bioenvironmental Science
Journal homepage : http://jfhb.dusit.ac.th/

UV-C Disinfection in the Environment of Pathogen Transmission

Charuvan Kasemsap*

Department of Engineering Management, Graduate School, Kasem Bundit University, Bangkok, 10250 Thailand

Article info

Article history:
Received : 6 September 2020
Revised : 11 January 2021
Accepted : 20 January 2021

Keywords:
UV-C, Disinfection, Environment, COVID-19

Abstract

Coronavirus disease 2019 (COVID-19) is a respiratory infection caused by SAR-COV-2 (COVID-19 virus). COVID-19 typically rapidly spread from one person to another via respiratory droplets (>5-10 µm in diameter) during coughing and sneezing or touch. Thus, environmental surfaces should be frequently cleaned with water, detergent, and followed by application of disinfection as chemical disinfectants and physical disinfection. Ultraviolet germicidal irradiation (UVGI) is the use of ultraviolet energy to inactivate viral, bacterial, and fungal species because the UVC directly damages deoxyribonucleic acid (DNA), Ribonucleic acid (RNA), and also prevent the bacterium from being viable. The most effective wavelength is in 245 -285 nm. Conventional ultraviolet disinfection consists of a mercury amalgam, which is a hazardous material to the environment. In addition, excessive exposure causes sunburn skin, skin cancer and damage to the corneas of the eyes. Therefore, the risk management such as enclosure cabinets, indicator warning sign light, and personal protection equipment (PPE) should be considered.

Introduction

On 31 December 2019, Wuhan Municipality in Hubei Province, People's Republic of China reported a cluster of pneumonia cases with unknown etiology. On 30 January 2020, more than 9,700 confirmed cases in China and 106 confirmed cases in 19 other countries, the World Health Organization (WHO) Director General declared the outbreak a public health emergency of international concern (PHEIC). On 11 February, WHO named the disease, COVID-19, short for "coronavirus disease 2019." On the same day, the International Committee on Taxonomy of Viruses (ICTV) announced "severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)" as the name of the new virus which causes COVID-19 (Pan American Health Organization [PAHO] & World Health Organization [WHO], 2020; Ragan et al., 2020). Coronavirus disease 2019 (COVID-19) is a respiratory infection caused by SAR-COV-2 (COVID-19 virus). Common symptoms include fever, cough, sneezing, sore throat, breathlessness, fatigue, pneumonia, acute respiratory distress syndrome (ARDS) (Hafeez et al., 2020) and multi organ dysfunction (Singhal, 2020; Hafeez et al., 2020; Occupational Safety and Health Administration [OSHA], 2020). Some symptoms of SARS-CoV-2 induced COVID-19 are a bit similar to influenza and seasonal allergies (pollen allergies) therefore suspected patients may also exhibit

* Corresponding Author
e-mail: charuvan.kas@kbu.ac.th

temperature which can be detected by thermo-scanners, as well as be detected with an accurate and rapid diagnostic kit of SARS-CoV-2 (Shereen et al., 2020). Time from exposure and symptom onset is generally between two and 14 days, with an average of five days. The elderly and people with underlying diseases are susceptible to infection and prone to serious outcomes (Guo et al., 2020).

COVID-19 transmission

SARS-CoV-2 is an enveloped virus with an outer lipid envelope as shown in Fig.1 (Hafeez et al., 2020), which makes it more susceptible to disinfectants compared to nonenveloped viruses. The virus that causes COVID-19 is typically rapidly spread from one person to another via respiratory droplets (>5-10 µm in diameter) during coughing and sneezing (WHO, 2020a) or close contact (Salem et al., 2020). Droplet transmission of the COVID-19 virus can occur by direct contact with infected people and indirect contact with surfaces. Environmental infection control of surfaces and limiting person-to-person contact are important steps (Jones, 2020). Recommended preventive measures include washing your hands with soap, covering the mouth when coughing, and monitoring and self-isolation for fourteen days for people who suspect they are infected (Hafeez et al., 2020). The survival time of the coronavirus 2019-nCoV were differed at different environment as shown in Table 1 (Zhou, 2020). Regular housekeeping practices include routine cleaning of surfaces, equipment, and other elements of the work environment to reduce exposure to hazards (OSHA, 2020). In addition, healthy indoor air quality (IAQ) should be interpreted by cleaning and disinfection of environmental surfaces (Kamaruzzaman & Sabrani, 2011).

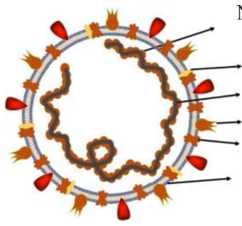

Fig. 1 A structure of SARS-CoV-2
Source: Hafeez et al. (2020)

Table 1 Survival time of the coronavirus 2019-nCoV on different surfaces and specific temperatures

Different environments	Temperature	Survival time
Air	50 – 59 F	4 hours
	77 F	2 – 3 minutes
Droplets	<77 F	24 hours
Nasal mucus	132.8 F	30 minutes
Liquid	167 F	15 minutes
Hands	68 – 86 F	< 5 minutes
Non-woven fabric	50-59 F	< 8 hours
Wood	50 – 59 F	48 hours
Stainless steel	50 – 59 F	24 hours
75 % alcohol	Any temperature	< 5 minutes
Bleach	Any temperature	< 5 minutes

Source: Zhou (2020)

Environment disinfection

Cleaning is the removal of gross contamination, organic material, and debris from the premises or respective structures, via mechanical means like sweeping (dry cleaning), mechanical action (brushing or scrubbing) and/or the use of water and soap or detergent (wet cleaning). Its goal is to minimize dirt, debris, and organic material such as blood, secretions and excretions but does not kill microorganisms (Foreign Animal Disease Preparedness and Response Plan [FAD PReP], 2018; WHO, 2020a; WHO, 2020b). Disinfection is the methods used on surfaces to destroy or eliminate a specific species of infectious microorganism through physical (e.g., heat) or chemical (e.g., disinfectant) means (FAD PReP, 2018). It is the primary mechanism for the inactivation of pathogenic organisms to prevent the spread of diseases to the environment (Environmental Protection Agency [EPA], 1999).

