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Pollution free UV-C radiation to mitigate COVID-19 transmission

Ashutosh Kumar [a], Abhishek Raj [a,b], Ankit Gupta [b,c], Sneha Gautam [d], Manish Kumar [e], Hemant Bherwani [a,b], Avneesh Anshul [a,b,*]

[a] CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur 440020, India
[b] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
[c] CSIR-NEERI, Delhi Zonal Centre, Naraina Industrial Area, New Delhi 110028, India
[d] Karunya Institute of Technology and Sciences, Karunya Nagar, Coimbatore 641114, India
[e] Experimental Research Laboratory, Department of Physics, ARSD College, University of Delhi, New Delhi 110021, India

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ABSTRACT

The high rate of transmission of the COVID-19 virus has brought various types of disinfection techniques, for instance, hydrogen peroxide vaporization, microwave generating steam, UV radiation, and dry heating, etc. to prevent the further transmission of the virus. The chemical-based techniques are predominantly used for sanitization of hands, buildings, hospitals, etc. However, these chemicals may affect the health of humans and the environment in unexplored aspects. Furthermore, the UV lamp-based radiation sanitization technique had been applied but has not gained larger acceptability owing to its limitation to penetrate different materials. Therefore, the optical properties of materials are especially important for the utilization of UV light on such disinfection applications. The germicidal or microorganism inactivation application of UV-C has only been in-use in a closed chamber, due to its harmful effect on human skin and the eye. However, it is essential to optimize UV for its use in an open environment for a larger benefit to mitigate the virus spread. In view of this, far UV-C (222 nm) based technology has emerged as a potential option for the sanitization in open areas and degradation of microorganisms present in aerosol during the working conditions. Hence, in the present review article, efforts have been made to evaluate the technical aspects of UV (under the different spectrum and wavelength ranges) and the control of COVID 19 virus spread in the atmosphere including the possibilities of the human body sanitization in working condition.

1. Introduction

COVID-19 issue is still a challenge even after availability of medicine and vaccine (Cao and Li, 2022; Jamrozik and Selgelid, 2020; Khan et al., 2020; Yang and Wang, 2020; Zhang et al., 2020). Asymptomatic patients were also found and the random deaths of patients were also reported in almost every country including India (Changotra et al., 2021). In case of asymptomatic patient precaution is essentially required among the healthy population because silent transmission may be occurred rapidly in population (Bai et al., 2020; Bherwani et al., 2021; Gao et al., 2021; Yu and Yang, 2020; Zhou et al., 2020). If such kind of disease dispersed among countries, then it can be a high-risk challenge. However, vaccination has positive impact in the control of death but its high transmission rate and its variable acute impact on different patient is still a challenge (Andrews et al., 2022; Coccia, 2022; Wang et al., 2022). One of the serious threats of the virus spreading between countries is due to unavailability of any handy monitoring of COVID-patient during travelling. Therefore, it can be a threat issue at any time in several countries. If the technology is developed to stop the contamination of such kind of viruses, then it will help the country to avoid major impact on economy, health and security (Ferdib-Al-Islam and Ghosh, 2022; Glass et al., 2022; Pensini and McMullen, 2022; Shin et al., 2022).

Typically, different kind of disinfectant techniques hydrogen peroxide vaporization, microwave generating steam, UV radiation and dry heating are available to stop the spreading of COVID-19 (Arellano-Cotrina et al., 2021; Mahanta et al., 2021; V et al., 2020). Among different chemicals, 75% ethanol, peroxy-acetic acid, chloroform and other chlorine containing disinfectant (sodium hypo-chloride etc.) used to stop the dispersion of virus. These

* Corresponding author at: CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur 440020, India.
E-mail address: anshul@neeri.res.in (A. Anshul).

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chemical based techniques are predominantly used for sanitization of hand, buildings, hospitals etc. The sanitization of staff, doctors, nurses, and other COVID-19 warriors were also carried out by using ethanol-based sanitizer or other chemicals. Therefore, the consistent use of these chemicals may affect the health of human and environment in unexplored aspects (Abuga and Nyamweya, 2021; Ghafoor et al., 2021; Golin et al., 2020; Mallhi et al., 2020). Moreover, the radiation-based sanitization was available in the form of UV lamp-based technology but it has certain limitations. The UV wavelength lies between 10 and 400 nm and it is a non-ionising part of electromagnetic spectrum (Biasin et al., 2021; Gidari et al., 2021; Saadati, 2016). Recently, Stawicki has suggested utilizing the UV-C for the treatment of COVID 19 virus present in trachea-bronchial region of patient (Stawicki, 2020).

