International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 1 ǁ January 2024 ǁ PP. 176-181

A review of microbial research on disinfection of ultraviolet cabins under the background of the new crown epidemic

Yue Zhang
[*1] *Department of Civil Engineering, University of Shanghai for Science and Technology, Shanghai, China*
Corresponding Author:Yue Zhang

Abstract
This article reviews the research on UV cabin irradiation disinfection microbial for many years in the context of the current COVID-19 epidemic. Based on the previous research on the ultraviolet experimental chamber and the simulation chamber, By studying the key parameters such as ceiling fan (speed, blade shape), particle size, microbial species, irradiance (UV fixation device，UV system form), the research affecting the disinfection effect of the ultraviolet cabin is summarized from the aspects of economy and efficiency. At the same time, it is pointed out that COVID-19 is sensitive to ultraviolet rays, the maximum absorption wavelength of RNA molecules is 250 nm, and it is recommended to use UVC near the wavelength of 254 nm to irradiate the virus to achieve the purpose of in vitro inactivation of the virus. It provides a reference for the application of UVGI technology in special places such as negative pressure isolation wards in hospitals.

Keywords: *exposure time, microbial species, irradiance, COVID-19.*

Date of Submission: 05-01-2024 Date of acceptance: 17-01-2024

I. INTRODUCTION

SARS-CoV-2 was first detected in Wuhan in December 2019 and has since spread rapidly across the globe [1]. As of June 3, 2022, a total of 2754999 people have been confirmed with COVID-19 in China. Patients with new crown pneumonia have fever, fatigue and dry cough as the main symptoms, and severe cases can rapidly progress to acute respiratory distress syndrome, septic shock, metabolic acidosis and coagulation dysfunction. While humans are using vaccines to fight the epidemic, the new coronavirus is also constantly evolving, producing a variety of variants. On 14 April 2022, the Omicron BA.5 variant was first detected in Hong Kong. Therefore, the study of Omicron BA.5 is very important for public health and epidemic prevention and control. Epidemiological investigations into the dynamics of SARS-CoV-2 have shown that close person-to-person contact is the primary route of transmission [2]. However, SARS-CoV-2 has also been shown to survive in aerosols, water, and surfaces, leading to concerns about the role of contaminated surfaces and air environments in the spread of this highly infectious agent. Therefore, it is urgent to find an effective way to inactivate the novel coronavirus. In the "Diagnosis and Treatment Protocol for Pneumonia Caused by Novel Coronavirus" (Trial Fifth Edition), it is clearly stated that the novel coronavirus is sensitive to ultraviolet light, so it is theoretically possible to use ultraviolet light to inactivate the novel coronavirus.

The principle of ultraviolet light to kill bacteria is DNA, and the maximum absorption wavelengths of RNA molecules are 260nm and 250nm respectively, and microorganisms in the air are particularly susceptible to UV damage at 254nm wavelength. At this wavelength, UV light is absorbed by deoxyribonucleic acid (DNA) to form pyrimidine dimers and other deadly products [3]. At the same time, inappropriate use or direct exposure to ultraviolet light in humans may lead to unnecessary complications [4]. Short-term overexposure to UVGI can lead to skin erythema and keratitis of the eye. Long-term exposure to ultraviolet light can cause skin cancers.

With the large-scale human infection caused by the outbreak of the epidemic in Shanghai, there is an urgent need to research and develop reasonable disinfection methods and equipment under the existing technical conditions for densely populated places such as shelter hospitals. Over the decades, UVGI technology has developed rapidly, and related research has been carried out. Therefore, this paper summarizes and discusses the key parameters that affect the disinfection efficiency of ultraviolet chambers over the years, in order to provide reference for the future research and application of ultraviolet chambers.

1.1.1 Selection of disinfection parameters for ultraviolet cabin

UVGI performance depends on the irradiance field produced by the UV lamp.The duration of microbial exposure to the field and the sensitivity of the microorganism to UVC irradiation. Irradiance and exposure time are determined by the system design and airflow organization. The product of these two variables defines the dose of UV light received by airborne microorganisms.