1. Chemical disinfection

Environmental surfaces should be frequently cleaned with water, detergent, and disinfectant, respectively. Chemical disinfectants inactivate a wide variety of microorganisms. In indoor spaces, routine application of disinfectants to material surfaces via spraying or fogging (also known as fumigation or misting) is not recommended (WHO, 2020a). Spraying individuals with disinfectants (such as in a tunnel, cabinet, or chamber) is not recommended under any circumstances owing to health effects on eyes, respiratory system, skin irritation, and gastrointestinal (WHO, 2020a; WHO, 2020b). The concentration and contact time of disinfectant are also critical for effective surface disinfection (WHO, 2020b) as shown in Table 2 (Rutala et al., 2019; Ogilvie et al., 2021). The most commonly used alcohol-based disinfectants are ethyl alcohol (ethanol 70-90%) and isopropyl alcohol (isopropanol). The oxidizing agents peroxide-based disinfectants are hydrogen peroxide, which solutions of 5-20% are considered for bactericidal, enveloped virus, fungicidal, and sporicidal (FAD PReP et al., 2014). The chlorine-based product (e.g., hypochlorite) at 0.1% (1000 ppm) was recommended for general environmental disinfection (WHO, 2020a). Chlorhexidine (also known as chlorhexidine gluconate) also effectively inactivates the virus (Zhou, 2020). Owing to the length of time that COVID-19 virus can survive on inanimate surfaces varies depending on factors such as the amount of contaminated body fluid (e.g. respiratory droplets) and environmental temperature as well as humidity; routine environmental cleaning on touched surfaces e.g. door handles, tabletops, light switches by using detergent solution and disinfectant solution can reduce environmental contamination (WHO, 2020c).

Table 2 Concentration and contact time of different chemical disinfectants for surface disinfection

Chemical disinfectants	Concentration required to destroy	Contact time
Alcohol	Ethyl alcohol and isopropyl alcohol 60%–90% solutions in water (volume/volume)	10 seconds
Chlorine compounds	5.25%–6.15% Sodium hypochlorite	1 minute
Formaldehyde	Formalin, which is 37% formaldehyde by weight	2 minutes
Glutaraldehyde	≥2% Aqueous solutions of glutaraldehyde, buffered to pH 7.5–8.5 with sodium bicarbonate	<2 minutes
Hydrogen peroxide	0.5% Hydrogen peroxide	1 minute
Iodophors	Iodine 75–150 ppm	seconds to minutes
Ortho-phthalaldehyde (OPA)	0.55% 1,2-benzenedicarboxaldehyde (OPA).	5 minutes
Peracetic acid or peroxyacetic	1,500–2,250 ppm	15 minutes
Peracetic acid and hydrogen peroxide	0.08% Peracetic acid plus 1.0% hydrogen peroxide, 0.23% Peracetic acid plus 7.35% hydrogen peroxide	20 minutes
Benzalkonium chlorides	0.2% w/w in water	15 seconds

2. Physical disinfection

Physical disinfection can be used by heat and ultraviolet radiation. Heat is the thermal inactivation of infectious agents. Heat destroys microorganisms by causing deoxyribonucleic acid (DNA) disruption, protein denaturation, oxidative damage, and loss of membrane integrity. The time required is inversely related to the temperature and directly related to the number of microorganisms. Heat can be applied under moist (e.g., autoclave, steam) or dry (e.g., incineration, baking) conditions. Moist heat can be effectively applied through steam under pressure when dealing with thermally resistant bacterial spores. Dry heat applications can be useful for the disinfection of heat-resistant materials, such as glass or metals. Moist heat applications are generally more effective and require less time than dry heat. In addition, the coronavirus is sensitive to sustained heat at 132.8°F for 30 minutes (Zhou, 2020).

The Ultraviolet (UV) in sunlight is in the wavelength 300-400 nm and is not very effective to inactivate microorganisms. The most effective biocidal wavelength is in 245-285 nm. Inactivation of microorganisms results from destruction of nucleic acid through induction of thymine dimers. Bacterial spores will require 10 times the exposure time as the vegetative forms of the organisms. Its germicidal effectiveness is influenced by wavelength; UV intensity, type of suspension; and type of microorganism (Rutala et al., 2019). In addition, UV in 245–285 nm may be useful for the control of SAR-COV-2 airborne pathogens in enclosed areas because the coronavirus is sensitive to ultraviolet rays (Zhou, 2020).

Ultraviolet disinfection

UV emitted from the region of the solar spectrum between visible light (400-750 nm) and x-rays. The UV spectrum is commonly divided into UVA (wavelength of 400 nm to 315 nm), UVB (315 nm to 280 nm), UVC (280 nm to 200 nm) (Martin et al., 2008), and vacuum UV (VUV) at 100-200 nm (Vatansever et al., 2013). The atmospheric ozone layer in the stratosphere, about 10-50 kilometers above the Earth's surface absorbs and scatters UV light (UVB and UVC) from the Sun (Carlowicz, 2013). The absorption of radiation by atmospheric gases and scattering by atmospheric aerosols, and clouds, as well as the earth's surface prevent all UVC radiation from reaching the troposphere and the earth's surface (Kerr, 2005). The earth absorbs much radiation from the Sun to warm the atmosphere, the land, and the oceans.