The UV spectrum are divided into four major fragment UV-A, UV-B, UV-C and V UV(vacuum UV) depending on the range of wavelength as shown in Fig. 1. It is easier to absorb rather than penetrate, reflect or refract, because of lower wavelength compared to visible light. Therefore, optical properties of materials are very important for utilization of UV light on certain applications. UV-A has lowest energy and VU-V region has highest energy because wavelength is inversely proportional to the energy. Therefore, lower wavelength of the UV does not have a good quality of reflection, refraction or transmission. Among UV spectrum, UV-C was used prominently for germ removal (McDevitt et al., 2012; Memarzadeh et al., 2010). However, it can be used in close chamber to inactive microorganism within 20 s in air, but the major concern is related to harmful effect on human skin and eye. UV-C is carcinogenic as well as mutagenic in nature (Davies et al., 2002). Therefore, UV-C is avoided to be used in open working place in the presence of people and it must be handled very carefully in close chamber equipment.

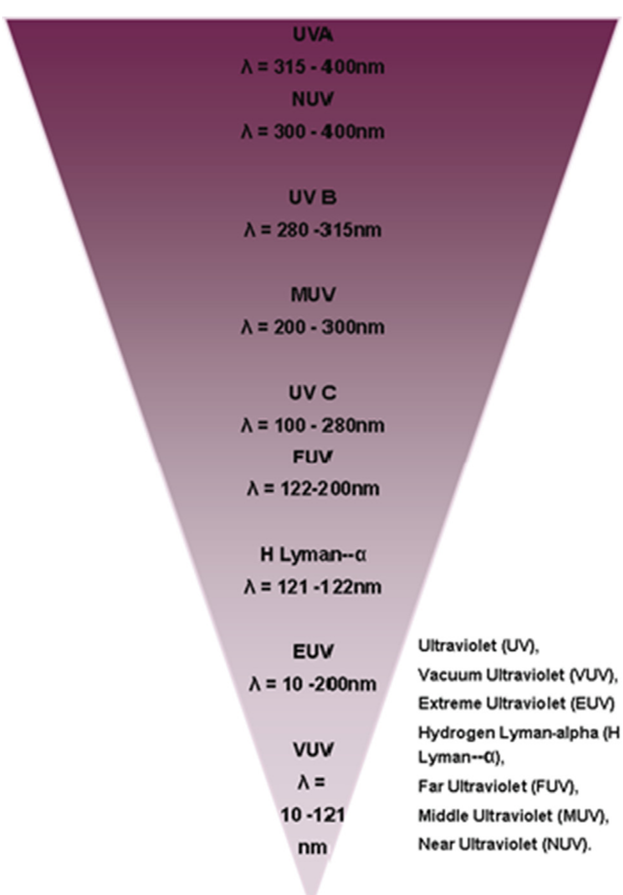

Fig. 1. Different types of UV on the basis of their wavelength as per ISO 21348.

During the literature we have not found any review article published before which summarized the technical aspects and application of UV-ray based disinfection techniques along with suitable measures. Hence, the purpose of present review article is to evaluate the technical aspects of UV (under the different spectrum and wavelength ranges) and the control of COVID-19 virus spread in the atmosphere including the possibilities of the human body sanitization in working condition.

2. UV-radiations against COVID-19 pandemic

Generally, epidemic viral infections are more effectual in cold weather, and infections due to COVID-19 will go longer time and or may also repeat. The variation in atmospheric conditions for instance rain, cold, change in temperature with wind, and snow were found as significant component which are influencing upper respiratory zone viral infections (Arora et al., 2021; Mecenas et al., 2020; Rajput et al., 2021; Türsen et al., 2020). Despite, the real impact of above motioned circumstance on corona virus is mysterious. However, some studies reported that the transmission of coronavirus can be slow down with increase in temperature. It has also found that the heat is the key components which affect the coronavirus survival and within the temperature range of 23–25 °C viral load reduce quickly compare to 4 °C temperature. However, study conducted in some cities by Kumar et al. reported that the transmission of coronavirus was not related with heat or UV rays (Kumar et al., 2020).

During the summer season higher amount of UV–radiations reached to the earth and it can become a critical component in stopping corona virus transmission. Regarding the overexposure of UV-rays at a meticulous position at certain time has been provided by UV index which is an international standard measurement. Depending upon the various factors such as category of organism and wavelength of UV-rays, different types of viruses for instance influenza virus, MERS and SARS can be permanently destroy or damage by UV-radiations. In the various countries like China different public transports and central banks were disinfected of coronavirus through UV-light (Dietz et al., 2020; Malateaux, 2020; Parsa et al., 2021). The UV-C light, containing wavelength range of 250–270 nm are effectively absorbed by microbial DNAs and therefore this wavelength range is deadly wavelength for microorganism. Here, nucleic acid bases absorb UV-C radiation which resulted in damage the molecular structure through photodimerization which leads to inability to replicate and inactivation of virus. The treatments of coronavirus infected humans through UV-C radiations are very rare or in very initial stage. However sanitization of N-95 masks during covid-19 pandemic was highly recommended through this technique (Peters et al., 2021; Rohit et al., 2021). Besides, the contaminated waste water containing COVID-19 virus can be treated through high temperature (greater than 56 °C) and UV C (100–280 nm) (Parsa et al., 2021). Auspiciously, UV-germicidal irradiations (UVGI) or UV-C (222 nm) is emerged as a potential contender that does not hurt human skin and eyes nevertheless various kind of study is still required to get deep into it. It has also found that UV-C is lesser carcinogenic compare to UV-B. Hence the uses of UVGI or UV (222 nm) are found to be more effective to disinfect the corona virus. Owing to carcinogenic effects corona virus on humans the use of UV-C in public areas such as railways stations, transportations, airports, malls, hospitals etc are still restricted and required some more approaches need to be included for better disinfection of corona virus (Dietz et al., 2020; Kumar et al., 2020; Welch et al., 2018).