1.1.2 Ceiling fan speed

For indoor upper-space ultraviolet irradiation devices (UR-UVGI), adequate vertical air mixing is essential to bring infectious particles to the upper rooms, irradiate and inactivate them, and subsequently return fresh air to the lower rooms, which is essential for safe breathing of the lower room personnel [5]. In order to facilitate vertical air movement and rapid transport of microorganisms to the upper rooms, ceiling fans were considered the most suitable solution to improve the performance of the UR-UVGI system. At the same time, due to energy constraints, the state encourages the use of energy-saving electrical appliances. The use of ceiling fans can achieve energy conservation and emission reduction while achieving indoor thermal comfort [6].

One study has shown that UR-UVGI with ceiling fans can achieve 70%-80% effectiveness in air disinfection in a real hospital environment. With the use of ceiling fans, the vertical airflow increases significantly as the fan speed increases. Under the same number of air changes, the higher the fan speed, the higher the visit frequency VF (average number of times microorganisms visit the UV irradiation field), and the shorter the average exposure time. When the air change rate is reduced from 6 ACH to 2 ACH at the same fan speed, the VF increases by a factor of about 3 and the average exposure time changes very little. Therefore, the total exposure time is inversely proportional to the air exchange rate. Contrary to the intuitive results, the mixing effect of ceiling fans on vertical airflow in the range of 2 to 6 ACH was independent of the number of air changes [7].

In addition, when the number of air changes was 6 ACH, the proportion of residual microorganisms decreased slightly as the fan speed increased. However, at 2 ACH air changes, the proportion of residual microorganisms was greatly affected by the fan speed, which was the lowest at 150 rpm and the highest at 235 rpm. The results show that when the number of air changes in the ultraviolet chamber is small, the fan-induced airflow has a great influence on the disinfection effect of UR-UVGI. Ceiling fans create local air movement and mixed air in the space, and higher operating speeds contribute to a more even concentration distribution. With better dispersion of bioaerosol particles, the use of ceiling fans reduces the concentration of the exposed person's breathing zone by more than 20%.

With the use of ceiling fans, vertical air movement is facilitated and the UV dose gradient becomes homogeneous. The higher the fan speed, the more uniform the dose distribution. In addition, when using ceiling fans, the UV dose shows a relatively symmetrical distribution in the vertical sections.

Table 1 Study on the effect of ceiling fan speed on air mixing.

Table 1: Study on the effect of ceiling fan speed on air mixing.

Room size (m×m×m)	Rotate speed (rpm)	Number of ceiling fans
1. 4.6×2.97×3.05	*61、107、176*	1
2. 4.0×4.0×4.0	*40、70、150、200*	1
3. 20.66×10.35×3.65	*60、182*	8
4. 4.0×3.0×3.0	*99、160*	1
5. 5.5×5.5×2.5	*72、124、182*	1
6. 9.9×6.3×3.65	*480、600、750*	4
7. 7.0×3.5×3.0	*380*	4
8. 5.5×5.5×2.53	*72、124、184*	1
9. 7.4×4.3×2.8	*131*	2
10. 4.0×2.5×3.0	*330*	1
11. 7.6×5.6×4.3	*60、100、140、182*	2
12. 5.49×5.49×2.53	*70.5-175*	1
13. 3.6×3.6×3.0	*60、120、180、240*	1

1.2.1 Blade shape

At the same time, efforts have been made to improve the design of the fan blades to increase the air flow, uniformity along the radius of the fan, and the coverage area of the air flow. Adeeb et al. focused on leaf count and found that increasing the number of blades resulted in higher air flow. Jain et al. found that the introduction of winglets and spikes at the leaf tip increased air flow. Afaq et al. measured the effect of the rake angle (the fan blades tilting above the horizontal plane) on air flow and found that the rake angle of 6° upwards provided the highest flow rate. Sonne and Parker developed a twisted tapered blade with an airfoil cross-section.

The twisted tapered blades improve the efficiency of airflow in the airfoil cross-section by reducing energy losses due to wingtip turbulence and airflow separation. The fan blades have been aerodynamically modified to provide a more constant air velocity in the area below the blades, resulting in a more homogeneous mixture of air in the UV chamber.

1.2.2 The size of the aerosol particle

The published data on the size distribution of droplets in experimental coughs and sneezes suggest that the size of the particles exhaled by the human body varies between 1 mm and 100 mm. The geometric mean diameter of the exhaled droplets from coughing was reported to be 13.5 mm and 16.0 mm when speaking. However, exhaled particles quickly lose water, reaching about half their initial diameter. Droplets larger than 20mm will quickly settle to the surface, while droplets between 0.5~20mm will stay in the air for a long time and are more likely to be captured by the respiratory tract.