UVA and UVB cause sun burning, photo aging skin (Vatansever et al., 2013), and also damaged eyes (Solomon, 2008). Prolonged human exposure to solar UV radiation may result in acute and chronic health effects on the skin, eye and immune system (WHO et al, 2002). UV radiation emitted by sunbeds, is a complete carcinogen, as it acts both as an initiator and a promoter.

An initiator causes a genetic mutation or epigenetic changes while a promoter causes rapid cell growth. There is no threshold level of UV–fluence and UV-dose for the induction of skin cancer. The beneficial effects of sunbed use, such as generation of vitamin D (Orazio et al., 2013), are outweighed by the adverse effects. There is no need to use sunbeds to induce vitamin D production because alternative sources of vitamin D are readily available. Therefore, there is no safe limit for exposure to UV radiation from sunbeds (Scientific Committee on Health, Environmental and Emerging Risks [SCHEER], 2017). In addition, solar UV radiation penetrates to ecological significant depths in aquatic systems and can affect in the food web (Häder et al., 2007). Exposure to solar UV radiation can reduce productivity of aquatic organisms. Corals live in an environment characterized by high ambient levels of UVC radiation resulting in the death of gastrodermal cells and injured as evidenced by pale coloration (Basti et al., 2009).

UVC has also been an important tool for wastewater treatment (Vatansever et al., 2013). The Photocatalytic of UVC radiation and the adsorption with nanoclay can remove an anionic dye (RR120) from wastewater (Siahpoosh & Soleimani, 2017). The application of UVC radiation caused COD removal in the Sulphate Radical-Based Advanced Oxidation Processes (SR-AOP) of winery wastewater treatment (Amor et al., 2019). The harmful anionic surfactants in aqueous ecosystems can be degraded by using H_2O_2/UVC system (Rios et al., 2017). The UVC/H_2O_2, VUV and VUV/H_2O_2 processes removal total organic carbon (TOC) from the Biologically-treated hospital wastewater (BHW) (Moussari et al., 2019). The combined ozone/UV treatments were able to achieve zero *E. coli* and *A. niger* count for cloudy and turbid medium, like flour slurry (Sangadkit et al., 2020).

UVC has also been an important tool for food processing industry (Vatansever et al., 2013). It over 60 seconds decreased the inoculated *Staphylococcus aureus* population in precooked shredded bullfrog meat (Silva et al., 2015). It reduced the Salmonella spp. in caiman meat (Canto et al., 2019). Its radiation improved the safety of fish fillets from fresh water and marine sources (Ahmed & Amin, 2019). The combination of its irradiation and lactic acid bacteria (LAB) inhibited the growth of *Salmonella enteritidis* during storage of fresh-cut apples (Chen et al., 2017). It treated strawberries inhibit microbial loads and delay ripening process of fruit products (Idzwana et al., 2019). Its treatment reduced the natural microflora growth of fresh rocket leaves (Rivera-Gutiérrez et al., 2015). The combination of it and aerosolized 2% malic acid can inhibit the growth of foodborne pathogens on fresh-cut lettuce (Seong et al., 2016). Its radiation removed larvae (Adams et al., 2018) and increased mortality of adult insects (Poushand et al., 2017).

Ultraviolet germicidal irradiation (UVGI) has been used in disinfection infectious agents. UVGI emits nonionizing electromagnetic radiation with UVC wavelength of 254 nm inactivate viral, bacterial, and fungal species (Martin et al., 2008) through the damage to DNA and ribonucleic acid (RNA). The UVC spectrum has been produced by mercury vapor arc lamps enclosed in a quartz tube (Martin et al., 2008; Vatansever et al., 2013). The dosage of UVC was proportional to distance from the UV device, exposure time, the amount of energy in watts per unit surface area (WHO, 2020b). Dose and is expressed in microwatt seconds per centimeter squared ($\mu Wsec/cm^2$). Divide by 1000 to express the dose in the preferred notation millijoule per centimeter squared (mJ/cm^2) (Renzel, 2016). Furthermore, humic materials can shield embedded bacteria (EPA, 1999). Thus, UV-disinfection reactors should be designed to deliver the highest amount of radiation at direct radiation zone (Artichowicz et al., 2020). UVGI can reduce the concentrations of airborne bacteria in the indoor environment (Kujundzic et al., 2006; Makarapong et al., 2020; Szeto et al., 2020). The combination of UVC mainly 254 nm and VUV at 185 nm can inactivate airborne human pathogens for bacteria (Szeto et al., 2020). In addition, airborne bacteria were reduced between 79 and 91% while most surfaces also showed reductions in bacteria from 48 to 69% (Lee, 2017). The capacity of a portable ultraviolet-C equipment (UV Sanitizer Corvent® -UVSC-) in disinfection Pathogens: *Acinetobacter baumannii, Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus and Candida albicans* was achieved with 99.99% at 120 seconds of exposure time (Guridi et al., 2019). UVGI was disinfection of air in health care facilities to meet indoor air quality (IAQ) requirements (Memarzadech et al., 2010; Warren et al., 2020). The advantage of UVC using in environmental disinfection were shown in Table 3 (Ontario Agency for Health Protection and Promotion, 2018; Elguijja et al., 2020).