3. UV-based disinfection system

Recently, various types of studies reported to inactivate the coronavirus from the surface of any objects. The main objective was to identify the cost effective technique to disinfect the virus at particular wavelength. As the LEDs are available in market with different wavelength which are different from conventional discharge lamp with constant wavelength emission can optimize the response and provide most appropriate wavelength (Alnaser et al., 2020; Trivellin et al., 2021).

UV light-emitting diodes (UV LEDs) based disinfections technique is becoming more popular due to precise control of radiation pattern, flexible design and reduced size of disinfector. The requirement of low voltage and short turn-on time can be also operated though solar panel and battery. UV LEDs based disinfection unit has established for more efficient for various types of pathogens. On the other hand, UV LEDs with narrow emission characteristic as shown in Fig. 2 (a), and lower wavelength leads to provided lower output. These limitations demanded the UV-LEDs with high wavelength and its efficacy towards various types of pathogens must be examined. Gerchman et al. have studied the disinfection of coronavirus through UV LED and evaluated the wavelength effects. They have investigated the sensitivity of corona virus (HCoV-OC43 used as SARS-CoV-2 surrogate) at different wavelength in human. The UV LED having peak emission at nearly 286 nm was found more effective as shown in Fig. 2(b) and can be used as useful tool for fight against coronavirus (Gerchman et al., 2020). Further, they have designed UV chip technology to test the virucidal activity on SARS-CoV-2 of a device. The obtained result showed a SARS-CoV-2 charge decline of more than 99.9% after 3 min of operation. The highest measurable attenuation of 5.7 Log (99.9998%) was calculated at an irradiation time of 10 min, for all the repetitions, regardless of direct or reflected UV radiation hitting the virus samples in the device (Messina et al., 2021). In the other study, Choi et al. have introduced UV LED irradiation robot for the disinfection of patient room after discharge of patients. They have collected 216 environmental samples from 17 rooms and found the presence of SARS-CoV-2 RNA at various

