Disinfection Efficacy Analysis of an Ultraviolet-C (UVC) Device for Escalator Handrails

Qingping Guo[1], Andrew Kenny[1], Guentsch Johannes[1]
Benjamin Hatton[2], Dalal Asker[2]

[1] Draka EHC 1287 Boundary Rd. Oshawa, Ontario, Canada
[2]University of Toronto, 1284 College St. Toronto, Ontario, Canada

Keywords: Ultraviolet-C (UVC), Disinfection efficacy, Continuous and pulsed test, Escalator Handrails, Viruses and bacteria.

Abstract. The global Coronavirus pandemic is of urgent concern with its high transmission rate and rapid spread throughout the world from 2019. This paper introduces an Ultraviolet-C (UVC) device to be fitted on escalators which was designed to inactivate bacteria and viruses on the surfaces of handrails during escalator operation. Through a combination method of measurement and finite element analysis (FEA) simulation, the authors accurately calculated the UVC intensity, dosage, and distribution of the UVC device on a surface. The authors also describe how the UVC device works and detail the disinfection efficacy of the device to inactivate bacteria and viruses. In this work, efficacy of the device against two bacteria (E. Coli and S. Aureus) and two corona viruses (HCoV-229E and HCoV-OC43) were tested. All tests were conducted in two modes of the UVC device: continuous mode and pulsed cyclic mode. Based on the test results and combining UVC parameters, the disinfection efficacy of the UVC device was analysed. The investigation found, i) the relationship between the disinfection efficacy and the UVC parameters of the device, ii) the relationship between the disinfection efficacies of continuous and pulsed test mode and iii) the dosage for killing 99% pathogens (D_{99}) of the UVC device for the two bacteria and viruses based on escalator operation.

1 INTRODUCTION

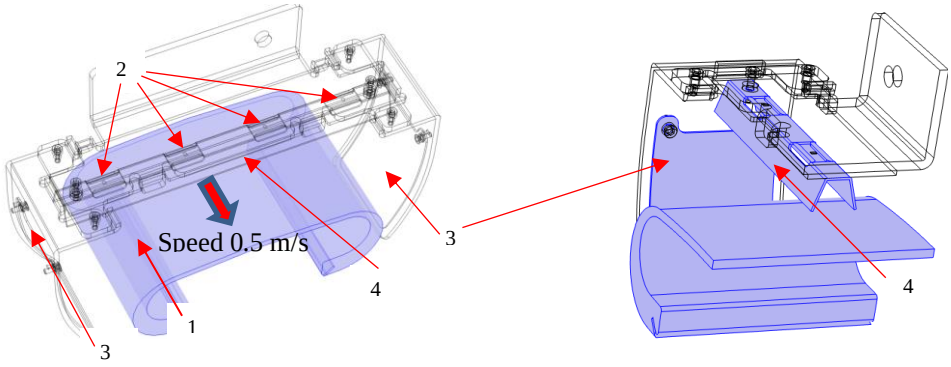
The COVID-19 pandemic brought the importance of available and reusable Personal Protective Equipment (PPE) into sharp relief. As requirements for clean, hygienic spaces become more critical to our health and wellbeing, UV devices provide a proven and effective means of disinfecting public and shared spaces. Studies show that bacteria, mold and fungi can be killed, and viruses can be inactivated by UVC [1-3]. UVC energy photochemically interacts with the RNA and DNA molecules in a virus or bacteria to render these microorganisms non-infectious [1- 4].

The efficacy of UVC with wavelengths of 222 and 254 nm has been analyzed in many studies. But some researches also pointed out: the reality is that 254 nm is not the peak absorption wavelength of bacteria and viruses but is simply a convenient wavelength for mercury lamps. In fact, the peak absorption wavelength of bacteria and viruses is around 265 nm. More efficient and compact UVC light emitting diodes (LEDs) have a peak wavelength between 275 nm and 280 nm and are just as effective as 254 nm for purification purposes. Short wavelength UVC, of 250–280 nm, is considered the most lethal of wavelengths due to its capability of inactivating microorganisms as it gets strongly absorbed in their nucleic acids. This often leads to the formation of cyclobutene pyrimidine dimers (CPD) in the nucleic acid strands, which might cause defects in cell replication and eventual cell death [5, 6].