Table 3 Advantage and disadvantage of UVC using in environmental disinfection

No.	Advantage	Disadvantage
1.	Broad-spectrum activity against pathogens involved in healthcare-associated infections	-
2.	Can be used for disinfecting both environmental surface as well as medical devices	Cannot be used as stand-alone disinfection
3.	Rapid contact time, for example, 15 minutes for vegetative bacteria	-
4.	Has a sporicidal activity after longer exposure for up to 50 minutes	-
5.	Does not require closing the HVAC (Heating-Ventilation-Air Conditioning) system, nor sealing the room	The room must be vacated for decontamination
6.	Eco-friendly, with no residue	-
7.	Low operating costs	High capital costs

Conventional ultraviolet (UV) disinfection consists of a mercury amalgam encapsulated within a quartz sleeve (Simons et al., 2018). Due to the Minamata conventional of The United Nations Environment Programme (UNEP) relating to storage of Mercury compounds (Article10) and mercury waste in Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (Article 11), the mercury content of conventional was limited in order to ensure human and environmental health (Kim & Kang, 2018). Because of Mercury is a very toxic substance on both human health and the environment. Inhalation of mercury vapour can cause harmful effects on the nervous as insomnia, memory loss, digestive and immune systems. With the environment, mercury vapour can bio-accumulates and converted to methyl mercury by microorganisms. Therefore, the Ultraviolet Light-emitting diode (UVC LED), which does not contain mercury, and Xenon lamps have gained prominence. In addition, arrays of LED and pulsed xenon-based ultraviolet light (PX-UVC) can be efficient inactivation (Mori et al., 2007; Simons et al., 2018; Kim & Kang, 2018; Xiao et al., 2018; Casini et al., 2019). However, the UV-C Light-emitting diode (LED) at a wavelength of 240 nm produces ozone, which is a strong oxidant and toxic air pollutant (Vatansever et al., 2013; Global Lighting Association, 2020).

UVC Disinfection of COVID-19 virus

Owing to SARS-CoV-2 as the virus which causes COVID-19, the previous UVC methodology and results of other researchers concentrating on virus were concluded as shown in Table 4.

Table 4 Example of UVC exposure on virus

Description of virus	Methodology (wavelength, fluence, duration of exposure)	Results	References
H1N1 on Petri dishes at distance of 5 cm at 25°C	VUV 185 nm, 21 mW /cm^2, 0 to 15 minutes	Inactivate by 2.2-log10 within 5 minutes and more than 4-log10 within 20 minutes	Szeto et al. 2020
H3N2 on Petri dishes	VUV 185 nm, 21 mW /cm^2, 0 to 15 minutes	Inactivate by 3.0-log10 within 5 minutes and more than 4-log 10 within 20 minutes	Szeto et al. 2020
SARS-CoV-2	UVC 254 nm, 80 J/mL, 52 minutes	Reduction ≥ 4.79 ± 0.15 log10 in plasma and 3.30 ± 0.26 log10 in whole blood	Ragan et al. 2020
SARS-CoV in plasma	UVC 254 nm, 30 J/cm^2	Inactivate by ≥3.1-log10	Eickmann et al. 2020
Crimean–Congo haemorrhagic fever virus (CCHFV) in plasma	UVC 254 nm, 30 J/cm^2	Inactivate by ≥3.2-log10	Eickmann et al. 2020
Nipah virus (NiV) in plasma	UVC 254 nm, 30 J/cm^2	Inactivate by ≥2.7-log10	Eickmann et al. 2020
SARS-CoV-2 on Petri dishes	Deep ultraviolet light-emitting diode (DUV-LED) 280 ±5 nm, 225 mW/cm^2, 60 seconds	Inactivate >3.3-log10	Inagaki et al. 2020
MS2, Qβ, and ϕX174 viruses in a chamber-type air disinfection system	UVC LED 254 nm, 45 mJ/cm^2, 10 minutes	Inactivate 5-log10	Kim & Kang, 2018
Ebola on Petri dishes	UVC 254 nm, 4-17 J/m^2, 0 to 30 seconds	Survival 3%–4%	Sagripanti & Lytle, 2011
Lassa on Petri dishes	UVC 254 nm, 4-17 J/m^2, 0 to 30 seconds	Survival 9%–10%	Sagripanti & Lytle, 2011
Respiratory Adenovirus	UVC 254 nm, 2608 W s/cm^2, 30 minutes	Survival 32.9%	Walker & Ko, 2007
Coronavirus.	UVC 254 nm, 599 W s/cm^2, 30 minutes	Survival 12.2%	Walker & Ko, 2007
SARS-CoV	UVC 254 nm, 4016 μW/cm^2 (where μW = 10^{-6} J/s), 15 minutes	Inactivation 400-fold within 6 minutes	Darnell et al. 2004
SARS coronavirus strain CoV-p9 at distance of 80 cm	260 nm, > 90 w/cm^2, 15 to 150 minutes	CPE (cytopathic effect) dropped from +++CPE (51–75% cells) to +CPE (less than 25% cells) after 15 minutes	Duan et al. 2003

UVC technology is an important component of eliminating viral infections in environment (Paria et al., 2018) and also blood-borne pathogens (Ragan et al., 2020). The robotic UVC radiation was effective in inactivating 99.9% of *Pseudomonas aeruginosa,* which is more tolerate to UVC than the coronaviruses, on various surfaces including glass, plastic and stainless-steel within 10 minutes at the distance of 3 meters from the device (Vorapaluk et al, 2020). In addition, UVC 254-nanometer light robots of The San Antonio-based company Xenex Disinfection Services, which the robot named KENNEDY could eliminate corona virus 99.999% after two minutes of exposure at one-meter distance (Kalyani et al., 2020). Increasingly placed on the market with a greater range of UVC applications comes a greater risk of accidental exposure (Global Lighting Association, 2020). Excessive exposure causes sunburn skin, skin cancer and damage cornea of eyes. Risk management were engineering controls such as enclosure cabinets, screened area and administrative controls such as indicator warning sign light elimination of reflected UV from shiny surfaces, personal protection equipment e.g. latex gloves and eye protection. A UV-C warning symbol according IEC 61549-310-1 (Fig. 2), should be black on the yellow background with wording “Warning UV-C emitted from this product. Avoid eye and skin exposure to unshielded product. Follow installation instruction and user manual” (Global Lighting Association, 2020). In addition, humans and animals should not be exposed to high levels of UV light due to the potential for damage to the skin or eyes (FAD PReP et al., 2014). Notably, these technologies developed for use in health-care settings are used during terminal cleaning (cleaning a room after a patient has been discharged or transferred), when rooms are unoccupied for the safety of staff and patients (WHO, 2020b).