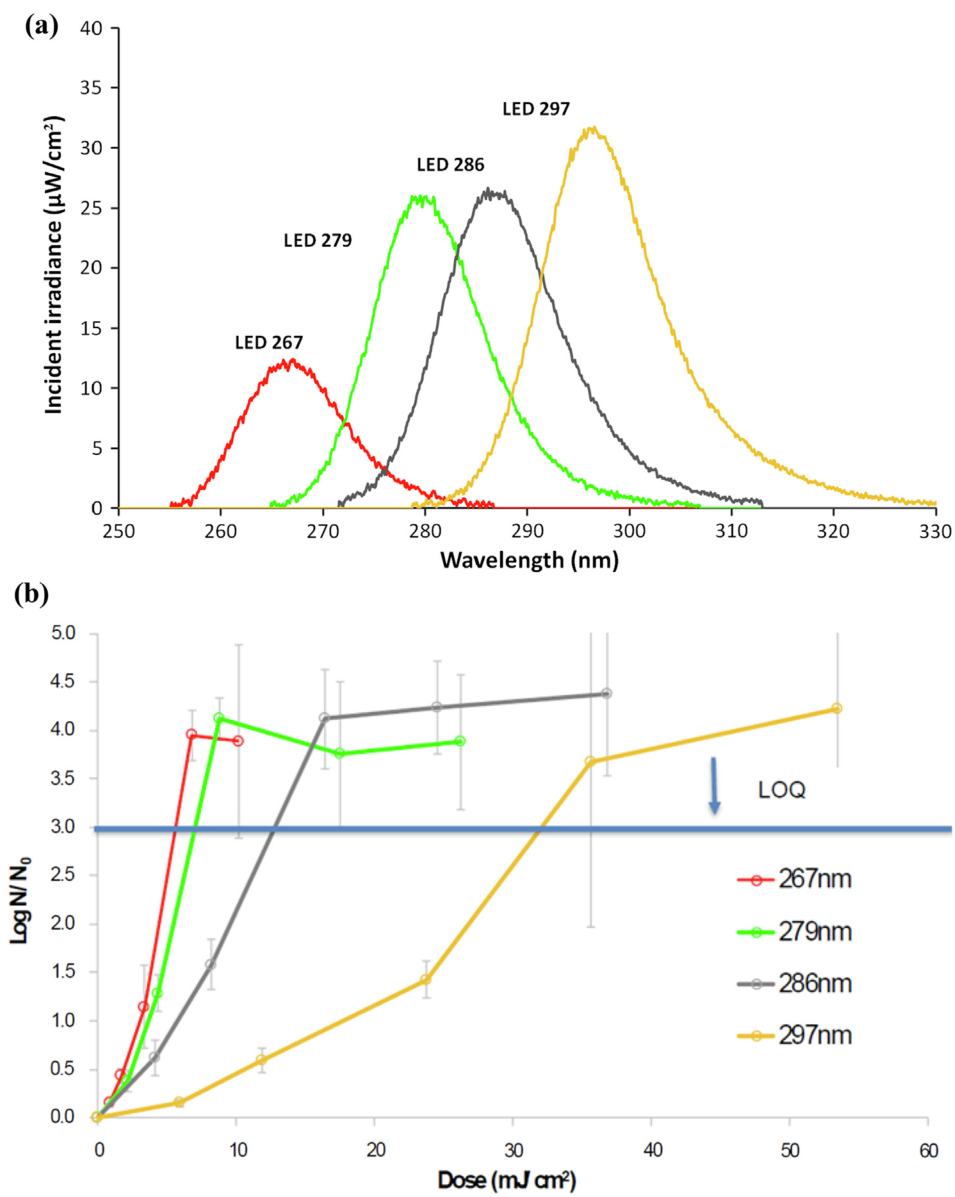

Fig. 2. (a) Various emission spectrum of UV LED. (b) Dose response characteristic of the HCoV-OC43 disinfected through UV-LEDs. N signifies the virus count after the designated irradiation and N_0 represent the time zero (without irradiation). Panel (a-b) are reprinted with permission from (Gerchman et al., 2020), copyright Elsevier 2020.

surface. The obtained result demonstrated that UV LED based robot is more effective in spacious area like ICU but it performance varied with small places like CTC rooms (Choi et al., 2021).

Guettari et al. have designed a mobile robot named I-Robot UV-C to inactive the coronavirus at various environmental surfaces. The developed i-Robot UV-C includes two lamp on the top and eight UV-C lamp on the central column. The column of the designed robot was fixed on the mobile base and also included temperature and humidity sensor, pulse motion detector sensor. The designed device disinfected 99.999% bacteria (Guettari et al., 2021). Further, Table 1 summarized the different form of UV in terms of disinfection of SARS-COV-2 with respective to dose and time duration. It is clear from the table that UV LED, UV chip, UV-A, B, and C with range of different wavelength are able to deactivate about 99% of SARS-COV-2 virus at particular UV-dose and time.

Inagaki et al. demonstrated that the deep ultraviolet light-emitting diode (DUV-LED) of at wavelength of 280 ± 5 nm rapidly inactivated the SARS-CoV-2 which was collected from infected patient. For the observation of inactivation of virus through DUV-LED irradiation aliquots of 150 μL of virus stock were placed in petri dish of 60 mm and 3.75 mW/cm^2 light were projected from work station of 20 mm for different times as shown in Fig. 3(a-c). The infectious titer decrease the ratio of 87.4% was observed for 1 s irradiation which enhanced up to 99.9% for 10 s irradiation (Inagaki et al., 2020).

4. Technical aspects of UV based COVID 19 dispersion mitigation equipment

Among UV light UV-A has capability to penetrate the deep layer of human skin whereas UV B and UV-C are considered as actinic (causing photochemical reactions). Recently, Doremolen et al. explored that inaerosol COVID-19 virus remain stable for 3 h. This study was based on Bayesian regression model and it was suggested that stability of virus depends on the kind of surfaces and inoculum shed. The stability was found higher on stainless steel and plastic as compared to copper and cardboard (van Doremalen et al., 2020). Therefore, mitigation technology advancement like UV based tools were designed in most of the countries but UV light source was typically based on low pressure containing mercury vapour arc lamp having wavelength of 254 nm or xenon lamp with broad spectrum. The UV-C tube also emits a considerable concentration of ozone. The germicidal effect of UV-C is already established with several germs and its use in the disinfecting of medical kits were also under process for COVID 19 virus (Hashem et al., 2019; Momattin et al., 2019; Szeto et al., 2020; Torres et al., 2020). Beside this applications, the different designs were also advanced for sanitization of currency, surface, documents, mask and PPE kit etc (Pandya et al., 2021; Ravi et al., 2021; Tiwary et al., 2021). However, these developed design technologies are able to decontaminate the assets up to certain extents but few scientific facts must be considered for effective application.