The UVC disinfection efficacy is related to the dose of UVC on a surface (or in a space) [1]. Although the UVC may not be powerful enough (intensity) for large spaces and areas, it can be controlled to provide very high intensity on a small spaces or areas to create a high disinfection efficacy for bacteria and viruses.

Draka EHC is the largest escalator handrail manufacturer in the world and these are widely used in public places. From the beginning of the COVID-19 pandemic, Draka EHC cooperated with IRtronix

Inc. to develop a UVC device for cleaning the surface of escalator handrails. The UVC device is mounted inside the escalator system, so it is not visible or exposed to people using the escalator. Please see Figure 1, it shows the structure of the UVC device and position relationship between the UVC device (transparent part) and an escalator handrail cover in service. The UVC device mainly consists of a frame, 4 UVC LEDs, 2 side reflectors and a top reflector. Table 1 shows the main parameters of UVC LEDs.



1. Handrail, 2. UVC WICOP LED, 3. Side reflectors, 4. Top reflector, 5. Frame

Figure 1 The UVC device and a piece of handrail

Table 1 Electro-Optical Characteristis at 150mA (T_a=25°, RH=30%)

Parameter	Symbol	Value	Unit
Peak Wavelength	λ_p	275	nm
Optical Output Power	Φ_e	11.5×4	mW
Forward Voltage	V_F	6.5	V
Spectrum Half Width	$\Delta\lambda$	11	nm
View Angle	$2\Theta_{1/2}$	135	deg.

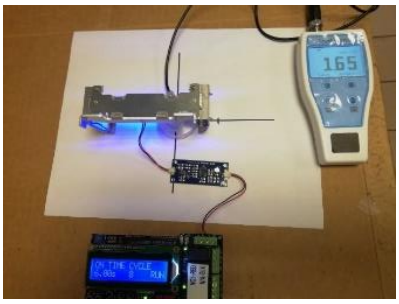
To best understand the disinfection performance of this device it is necessary to know the UVC dose that will be delivered to the surface of an escalator handrail and the effect of this dose on pathogens. To determine the dose delivered the UVC device was analyzed by combining UVC measurement (calibration) and FEA simulation; and further the relationship between the UVC intensity and dose with the setting parameters of the UVC device and handrail was obtained. To determine the disinfection efficacy of this device, Draka EHC collaborated with the University of Toronto (UofT) department of Materials Science and Engineering. The UofT team tested the device against two bacteria (E. Coli and S. Aureus) and two corona viruses (HCoV-229E and HCoV-OC43) under different conditions. Based on the test results we were able to determine; i) the relationship between the disinfection efficacies of continuous and pulsed cyclic test modes and ii) the D_{99} (99% dosage) of the UVC device for the two bacteria and two viruses based on an escalator in normal operation.

2 THE UVC DEVICE AND FEA ANALYSIS

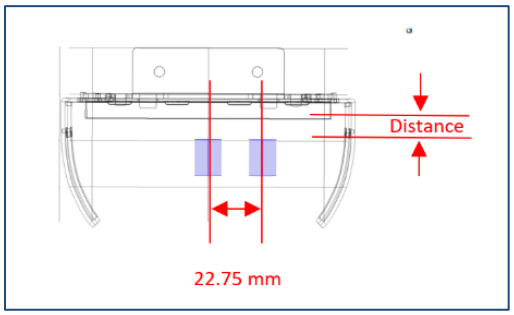
The UVC device will be installed inside the escalator. It creates a wide band of high intensity UVC on the handrail surface and scans the entire length as the escalator operates. The typical handrail running speed is 0.5 m/s and typical length is 30 m, so in around 60 seconds the handrail completes one cycle and the UVC device completes scanning the entire surface of the handrail.

A study has shown the disinfection efficacy of UVC is proportional to the UVC dose [1]. How to scientifically measure the dose on the handrail surface is essential to evaluate the disinfection efficacy of the UVC device. To analyze the UVC intensity and dose delivered to the handrail surface, a combination of FEA simulation and experimental measurement was used. After building the relationship between the simulation values and real UVC values, the FEA simulation was used to calculate the UVC intensity, dose, and distribution for the handrail surface.