When the geometric mean diameter of the droplet reaches 10 mm, the maximum concentration of bacteria increases with the increase of the geometric mean diameter of the droplet. As the size of the germ particles carried increased from 2.5 mm to 20 mm, the disinfection rate of the upper zone decreased from 88% to 78%. This can be explained by the fact that the deposition of a large number of aerosol particles can remove more bacteria, which reduces the percentage of bacteria removed by UV exposure.

1.2.3 Microbial species

In general, viruses and bacteria have a higher K value than fungi. Therefore, the UR-UVGI system is not well suited for removing fungal spores from the air, as the fungal spores have a lower K value, resulting in shorter exposure to UV light. When bacteria and viruses are exposed to ultraviolet light, the sensitivity constant K value may also vary with the environmental conditions in which the microorganism is exposed. Most bacteria and viruses are more susceptible to UV rays in the air than in water.

Differences in relative humidity between experiments can cause significant variations in the measured K values. Studies on aerosols of bacteria such as Serratia marcescens have shown that the K value is at relative humidity of 22~33%, 40~50%, and 78%, respectively0.36~0.79, 0.35~0.45, 0.095, with the increase of relative humidity, the ultraviolet sensitivity constant showed a decreasing trend.

The K values of E. coli, Streptococcus marcescens and Streptococcus epidermidis obtained with the LED-based UR-UVGI system were 1.068, 1.148 and 0.156 m^2/J, respectively, and the results were compared with those obtained using the mercury-based UR-UVGI system. The K values of Escherichia coli, Streptococcus marcescens and Streptococcus epidermidis were 0.034, 0.042 and 0.014 m^2/J, respectively, indicating that the K values of the three bacteria measured using the LED-based UR-UVGI system were significantly larger than those measured by the UR-UVGI system using mercury lamps.
Table 2 The data shows the K value of microorganisms under specific conditions.

Table 2: The K value of the microorganism under specific conditions.

Microbial species		K（m^2/J）	Relative humidity
14.	Serratia marcescens	*0.35～0.45*	40～50%
15.	Mycobacterium bovis	*0.07～0.47*	22～33%
16.	Incidental polybacterium	*0.2～0.22*	20～40%
17.	Mycobacterium tuberculosis	*0.44～0.55*	50%
18.	Bacillus subtilis	*0.063～0.066*	20～40%
19.	Bacillus anthracis	*0.272*	-
20.	colibacillus	*0.99*	70%
21.	Decylbenzene	*1.032*	-
22.	Pseudomonas fluorescens	*0.63*	-
23.	Candida albicans	*0.1098*	-
24.	Red myxomyces cerevisiae	*0.1038*	-
25.	Aspergillus amsterdam	*0.00344*	-
26.	Influenza A virus	*0.1187*	-

2.1 Ultraviolet light source

Conventional UR-UVGI systems are often equipped with low-pressure mercury UVC lamps, which can lead to the following problems in the design of the system: 1) The mercury UVC lamps are only about 30% efficient at converting input power into UVC radiation. 2) Ozone is a by-product, and the safety of the system is affected to a certain extent. 3) The size of the lamp is too large, and the room may need a variety of devices, which affects its aesthetics. One potential solution to these problems is the use of LED light sources. It is currently considered one of the best alternative sources for traditional low-pressure mercury UVC lamps. In addition, the unique properties of UV light-emitting diodes in LED lamps provide great help in the field of air disinfection. For example, due to the compact size of the LED lamp, one of the potential functions of this UV lamp is to allow the system to generate rotational radiation.

In recent years, the research on irradiance mainly includes ultraviolet lamp source, ultraviolet system form, ultraviolet fixation device location, etc.