The intensity of light and contact time in between virus and UV rays are two vital parameters to denature the virus (Hamzavi et al., 2020). The distance of the inoculums from the light source is also an important parameter. Most of the study was performed to kill the virus present in aerosol. In aerosol the intensity required for different viruses are different. For example, for H1N1 influenza virus UV dose was reported 1.1 mJ/cm^2 whereas, for alpha (HCoV–229E) and beta (HCoV-OC43) coronavirus required 0.56 mJ/cm^2 and 0.34 mJ/cm^2 respectively (Buonanno et al., 2020; McDevitt et al., 2012). The D_{90} dose was found 0.7 mJ/cm^{2}in the earlier corona virus strain germicidal studies (Kowalski, 2015). These variations are due to difference in number of base pair in DNA/RNA. The pyrimidine dimer (especially thymine) is more sensitive towards photo-degradation by UV and hence DNA based viruses are more sensitive with UV-C (Lytle and Sagripanti, 2005). In these studies, the contact time is very less. But the contact time will not be common for each kind of materials such as medical kits, mobile, purse, floor etc (Huber et al., 2021; Narla et al., 2020). Moreover, the virus will denature at different contact time if it is present over the material surfaces and in aerosol. It occurred due to the surface roughness and band gap energy of the material. The transmission of any light without adsorption is only possible if material has lower band gap energy as compared to light energy. The virus may be present in between trough and nano hollow pits at the surface material. Most of the materials are opaque to UV light because of lower wavelength or higher energy. For example, among very few materials, fused quartz (Type 214) is able to transmit at least 86% of incident UV-C light (Sosnin et al., 2015). The utilization of this UV-C light is not applicable to be used in working area because of different kind of harmful effects on human cells.

5. Far UV based option

Recently, a review was published by Toress et al. enlightening the different methods opted for sanitization of accessories for

Table 1
Different form of UV in terms of disinfection with respective dose and time duration.

Sr. No.	UV Categories	Time	UV Dose	Remarks	Ref.
1.	UV-LED (267 & 279 nm)	–	7 mJ/cm^2	3-log inactivation of HCoV-OC43	(Gerchman et al., 2020)
2.	UV-C (254)	9 min	1048 mJ/cm^2	High infectious titer of 5 × 10^6 $TCID_{50}$/mL was totally inactivated	(Heilingloh et al., 2020)
3.	UV-A (365 nm)	15 min	1048 mJ/cm^2	Weak effect was observed on infectious titer of 5 × 10^6 $TCID_{50}$/mL	(Heilingloh et al., 2020)
4.	UV-chip	3 min	15 mJ/cm^2	The SARS-CoV-2 charge decline at 99.94%	(Messina et al., 2021)
		10 min	35 mJ/cm^2	Highest measurable attenuation of 5.7 Log (99.9998%)	(Messina et al., 2021)
5.	Far UV-C (222 nm)	25 min	3 mJ/cm^2	Aerosolized coronavirus 229E and OC43, respectively inactivated by almost 99.9%.	(Buonanno et al., 2020)
6.	UV-C (254)	2.98 s	6.556 mJ/cm^2	UV Clight was able to inactivate more than 99 % of SARS-CoV-2 viral particles	(Sabino et al., 2020)
7.	UV-C(222 nm)	30 s	3 mJ/cm^2	The obtained result exhibited a 99.7% reduction of viable SARS-CoV-2 based on the TCID 50 assay	(Kitagawa et al., 2021)
8.	UV-C (254 nm)	–	1.5 J/cm^2	Efficiently deactivate the facepieces of 3 M 1860 and Moldex 1511	(Ozog et al., 2020)
9.	UV-C (222 nm)	15 s	81 mJ/cm^2	SARS-CoV-2 from forty-eight locations, become negative	(Su et al., 2022)
10.	UV-C (253.7 nm)	30 s	500 μW/cm^2	Reduced SARS-CoV-2 by 10$^{-4.9}$ fold	(Lo et al., 2021)