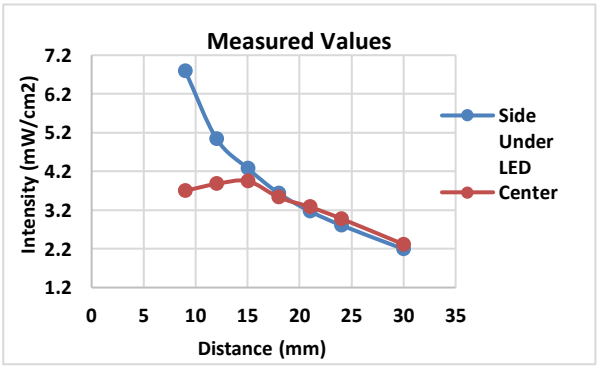
Ray Optics Module of COMSOL Multiphysics [7] was used to simulate UVC in this paper. Figure 2 shows the calibration procedure for UVC device intensity and how to build a relationship between the simulated result and measured result. The UVC intensity, dose, and distribution are not specified by the manufacturer and the actual values were measured. Then, based on the parameters of the measurement, COMSOL was used to simulate the UVC intensity and dose. Finally, by comparing both measured and simulated results the relationship was developed.



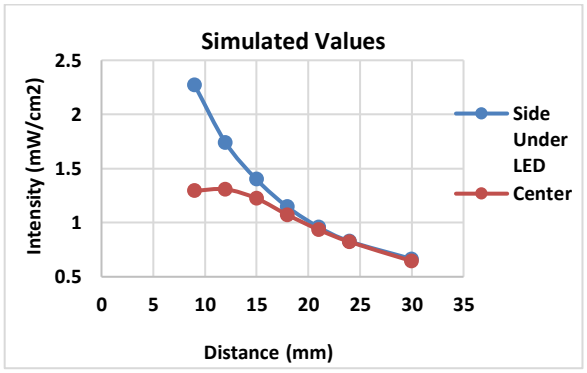
(a)



(b)



(c)



(d)

Figure 2 The calibration of the simulation results for UVC device

In Figure 2 (a), a commercial UV meter (ILT770-UV meter, International Light Technology) was used to measure the intensities of the UVC device. The sensor of UV meter has a round sensor with area 1 cm^2. The meter was used in two positions to measure the intensity of the UVC device. The first position was located exactly under the center of the UVC device (called center) and the second position was located either right or left side of center (called side) (See in Figure 2 (b)). The distance between the center and side positions was 22.75 mm. In Figure 2 (c), the measured intensities of these two positions with various distances (8, 12, 15, 18, 21, 24 and 30 mm) between the edge of the top reflector to sensor surface of the UVC meter are shown. In Figure 2 (d), the intensities of two positions with the exact distances used during the measurement in Figure 2 (a) were simulated. By comparing these two results it was found that they have a very similar shape and trend. That means the simulated FEA result well described the UVC physics. However, the absolute values are different between the measured and simulated results. Through linear regression method, the following relationship between the measured and simulated values were easily obtained:

$$\frac{\text{Real intensity}}{\text{Simulated intensity}} = 3.06$$

In this paper, all analysis of the UVC device such UVC intensity, dose, and distribution is based on FEA simulation results by using the correction parameter of 3.06.

In Figure 3, the simulated UVC intensity distribution on the handrail surface looks like a band shape. The band shape and dimension are mainly decided by the top reflector shape, dimension, and distance between the UVC device to the handrail surface. The top surface of the handrail is much closer to the UVC LEDs and the intensity is higher than on the two curved sides. Also, a higher intensity is shown in the center than on the two sides (Figure 3 (b)). The intensity decreases with increased distance between the UVC LEDs and handrail surface (Figure 3 (b)). At the same time, the UVC distribution band width is increased with distance.