Fig.2 Warning sign light

Moreover, the environmental measures proposed according to the probability level of COVID-19 virus infection spreading and workplace risk level were shown in Table 5 (Cirrincione et al., 2020). It aims at limiting the survival of the virus in key environments of non-healthcare facilities such as schools, institutions, offices, daycare centers, businesses, and community centers that do not house persons overnight. Extraordinary cleaning and disinfection procedures must be adopted using the appropriate disinfectants in the very airy confined spaces, personal protection equipment (PPE) as well as proper disposal of regulated waste (Department of Public Health, 2020).

Conclusion

COVID-19 typically rapidly spread from one person to another via respiratory droplets (>5-10 μm in diameter). Thus, environmental surfaces should be frequently cleaned with water, detergent, and followed

Table 5 Environmental measures proposed according to the workplace risk level

Risk level.	Probability level of infection spreading	Environmental measures
Low	• Located in areas where there are no reported cases of disease contamination in the entire province • With a maximum of 10 employees • With mainly carry out office activities with a limited flow of customers	• Take extraordinary cleaning and sanitization • Considering a density of 1 person every 10 square meters • Keep a distance of 2 m between 2 or more people
Medium	• Located in areas where there are reported cases of disease contamination in the province • With a maximum number of 50 employees • With mainly carry out commercial activities; Which expose employees to sporadic contact with customers	• All measures indicated for the previous level controls • Indoor temperature >20 °C, indoor humidity >60% • Preparation of special bins for the collection of contaminated materials
High	• Located in areas in which in the neighboring cities or in the same city of the workplace, there are clear cases of disease contamination • With a maximum number of over 50 employees • With carry out front-office activities in continuous contact with customers	• All measures indicated for the previous level • Prepare a suitable room for the isolation of any suspicious cases
Very high	• Very-high-exposure-risk jobs include healthcare workers such as doctors, nurses, dentists, paramedics, emergency medical technicians	• All measures indicated for the previous level • Ensure appropriate air-handling systems • Negative pressure compared to the atmospheric one • Sanitization through the use of physical means such as ultraviolet irradiation (UV)

by application of disinfection as chemical disinfectants and physical disinfection. UVGI in the wavelength of 245–285 nm directly damages deoxyribonucleic acid, ribonucleic acid, and also prevent the bacterium from being viable. However, its risk is mercury amalgam, which is a hazardous material. In addition, excessive exposure causes sunburn skin, skin cancer and damage to the corneas of the eyes.

References

Adams, E., de Paula, V.D. C.S., Carneiro, R. D., de Lima, R. M., Gomes, M.F., Ramsdorf, W.A., & de Freitas, A. M. (2018). Ecotoxicity of Malathion® 500 CE before and after UVC radiation and UV/H2O2 treatment. *Eclética Química Journal, 43*(2), 44-50.

Ahmed O.M., & Amin, H.F. (2019). Effect of UV-C radiation on survival of *Escherichia coli* O157:H7 inoculated fish fillets from fresh water and marine sources. *Egyptian Journal of Aquatic Biology & Fisheries, 23*(1), 151-159.

Amor, C., Chueca, J.R., Fernandes, J.L., Domínguez, J.R., Lucas, M.S., & Peres, J.A. (2019). Winery wastewater treatment by sulphate radical based-advanced oxidation processes (SR-AOP): Thermally VS UV-assisted persulphate activation. *Process Safety and Environmental Protection, 122,* 94-101.

Artichowicz, W., Luczkiewicz, A., & Sawicki, J.M. (2020). Analysis of the radiation dose in UV-disinfection flow reactors. *Water, 12*(231), 1-15.

Basti, D., Bricknell, I., Beane, D., & Bouchard, D. (2009). Recovery from a near-lethal exposure to ultraviolet-C radiation in a scleractinian coral. *Journal of Invertebrate Pathology, 101,* 43-48.

Canto, A.C.V. da C.S., Monteiro, M.L.G., Costa-Lima, B.R.C. da., Marsico, C.A. L.E.T., Silva, T.F.J. P.da., & Conte-Junior, C.A. (2019). Effect of UV-C radiation on *Salmonella* spp. reduction and oxidative stability of Caiman (*Caiman crocodilus yacare*) meat. *Journal of Food Safety, 39,* 1-7.

Carlowicz, M. (2013). The ozone layer: Our global sunscreen. *ChemMatters,* 12-14.

Casini, B., Tuvo, B., Cristina, M.L., Spagnolo, A.M., Totaro, M., Baggiani, A., & Privitera, G. P. (2019). Evaluation of an ultraviolet C (UVC) light-emitting device for disinfection of high touch surfaces in hospital critical areas. *International Journal of Environmental Research and Public Health, 16*(3572), 1-10.

Chen, A.- J., Luo, W., Luo, Y.-B., & Zhu, B.-Z. (2017). Combined treatment of ultraviolet-C and *L. phantarum* on *Salmonella enteritidia* and quality control of fresh-cut apple. *Journal of Food Processing and Preservation, 42,* 1-9.