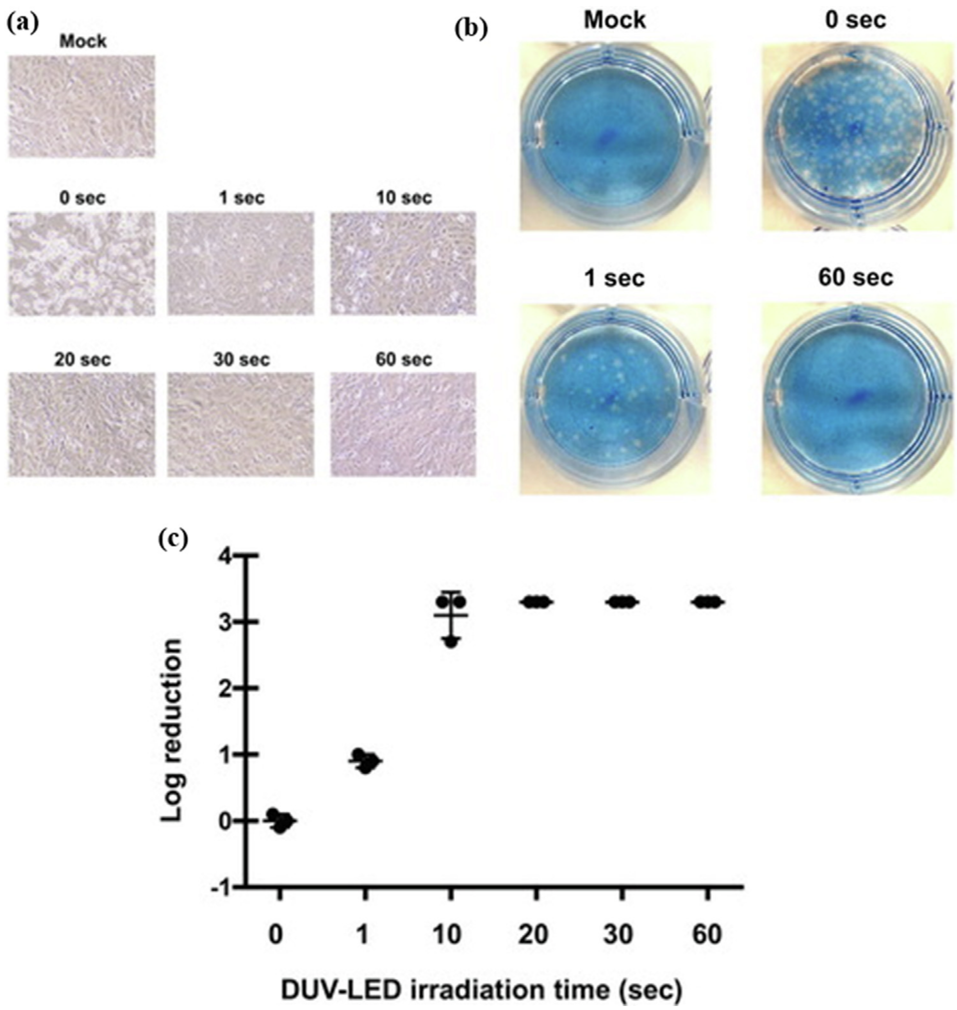

Fig. 3. Inhibitory result of DUV-light on SARS-CoV-2. (a) Cytopathic variation in virus infected Vero cells under different irradiation conditions including (0 s) without DUV LED –light or with DUV LED –light for 1, 10, 20, 30, 60 s and each of them corresponds to 3.75, 37.5, 75, 112.5, or 225 mJ/cm^2, respectively. (b) Formation of Plaque in Vero cell. (c) Disinfection of SARS-CoV-2 though DUV-LED irradiation under different time. Panel (a-c) are reprinted with permission from (Inagaki et al., 2020).

COVID-19 virus (Torres et al., 2020). Briefly, authors explained UV-C (254 nm) based sanitization and their limitations. However, Far UV based techniques were excluded irrespective of the advantages over UVC. However, the study of Far UV-C is started hundred years ago but, now a days, it attracts the researcher as an option to be used for sanitization-based application instead of 254 nm based UV (Buonanno et al., 2016; Kogelschatz, 2004; Seuylemezian et al., 2021; Welch et al., 2018). Because, it is able to kill the microorganism without affecting the skin and retina of human eyes (Barnard et al., 2020; Kang and Kang, 2019; Saadati, 2016; Seuylemezian et al., 2021; Wang et al., 2010; Welch et al., 2018). Significantly, It is non mutagenic to skin cell of human (Barnard et al., 2020; Haider et al., 2020). Therefore, far UV based techniques can be used in open working area for office staff, doctors, nurses and other COVID-19 warrior. Beside this advantage there are number of advantages of the far UV excil lamp as compared to other UV, represented (Oppenländer, 2007; Oppenländer and Sosnin, 2005). Advantages of far UV excil lamp (222 nm) over UV-C (254 nm): (i) variable geometries, (ii) narrow-band emission, (iii) no IR emission, (iv) variable power adjustment, (v) mercury free system, (vi) instant start at full radiation output, (vii) long lamp lifetime (viii) electrode-less configuration.

At present, the excil-lamps are most commonly used in photoscience because, it has extensive lifetime (several thousand hours). The pressure has considerable role in the emission of radiation in excil lamp. The radiant power depends on the pressure of the gas mixture (Schitz et al., 2008). If the pressure of the gas in a bulb exceeds 20–30 kPa, than narrow band radiation emission occurred. It also depends on the nature of filled gas or mixture of gas (Oppenländer and Sosnin, 2005). The efficiency of excil lamp can be increased by optimum voltage application on discharge gap (Lomaev et al., 2002). The emission maxima of halogens and rare gases with and without mixing are represented in Table 2. Among these radiations, KrCl based emission maxima (222 nm) have several advantages to be used over other exciplexes based emission.