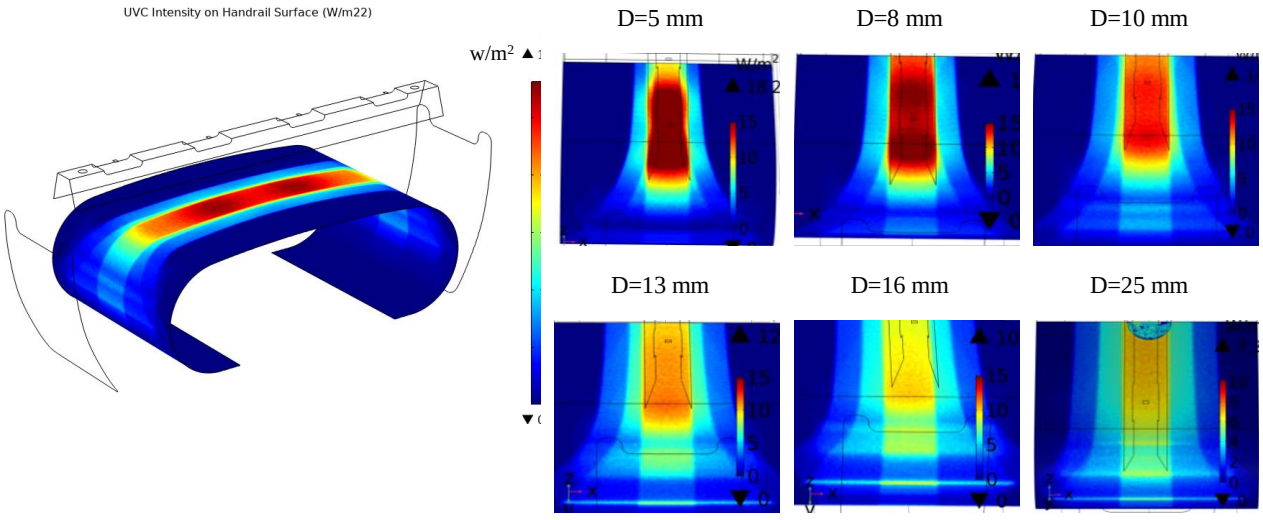
The dose delivered equals intensity multiplied by the exposure time. Based on the simulated intensity, the dose on the surface was easily calculated. However, because the intensity is not constant on distributed surface area, it is not easy to calculate the dose on the handrail surface because it is moving at a constant speed (0.5 m/s). Therefore, the dose received by the handrail surface is not even. In order to accurately calculate the dose on the handrail surface, several parallel lines (to mark the position on the handrail surface) were drawn (Figure 4). The dose received on each line is a constant. The following equation is used to calculate the dose along each line,

$$Dose = \int f(x,\, y)dt = \int f(x,\, y)\frac{dy}{v} = \frac{1}{v}\int f(x,\, y)dy$$

Where $f(x, y)$ is intensity at point (x, y), $\int f\ (x,\ y)dy$ is line integration (simulation easily provides this data for each line) along y axis (handrail travel direction). v is the handrail running speed.