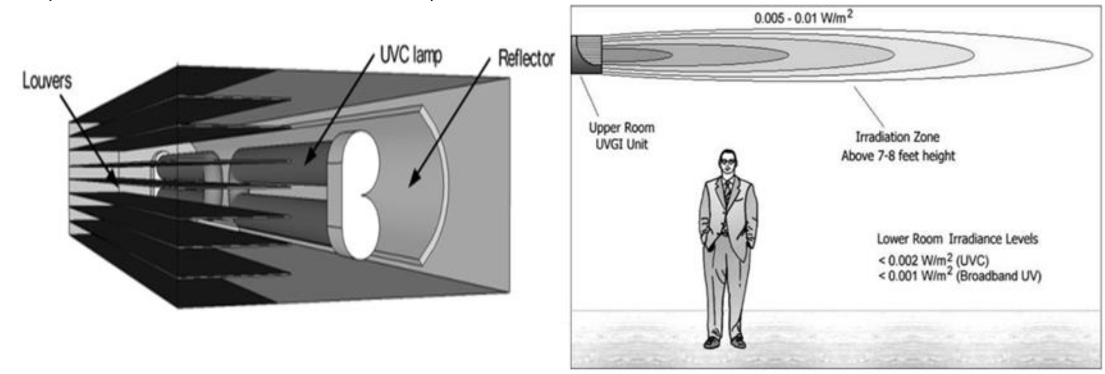

Figure 1: Schematic diagram of the ultraviolet disinfection device

3.1 Rotary UR-UVGI-LED system.

There is no significant difference in the performance of stationary and rotary UR-UVGI-LED systems under good air mixing conditions. Compared to the case of full mixing, the attenuation rates of E. coli described with the rotary UR-UVGI-LED system were 0.1015±0.07 min^{-1}, 0.1043±0.08 min^{-1}, 0.1190±0.03 min^{-1}, The attenuation rates of E. coli described by the fixed UR-UVGI-LED system were 0.0788±0.04min^{-1}, 0.0523±0.04min^{-1}, 0.0687±0.05 min^{-1}, respectively, and the results showed that the disinfection performance of the rotary UR-UVGI-LED system was increased by 22.36~49.86% compared with the fixed system.

4.1 Ultraviolet fixation device position

Theoretically, the magnitude of the irradiance drop is inversely proportional to the square of the distance from the light source. Studies have shown that the theoretical UV irradiance at an angle of 90° between the light source and the measuring object at a distance of 60, 120, 180 and 240 cm is 30, 7.5, 3.3 and 1.9 $\mu W/cm^{-2}$, respectively, which is comparable to the measured UV irradiance levels of 34, 8.1, 3.6 and 1.2 $\mu W/cm^{-2}$.At the same time, the sterilization effect of the ultraviolet fixation device is directly proportional to its irradiance and inversely proportional to the installation height. For UR-UVGI systems, UV fixtures installed at the lowest installation height tend to be optimally configured, but the safety of the system should also be taken into account during the design process, as the irradiation field generated by the UV fixtures is harmful to the occupants who are directly exposed, so a minimum installation height of 2m is recommended. At the same time, in order to maximize the efficacy of the UV fixation device and keep the irradiance below the threshold, it is recommended that the blinds always be tilted horizontally at a small angle to direct the collimated beam upwards to minimize human exposure.

Theoretically, the UV fixation device is best disinfected close to the outlet. Moreover, the disinfection effect of the flow sharing rate produced by multiple ultraviolet fixation devices was better than that of the non-uniform flow rate disinfection effect. Studies have shown that multiple low-irradiance UV lamps that are more widely distributed are more efficient than a single high-irradiance UV lamp located in the center of the room. In practice, it is recommended to use multiple UV fixation devices to obtain a more evenly distributed UV.