The presented chemical reaction occurred between krypton and chlorine (Eqn. (1)), at the pressure of approximately, 0.3–0.5 atm. This reaction is termed as harpoon reaction and KrCl* molecules are produced (Zhang and Boyd, 1996; Zhuang et al., 2010). Since KrCl* molecules are unstable and after coming into ground state it emits the radiation of 222 nm (Zhang and Boyd, 1996; Zhuang et al., 2010).

$$Kr^* + Cl_2 \rightarrow KrCl^* + Cl \tag{1}$$

$$KrCl^* \rightarrow Kr + Cl + \text{UV radiation (222 nm)} \tag{2}$$

However, the life of excimer lamp is very long but the molecular Cl is incompletely recovered during the intervals between voltage pulses. Hence, the concentration of Cl is reduced by the time. After

Table 2
The emission maxima from halogens with rare gases in their respective combinations (Kogelschatz, 2004; Lebedev and Pryanichnikov, 1993; Pikulev et al., 2012).

Halogen gases		Rare gases					
	Emission maxima of pure gas	**Xe**	**Kr**	**Ar**	**Ne**	**He**	
		172 nm	146 nm	126 nm	84 nm	74 nm	
F	157 nm	354 nm	248 nm	193 nm	108 nm		**Emission maxima of mixture gas**
Cl	259 nm	308 nm	**222 nm**	175 nm			
Br	289 nm	282 nm	207 nm	165 nm			
I	342 nm	253 nm	190 nm				

a long period, the hetero-phase chemical reaction between quartz wall and Cl resulted into degradation of quartz material. This reaction leads to the formation of chlorosiloxanes, a polymer as represented in Eqn. (3) (Zhuang et al., 2010).

$$nSiO_2\ (solid) + 2nCl\ (gas) \rightarrow Si_nO_nCl_{2n}\ (Solid) + (n/2)O_2 \quad (3)$$

6. Limitations and future prospects of Hg-based UV radiation on COVID-19 evolution

UV irradiation can be deliberated as a mediation which may displace chemical treatment due to non thermal treatment. It has really a number of benefits over conventional chemical treatment like no disinfectant residuals, insignificant development of disinfection by-products (Aoyagi et al., 2011; Dotson et al., 2012; Lubello et al., 2004; Mori et al., 2007). We can use low or medium-pressure mercury lamps most commonly used as a UV source in UV disinfection methods (Beck et al., 2015; Chevremont et al., 2013a). Although, UV technology is nowadays used as surface treatment but it has number of limitations: (i) UV is not able to facilitate directly to the surface microorganisms due to the characteristic shallow penetration depth. (ii) This shadowing effect of UV radiation also dominant if located in pores or other natural irregularities of surface (Gardner and Shama, 2000; Liu et al., 2015; Shama, 2007). (iii) Fragile quartz based UV lamps have mercury content and have the risk of damaging human health and the environment (Chevremont et al., 2013b; Close et al., 2006).

In the latest literature, researchers have developed "water-assisted UV system". This device separates and dissolves microorganisms on the sample surface via the agitation. As a result of it, all microorganisms can simply be deactivated via UV radiation whereas the sample is relocated arbitrarily to expose all surfaces to UV irradiation. This process raised UV inactivation effect (Huang and Chen, 2015, 2014; Raeiszadeh and Adeli, 2020). Such type of systems may be the path of the reduction of disinfectant effect on many surfaces from the COVOD-19 viruses. This system uses Hg-free photoluminescence technology with UV source and disinfects the samples via only the water without any sanitizer and have a great potential with respect to the conventional Hg-based UV device technology. Apart from that there is a need of number of efforts in renew such type of devices and structured by including a real agitating technology to help practical application in the current type of COVID situations.

7. Safety measures against UV-treatment

UV-light has creates numerous effects on skin may cause high risk of skin cancer and skin pigmentation. Besides, the exposure of naked eye under UV-light may lead to sever problem such as solar retinopathy, photokeratitis, retinal damage, and erythema of eyelids (Behar-Cohen et al., 2013; Ivanov et al., 2018; Izadi et al., 2018).

Hazardous UV-radiation exposure to human eye and skin is considered as direct radiation and secondary exposure are also possible due to reflection of UV-light from the surface and reached to our eye and skin. The secondary reflection of UV-ray from highly reflective surface must be critical consideration during the development of disinfection devices. For example various materials such as stainless-still, aluminium, PTFE surfaces have very high reflectance properties of 50%, 90% and 95% respectively. According to the regulations provided by various types of organizations such as European Agency for Safety and Health, American conference of governmental industrial hygienists and American cancer society, the threshold limit value is demonstrated as "effective" UV dose (irradiance $\times$ exposure time) of 3 $mJcm^{-2}$ under 8 h time frame to human exposure. The used of word "effective" in the regulation is considered as the highest value of sensitivity of human eye that was nearly obtained as 270 nm. This presented wavelength is considered as a reference wavelength to know the biological response of sample under different wavelengths condition. The exposure of UV-radiations to human eye and skin could be reduced with the use of some UV protected goggles and gloves, development of UV protected shield for prevent the exposure (Raeiszadeh and Adeli, 2020).