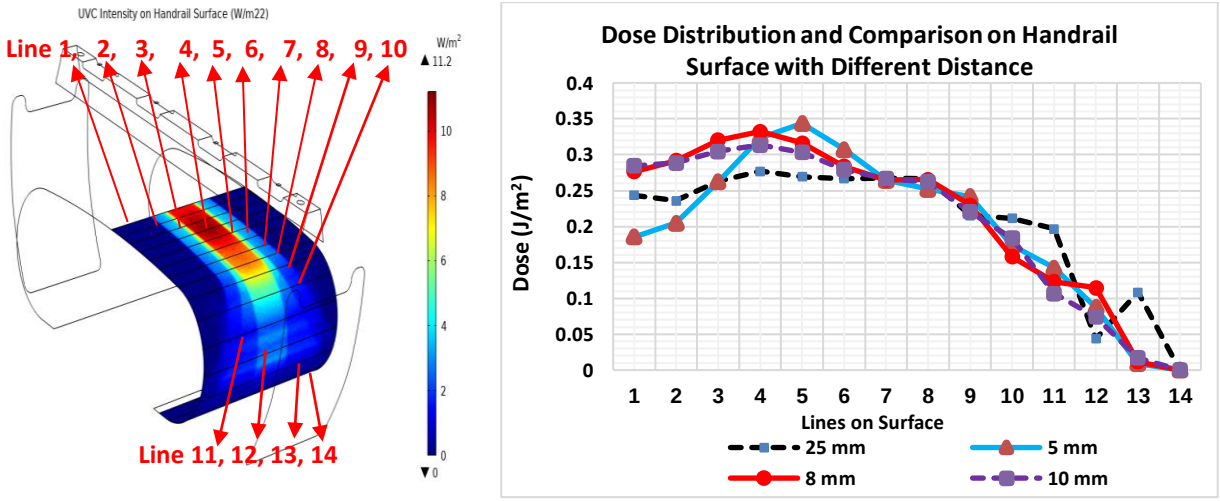
The intensity on each line was determined by using FEA simulation method. The UVC dose along each line with various distances between the device and handrail surface was calculated in one rotation of the handrail in service (in Figure 4 (b), only half was shown because of symmetrical shape). Obviously, the dose distribution on the surface varies with location and various distance. However, it seems to not be following any trend. The reason is although intensity is strong with closer distance, the width of distribution band area is narrower (Figure 3). The total integration may not be higher. On another side, the doses on two curved sides of the handrail is significantly lower than the top area despite of using side reflectors due to longer distance from the UVC LEDs. Based on this simulated result, the distance between the UVC device and handrail surface is less significant to the total dose received on handrail surface than originally suspected. A spacing of 8-10 mm is recommended as it provided the most balanced distribution on the handrail surface.

We have shown how the intensity and doses on the handrail surface were determined. To evaluate the disinfection efficacy of this UVC device, some pathogens needed to be tested using this UVC device. In this work, 2 bacteria and 2 viruses were chosen.



(a) (b)

Figure 3 The intensity distribution on handrail surfaces with various distances



(a) (b)

Figure 4 The calculated doses along each line on handrail surface

3 THE DISINFECTION EFFICACY TEST OF THE UVC DEVICE FOR PATHOGENS

In order to investigate how efficient the UVC device was at inactivating pathogens, Draka EHC collaborated with Professor Hatton's team at UofT. The disinfection efficacy logarithm (Log) reduction or percentage reduction of the UVC device for pathogens was tested under two conditions: continuous exposure time and pulsed cyclic exposure time. The continuous mode test means the UVC device is on all the time during the test until the preset test time is reached. The test of continuous mode was used to determine the exposure time range required to achieve a log reduction of 1 or greater for the tested pathogens. In pulsed cyclic mode, testing the device works in pulses: on (ON) for 0.1 seconds then off (OFF) for 59.9 seconds to complete one cycle of 1 minute. This cycle repeats until the specified number of exposure cycles were reached. For the test of pulsed cyclic mode, the total setting test time is determined according to the test results of continuous mode. It equals the pulsed cyclic time (0.1s) multiplied by the number of cycles.

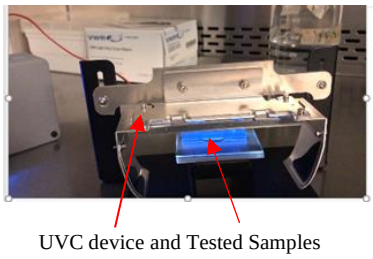
The pulsed cyclic test was designed to mimic the real condition during the running of the handrail on an escalator: the handrail surface receives a certain amount of UVC doses, which is not continuous. It is only exposed to UVC when it passes under the scanning band of the UVC device; after passing through that zone, there is a gap of almost 60 seconds (a loop cyclic time of a typical handrail is 60s) before the next UVC exposure. Also, by comparing these two test results (continuous mode and pulsed cyclic mode), it will show whether there was significant difference in disinfection efficacy between intermittent or continuous exposure.

For each pathogen, the test under continuous mode was first conducted to find the effective time range of the UVC device. Then, based on this result of the continuous mode, the test of pulsed cyclic mode was conducted to find the disinfection efficacy of the UVC device. The distance 8 mm between the edge of top reflector of the UVC device and test samples (surface) was used (real distance is 15 mm between LEDs to the test surface).