Cirrincione, L., Plescia, F., Ledda, C., Rapisarda, V., Martorana, D., Moldovan, R.E., …& Cannizzaro, E. (2020). Protocol COVID-19 pandemic: Prevention and protection measures to be adopted at the workplace. *Sustainability, 12*(3603), 1-18.

Darnell, M.E., Subbarao, K., Feinstone, S.M., & Taylor, D.R. (2004). Inactivation of the coronavirus that induces severe acute respiratory syndrome, SARS-CoV. *Journal of Virological Methods, 121*(1), 85-91.

Department of Public Health (2020). Novel Coronavirus (COVID-19) *Los Angeles County cleaning & disinfection matrix, 1-3.* Retrieved November 23, 2020, from http://www.publichealth.lacounty.gov/media/Coronavirus/docs/protection/CleaningMatrix.pdf

Duan, S.M., Zhao, X.S., Wen, R.F., Huang. J.J., Pi, G.H., Zhang. S.X., Han, J., Ruan, S.L., Dong, X.P., & SARS Research Team. (2003). Stability of SARS Coronavirus in Human Specimens and Environment and Its Sensitivity to Heating and UV Irradiation. *Biomedical and Environmental Science, 16,* 246-255.

Eickmann, M., Gravemann, U., Handke, W., Tolksdorf, F., Reichenberg, S., M€uller, T.H., & Seltsam, A. (2020). Inactivation of three emerging viruses-severe acute respiratory syndrome coronavirus, Crimean-Congo haemorrhagic fever virus and Nipah virus-in platelet concentrates by ultraviolet C light and in plasma by methylene blue plus visible light. *The International Journal of the Transfusion Medicine, Vox Sanguinis,* 1-5.

Elgujja, A.A., Altalhi, H.H., & Ezreqat, S. (2020). Review of the efficacy of ultraviolet C for surface decontamination. *Journal of Nature and Science of Medicine, 3*(1), 7-12.

Environmental Protection Agency.(EPA) (1999). *United States, Wastewater technology fact sheet: Ultraviolet disinfection, September, EPA 832-F-99-064, 1-7.* Retrieved November 23, 2020, from https://www3.epa.gov/npdes/pubs/uv.pdf.

Foreign Animal Disease Preparedness and Response Plan [FAD PReP], National Animal Health Emergency Management System (NAHEMS), USDA, & United States Department of Agriculture Animal and Plant Health Inspection Service Veterinary Services. (2014). *NAHEMS guidelines: Cleaning and disinfection, 1-58.* Retrieved November 23, 2020, from https://www.aphis.usda.gov/animal_health/emergency_management/downloads/nahems_guidelines/cleaning_disfection.pdf.

Foreign Animal Disease Preparedness and Response Plan [FAD PReP] & United State Department of Agriculture (2018). *Standard operating procedures: 15. cleaning and disinfection, 1-52.* Retrieved November 23, 2020, from https://www.aphis.usda.gov/animal_health/emergency_management/downloads/sop/sop_cd.pdf

Global Lighting Association (2020). *Position statement on germicidal UV-C irradiation: UV-C safety guidelines, 1-3.* Retrieved November 23, 2020, from https://www.globallightingassociation.org/images/files/publications/GLA_UV-C_Safety_Position_Statement.pdf.

Guo, Y.R., Cao, Q.-D., Hong, Z.-S., Tan, Y.-Y., Chen, S.-D., Jin, H.-J., … &Yan, Y. (2020). Review: The origin, transmission and clinical therapies on coronavirus disease 2019 (COVID-19) outbreak – an update on the status. *Military Medical Research, 7*(11), 1-10.

Guridi, A., Sevillano, E., Fuente, I., Mateo, E., Eraso, E., & Quindós, G. (2019). Disinfectant activity of a portable ultraviolet C equipment. *International Journal of Environmental Research and Public Health, 16*(4747), 1-11.

Häder, D.-P., Kumer, H.D., Smith, R.C., & Worrest, R.C. (2007). Effects of solar UV radiation on aquatic ecosystem and interactions with climate change. *Photochemical & Photobiological Sciences, 6,* 267-285.

Hafeez, A., Ahmad, S., Siddqui, S.A., Ahmad, M., & Mishra, S. (2020). A review of COVID-19 (coronavirus disease-2019) diagnosis, treatments and prevention. *EJMO Eurasian Journal of Medicine and Oncology, 4*(2), 116–125.

Idzwana, M., I.N., Chou, K.S., Shah, R.M., & Soh, N.C. (2019). The effect of ultraviolet light treatment in extend shelf life and pressure the quality of strawberry (*Fragaria X ananassa*) *CV.Festival. International Journal of Food, Agriculture, and Natural Resources, 1*(1), 15-18.

Inagaki, H., Saito, A., Sugiyama, H., Okabayashi, T., & Fujimoto, S. (2020). Rapid inactivation of SARS-CoV-2 with Deep-UV LED irradiation. *Emerging Microbes & Infections, 9*(1), 1744-1747.

Jones, C.L. (2020). Environmental surface contamination with SARS-CoV-2-a short review. *Journal of Human Virology & Retrovirology, 8*(1), 15–19.

Kalyani, V.L., Mathur, P., Makwana, N., & Singhal, N. (2020). Study on Coronavirus (COVID-19) and how UVC light helps to destroy it and its Applications. *Journal of Management Engineering and Information Technology. 7*(3), 19-23.

Kamaruzzaman, S.N. & Sabrani, N.A. (2011). The effect of indoor air quality (IAQ) towards occupants' psychological performance in office buildings. *Journal of Design + Built: IAQ in Office Building, 4,* 49-61.

Kerr, J.B. (2005). Understanding the factors that affect surface ultraviolet radiation. *Optical Engineering, 44*(4), 1-9.