5 UV lamp test.

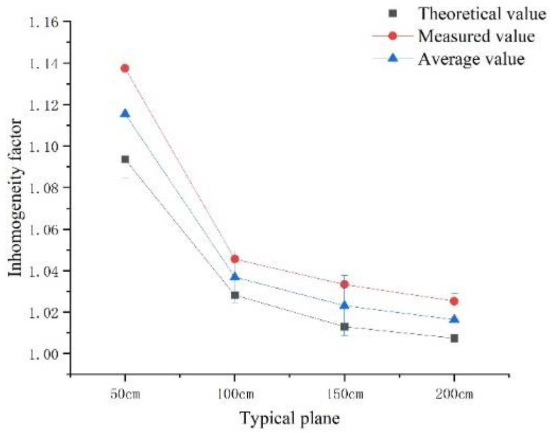

Figure 2: UV single lamp test

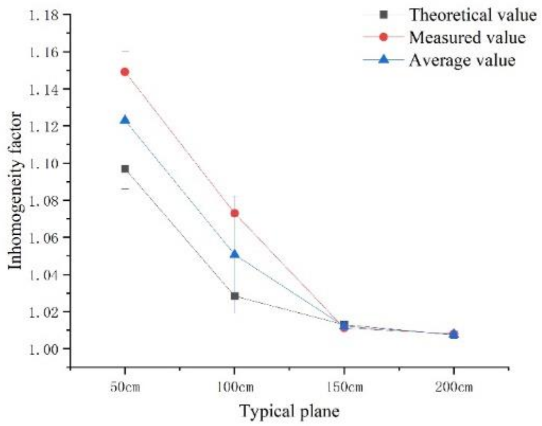

Figure 3: UV double lamps test

II. CONCLUSION

According to the study of exposure time, the presence of ceiling fans can improve the degree of air mixing for external auxiliary ventilation equipment, and the vertical air flow rate increases significantly with the increase of fan speed, and the higher the visit frequency VF (the average number of times microorganisms visit the ultraviolet irradiation field), the shorter the average exposure time. At the same time, the interaction between fan speed and air exchange times also affects the disinfection effect of the UV chamber: when the air exchange times are 6 ACH, the proportion of residual microorganisms decreases slightly with the increase of fan speed. However, at 2 ACH air changes, the proportion of residual microorganisms was greatly affected by the fan speed, which was the lowest at 150 rpm and the highest at 235 rpm. For the shape of the blades of the ceiling fan, through the aerodynamic transformation of the blades, the air flow of the ceiling fan is increased, the uniformity along the radius of the fan, and the coverage area of the air flow are achieved, so as to achieve the purpose of making the air mixing in the ultraviolet cabin room more uniform. The size of the aerosol particle size determines its state in the air environment, which indirectly affects the disinfection effect of the ultraviolet cabin: the aerosol particles with a particle size greater than 20mm will quickly settle to the surface due to the influence of gravity, reducing the content of the original aerosol, and the aerosol particles between 0.5~20mm will stay in the air for a long time, and the smaller the particle size, the aerosol particles are more likely to be irradiated by the ultraviolet light emitted by the UR-UVGI device.

According to the research on the sensitivity constant K, the main reason for the difference in the K value of microorganisms is the difference in the type of microorganisms, and generally speaking, the K value of viruses and bacteria is greater than that of fungi. In addition, the sensitivity constant K value may also vary with the environmental conditions in which the microorganisms are exposed, such as the relative humidity of the air and the concentration of the microorganisms in the agar plates. The causes of systematic error due to different UVGI system luminaires were also analyzed: the K values of E. coli, Streptococcus marcescens, and

Streptococcus epidermidis measured using the LED-based UR-UVGI system were significantly larger than those measured by the UR-UVGI system using mercury lamps.

From the study of irradiance, the traditional UR-UVGI system is usually equipped with a low-pressure mercury UVC lamp, which will lead to a variety of systems in the design, the paper recommends the use of LED lamp sources instead of the traditional low-pressure mercury UVC lamp source, and the use of a rotary UR-UVGI-LED system in the UV chamber when the air is mixed unevenly: the rotary UR-UVGI-LED system has a much higher disinfection performance compared to the stationary system. For the placement of the ultraviolet fixation device, it is recommended that the minimum installation height of the ultraviolet fixation device is 2m, and it should also be as close to the outlet as possible. In order to obtain a more evenly distributed UV irradiance and improve the disinfection effect of the UV chamber, multiple low-irradiance UV fixation devices can be used instead of a single high-irradiance UV fixation system.

REFERENCES

[1]. FABIO P. (2021) “A systematic scoping review of ultraviolet C (UVC) light systems for SARS-CoV-2 inactivation” Journal of Photochemistry and Photobiology

[2]. ZHOU F. (2020)” Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study” Lancet, Serial No. 395 Pp. 1054–1062

[3]. BEGGS C B. (2006) “Methodology for determining the susceptibility of airborne microorganisms to irradiation by an upper-room UVGI system” Aerosol Science pp. 885-902

[4]. KUMAR A (2021) “Possibility of using ultraviolet radiation for disinfecting the novel COVID-19” Photodiagnosis and photodynamic therapy, Pp. 102234

[5]. RUDNICK S N. (2015) “Influence of ceiling fan’s speed and direction on efficacy of upperroom, ultraviolet germicidal irradiation: Experimental” Building and Environment Pp.756–763

[6]. OMRANI S. (2021), “Ceiling fans as ventilation assisting devices in buildings: A critical review” Building and Environment pp.108010

[7]. ZHU S W (2013) “Numerical Investigation of Upper-Room UVGI Disinfection Efficacy in an Environmental Chamber with a Ceiling Fan” pp. 782 –791.