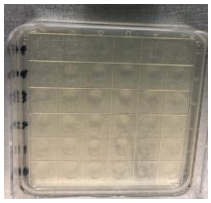
Two bacteria (E. coli and S. aureus) were tested using the setup in Figure 5 (a). The test samples were prepared using a square petri dish with a gird of thirty-six squares (6×6), each square with dimension 13×13 mm (Figure 5 (b)). Three pathogen droplets (10 uL each) were inoculated on the surfaces of a strip with size (1 cm×3.9 cm) (Figure 5 (c)). The strip (with 3 samples) was put on a flat surface (setup is shown in Figure 5 (a)).

Figure 5 (d) shows test setup for two seasonal corona viruses (HCoV-229E and HCoV-OC43). 50% Tissue Culture Infectious Dose (TCID50) assays are used to quantify virus titers.

If the setting distance between the UVC device and the pathogen sample surface is 8 mm, the simulated UVC distribution area on a surface is shown in Figure 5 (e). During the test, the test samples must be kept in the center red strip area (80×11 mm) and in this area the average UVC intensity equals 3.78 mW/m2. The UVC dose equals the UVC intensity multiplied by the exposure time for the continuous exposure mode or the pulsed cyclic mode. The total pulsed cyclic exposure time equals the exposure time of a cycle (i.e., 0.1s) times the total number of cycles.

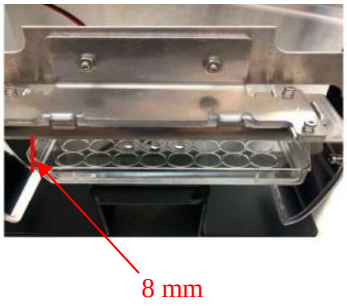


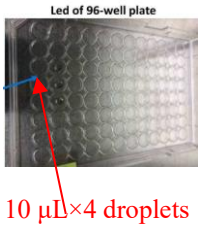
(a)



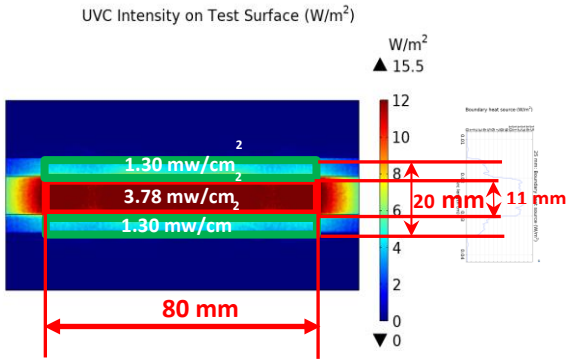
(b)

(c)





(d)



(e)

Figure 5 The test setup of sample positions and the UVC device

At the beginning of testing, 3 different exposure time durations were chosen for the continuous mode test based on some references in literature [8]. Then, based on the test results of the continuous mode, the 3 test time durations of the pulsed cyclic mode were chosen. In general, if the disinfection efficacy (measured as log reduction) obtained from the continuous mode test is in reasonable range (e.g., 1-4), the time of the pulsed cyclic exposure test will use the same "total" test time as the continuous mode test. Otherwise, an adjustment is needed. Figure 6 shows all tests conducted by the University of Toronto. It includes all information about the tests, pathogens, test times of continuous mode and test times of pulsed cyclic mode.