Although the developer of UV-based disinfector provides all the safety measures, the ultimate goal of success disinfection can be only achieved by an appropriate use of device from the user side. For instance, a person is handling the UV-based disinfector device so he must be aware about the safety measures such as any kind of hand sanitization cannot be done by it, how long and from what distance a surface or object can be irradiated. There providing a comprehensive manual from manufacturer and appropriate knowledge of given manual and handling protocol form user side must be required for the success of UV-based disinfections of coronavirus. The formation of ozone during air disinfection is recognized as one of the crucial problem associated with UV disinfection. The O_3 generation is common phenomena occurred with the reaction of O_2 with UV rays. However, the design, power and operation time of UV lamps significantly affect O_3 generation. It can be reduced by using particular wavelength (Fig. 4(a, b)) and the technology available such as activated carbon filters, tightly enclosing of lamp with ozone resistant material, ozone filters, particular wavelength filter of UV radiation etc. (Claus, 2021; Salvermoser et al., 2008). The O_3 generation simultaneously accompanied with its decay, hence it can be reduced in open area because natural half-life of O_3 is reported between 1 and 3 days (Claus, 2021; Koller, 1945). However, Welch et al. reported the formation of ozone was less than 0.005 ppm for far UV C (222 nm) and concentration was not up to the level which can offer antimicrobial effect (Chapman, 1930; Raeiszadeh and Adeli, 2020; Welch et al., 2018). Finally, the ozone formation also must be required to consider during development and use of UV-based disinfection system.

8. Conclusion

The capabilities of UV radiations to check the transmission of the Covid-19 virus are well established. In terms of harmful impact on human skin cells and retina from UV-C (254 nm), open area sanitization is quite possible by using far UV-C (222 nm) based tech-

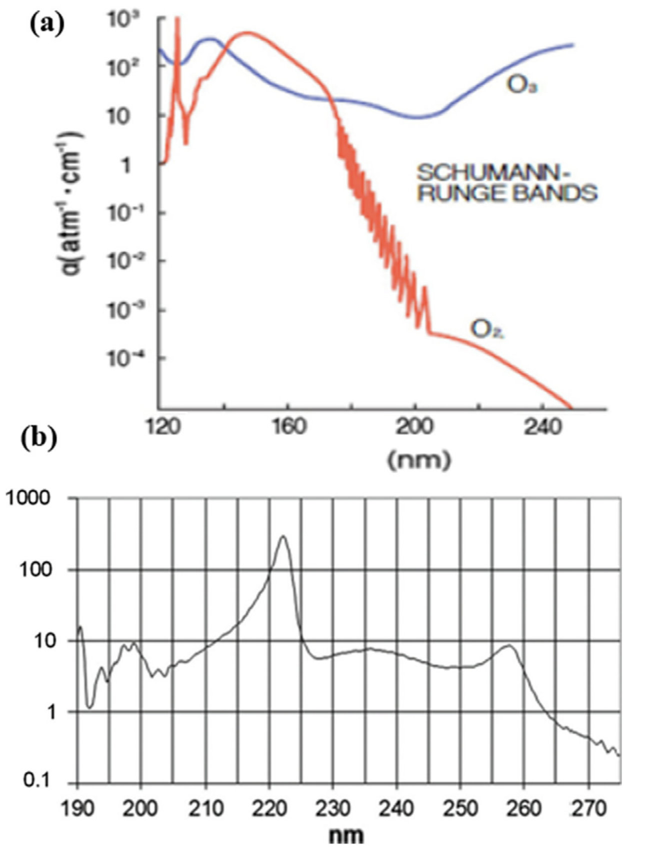

Fig. 4. Oxygen absorption with different wavelength of UV. (b) The plot of the spectral power distribution of a typical KrCl lamp in semi logarithmic scale. Panel (a-b) are reprinted with permission from (Claus, 2021), copyright John Wiley and Sons 2021.

nology. It can be used for the sanitization and degradation of microorganisms present in aerosol during the working condition. It is advantageous over mercury-based UV because Kr and Cl are used for UV-C (222 nm), which is non-polluting inert and halogen gas respectively. Hence, far UV-C-based applications instead of higher wavelength-based UV-C overall reduce the hazardous and radiation-based health impact. The other application can also be developed by exploring its different impacts on several microorganisms. The utilization of this technology will also indirectly reduce the use of UV-C (254 nm) based ozone emission and overall reduce air pollution. The various efforts are still required to be applied to achieve safe disinfection from UV light that will protect human life and the surrounding ecosystem.

CRediT authorship contribution statement

Ashutosh Kumar: Writing – original draft, Visualization, Formal analysis. **Abhishek Raj:** Writing – original draft, Visualization, Formal analysis. **Ankit Gupta:** Conceptualization, Formal analysis. **Sneha Gautam:** Conceptualization, Formal analysis. **Manish Kumar:** Conceptualization, Formal analysis. **Hemant Bherwani:** Conceptualization, Formal analysis. **Avneesh Anshul:** Conceptualization, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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