Kim, D.-K., & Kang, D.-H. (2018). UVC LED irradiation effectively inactivates aerosolized viruses, bacteria, and fungi in a chamber-type air disinfection system. *Applied and Environmental Microbiology, 84*(17), 1-11.

Kujundzic, E., Matalkah, F. Howard, C.J., Hernandez, M., & Miller, S.L. (2006). UV air cleaners and upper-room air ultraviolet germicidal irradiation for controlling airborne bacteria and fungal spores. *Journal of Occupational and Environment Hygiene, 3,* 536-546.

Lee, L.D. (2017). Surface and air: what impact does UV-C at the room level have on airborne and surface bacteria ? *Canadian Journal of Infection Control, 32*(2), 108-111.

Makarapong, D., Tantayanon, S., Gowanit, C., & Inchaisri, C. (2020). Development of an innovative apparatus using UV-C for controlling the number of microorganisms in raw milk after milking. *International Journal of Dairy Technology, 73*(1), 301-305.

Martin, Jr., S.B., Dunn, C., Freihaut, J.D., Bahnfleth, W.P., Lau, J., & Nedeljkovic-Davidovic, A. (2008). Ultraviolet germicidal irradiation current best practices. *ASHRAE Journal, 8,* 28-36.

Memarzadech, F., Olmsted, R. N., & Bartley, J.M. (2010). Applications of ultraviolet germicidal irradiation disinfection in health care facilities: Effective adjunct, but not stand-alone technology. *American Journal of Infection Control, 6,* S13-S24.

Mori, M., Hamamoto, A., Takahashi, A., Nakano, M., Wakikawa, N., Tachibana, S.,…& Kinouchi, Y. (2007). Development of a new water sterilization device with a 365 nm UV-LED. *Med Bio Eng Comput Medical & Biological Engineering & Computing, 45,* 1237-1241.

Moussari, G., Fathi, E., & Moradi, M. (2019). Advanced disinfecting and pest-treating the biologically treated hospital wastewater in the UVC/H2O2 and VUV/H2O2 processes: Performance comparison and detoxification efficiency. *Process Safety and Environmental Protection, 126,* 259-268.

Occupational Safety and Health Administration [OSHA]. (2020). *Guidance on preparing workplaces for COVID-19. U.S. Department of Labor, 3990-03, 1-35.* Retrieved November 23, 2020, from https://www.osha.gov/Publications/OSHA3990.pdf

Ogilvie, B.H, Solis-Leal, A., Lopez, J.B., Poole, B.D., Robison, R.A., & Berges, B.K. (2021). Alcohol-free hand sanitizer and other quaternary ammonium disinfectants quickly and effectively inactivate SARS-CoV-2. *Journal of Hospital Infection, 108,* 142-145.

Ontario Agency for Health Protection and Promotion (Public Health Ontario). (2018). *Best practices for environmental cleaning for prevention and control of infections in all health care settings* (3rd ed.). Toronto, Canada: Queen's Printer for Ontario.

Orazio, J. D'., Jarrett, S., Amaro-Ortiz, A., & Scott, T. (2013). UV radiation and the skin. *International Journal of Molecular Sciences, 14,* 12222-12248.

Pan American Health Organization [PAHO] & World Health Organization [WHO]. (2020). *Epidemiological Update: Novel coronavirus (COVID-19), 1-8.* Retrieved November 23, 2020, from https://iris.paho.org/handle/10665.2/51907.

Paria, M., Simpser, E., Becker, M., Mainquist, W.K., & Velez, K.A. (2018). The effect of ultraviolet-C technology on viral infection incidence in a pediatric long-term care facility. *American Journal of Infection Control, 46,* 720-722.

Poushand, F., Aramideh, S., & Forouzan, M. (2017). Effect of Ultra violet light (UV-C) in different times and heights on adults stage of whitefly (*Trialeurodes vaporariorum*). *Journal of Entomology and Zoology Stidies, 5*(1), 864-868.

Ragan, I., Hartson, L., Pidcoke, H., Bowen, R., & Goodrich, R. (2020). Pathogen reduction of SARS-CoV-2 virus in plasma and whole blood using riboflavin and uv light. *PLOS ONE, 29,* 1-11.

Renzel, A. (2016). *Disinfection with UVC General information, UV lamps and disinfection systems, UV measurement for UVC disinfection applications. uv-technik meyer gmbh, 1-12.* Retrieved November 23, 2020, from https://www.uv-technik.co.uk/assets/Uploads/product-documents/Disinfection-UV-C-Explained2.pdf

Rios, F., Kucharczyk, M.O., Gmurek, M., & Ledakowicz, S. (2017). Removal efficiency of anionic surfactants from water during UVC photolysis and advanced oxidation process in H2O2/UVC system. *Archives of Environmental Protection, 43*(1), 20-26.

Rivera-Gutiérrez, D., Char, C., Escalous, V.H., Chares, A.R., & RodRíGuEZ, S.v.D.C. (2015). Application of UV-C Radiation in the conservation of minimally processed rocket (*Eruca sativa Mill.*). *Journal of Food Processing and Preservation, 39,* 3117-3127.

Rutala, W.A., Weber, D.J., & the Healthcare Infection Control Practices Advisory Committee (HICPAC). (2019). *Guideline for disinfection and sterilization in healthcare facilities: 2008, Center for Disease Control and Prevention, Atlanta, 1-163.* Retrieved November 23, 2020, from https://www.cdc.gov/infectioncontrol/pdf/guidelines/disinfection-guidelines-H.pdf

Sagripanti, J.L., & Lytle, C.D. (2011), Sensitivity to ultraviolet radiation of Lassa, vaccinia, and Ebola viruses dried on surfaces. *Arch Virol, 156,* 489-494.

Salem, H., Binashikhbubkr, H., Wang, X., Zhou, L.T., Naji, W.Q., Chengwang, Z., & Zhong, G.Z. (2020). Novel corona-virus transmission and prevention. *Journal of Preventive Medicine, 5*(1:3), 1-2.

Sangadkit, W., Deepatana, A., & Thipayarat, A. (2020). Effects of combined ozonation and UV-C treatment or vapored hydrogen peroxide fumigation to inactivate *Escherichia coli* and *Asperjillus niger* contaminants in rice noodle industry. *Srinakharinwirot University (Journal of Science and Technology), 12*(23), 1-16.

Scientific Committee on Health, Environmental and Emerging Risks (SCHEER). (2017). *Opinion on biological effects of ultraviolet radiation relevant to health with particular reference to sunbeds for cosmetic purposes, 1-102.* Retrieved November 23, 2020, from https://www.kanker.be/sites/default/files/scheer_-_opinion_on_biological_effects_of_ultraviolet_radiation_relevant_to_health_with_particular_reference_to_sunbeds_for_cosmetic_purposes.pdf

Seong, J.Y., Kwon, K.-H., & Oh, S.W. (2016). Combined effect of aerosolized malic acid and UV-C for the inactivation of Escherichia Coli O157:H7, *Salmonella typhimurium,* and *Listeria monocytogenes* on fresh-cut lettuce. *Journal of Food Safety, 37,* 1-9.

Shereen, M.A., Khan, S., Kazmi, A., Bashir, N., & Siddique, R. (2020). COVID-19 infection: Origin, transmission, and characteristics of human coronaviruses. *Journal of Advanced Research, 24,* 91–98.

Siahpoosh, Z.H., & Soleimani, M. (2017). Photocatalytic degradation of azo anionic dye (RR 120) in ZnO-Ghezeljeh nanoclay composite catalyst/UV-C system: Equilibrium, kinetic and thermodynamic studies. *Process Safety and Environmental Protection, III,* 180-193.

Silva, H.L.A., Costa, M.P., Frasao, B.S., Mesquita, E.F.M., Mello, S.C.R.P., Conte-junior, C.A., ... Miranda, Z.B. (2015). Efficacy of ultraviolet-C light to eliminate *Staphylococcus aureus* on pre-cooked shredded bullfrog back meat. *Journal of Food Safety, 35*(3), 318-323.

Simons, R.M., Pagan, J., & Lawal, O. (2018). *Low-maintenance, Consumables-free disinfection by UV-C LEDs.* In the 48th International Conference on Environmental Systems, Albuquerque, New Mexico Retrieved November 23, 2020, from https://ttu-ir.tdl.org/handle/2346/74131.

Singhal, T. (2020). A review of coronavirus disease-2019 (COVID-19). *The Indian Journal of Pediatrics, 87*(4), 281–286.

Solomon, K.R. (2008). Effects of ozone depletion and UV-B radiation on humans and the environment, *Atmosphere-Ocean, 46(*1),185-202.

Szeto, W., Yam, W.C., Huang, H., & Leung, D.Y.C. (2020). The efficacy of vacuum-ultraviolet light disinfection of some common environmental pathogens, *BMC Infectious Diseases, 20,* 127-1-9.

Vatansever, F., Ferraresi, C., Sousa, M.V.P. de., Yin, R., Rineh, A., Sharma, S.K., & Hamblin, M.R. (2013). Can biowarfare agents be defeated with light? *Virulence, 4*(8), 1-30.

Vorapaluk, P. (2020). Effectiveness study of disinfection of microbes by innovation robotic UVC radiation: Response to COVID-19 pandemic. *Thai Journal of Anesthesiology, 46*(3), 8-15.

Walker, C., & Ko, G. (2007). Effect of ultraviolet germicidal irradiation on viral aerosols. *Environ. Sci. Technol, 41,* 5460-5465.

Warren, B.G., Masker, J., Brown, G., Gamez, I., Smith, B., Anderson, D. J., & Turner, N. (2020). Efficacy of UV-C disinfection in hyperbaric chambers. *Infectious Control & Hospital Epidemiology, 17*(Jun), 1-4.

World Health Organization, World Meterological Organization, United Nations Environment Programme, & International Committee on Non-Ionizing Radiation Protection. (2002). *Global solar UV index: A practical guide, 1-28.* Retrieved November 23, 2020, from https://www.who.int/uv/publications/en/UVIGuide.pdf.

World Health Organization (2020a) *Coronavirus disease (COVID-19) situation report-115. 1-18.* Retrieved November 23, 2020, from https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200514-covid-19-sitrep-115.pdf?sfvrsn=3fce8d3c_6.html.

World Health Organization (2020b). *Cleaning and disinfection of environmental surfaces in the context of COVID-19 interim guidance, 1-8.* Retrieved November 23, 2020, from https://apps.who.int/iris/bitstream/handle/10665/331058/WHO-2019-nCoV-Environment_protocol-2020.1-eng.pdf

World Health Organization. (2020c). *Surface sampling of coronavirus disease (COVID-19): A practical "how to" protocol for health care and public health professionals, 1-26.* Retrieved November 23, 2020, from https://apps.who.int/iris/handle/10665/331058. html

Xiao, Y., Chu, X. N., He, M., Liu, X. C., & Hu, J. Y. (2018). Impact of UVA pre-radiation on UVC disinfection performance: Inactivation, repair and mechanism study. *Water research, 141,* 279-288.

Zhou, W. (2020). *The coronavirus prevention handbook: 101 science-based tips that could save your life.* Wuhan, China: Hubei Science and Technology Press.