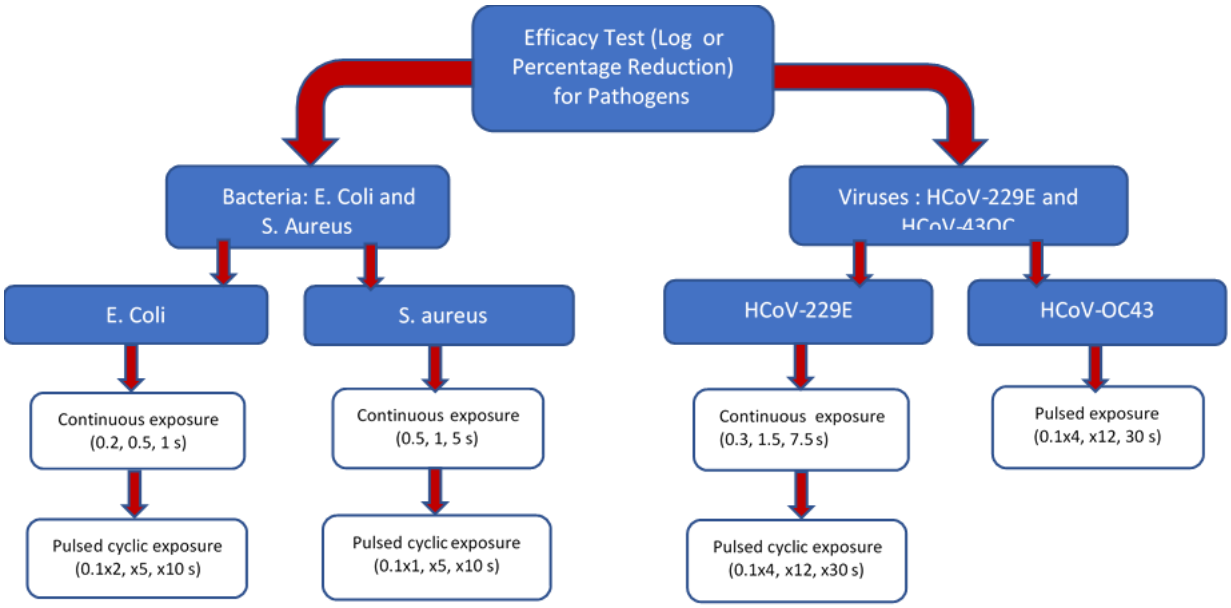


Figure 6 Efficacy Test of the UVC device for inactivation of pathogens

The disinfection efficacy of the UVC device is calculated by either percent reduction or logarithm (log) reduction. The calculation equations are:

$$Log\ Reduction = Log\ A/B$$

$$Percent\ Reduction = \frac{A-B}{A} \times 100\%$$

Where A is the number of viable pathogens before treatment; B is the number of viable pathogens after treatment.

Tables 2-5 show all the test results. Table 2 shows the test results for bacteria E. coli using continuous mode and pulsed cyclic mode. After completing the continuous mode test, the log reduction was very high. Based on this the total exposure times for the pulsed cyclic mode test were (0.1×1, 0.1×2 and 0.1×5 seconds), less than the times of the continuous mode test. The result was that the UVC device, with a 0.1 second exposure, could kill almost all E. coli bacteria (>99.8%).The UVC dose applied to the handrail surface in 0.1 seconds is; 3.78 mW/cm^2×0.1 s= 0.378 mJ/cm^2.

Table 3 shows the test results for bacteria S. Aureus using continuous mode and pulsed cyclic mode. After completing the continuous mode test, the time range (0.5 to 5s) was considered too broad, so for pulsed cyclic mode test, a narrower time range was chosen of 0.1 - 1.0s. This showed that the UVC device, with an exposure time of 1.0 s, which provides a UVC dose of 3.78 mW/cm^2×1.0 s= 3.78 mJ/cm^2, could kill almost all S. aureus bacteria (>99.87%).

Similarly, Table 4 shows the test results for corona virus HCoV-229E using continuous mode and pulsed cyclic mode. After completing the continuous exposure test, the time range (0.5 to 7.5 s) was broad, so for pulsed cyclic mode test, a narrower time range was chosen (0.4 - 3.0s). This showed

that the UVC device, with 1.5 second exposure time, i.e., the dose=3.78 mW/cm^2×1.5 s= 5.67 mJ/cm^2, could kill almost all virus HCoV-229E (>99.3%).

Finally, Table 5 shows the test results for corona virus HCoV-OC43 using pulsed cyclic mode. The time range was chosen based on the test results of HCoV-229E continuous mode test. It shows that the UVC device, with 0.4 second exposure time, i.e., the dose=3.78 mW/cm^2×0.4 s= 1.512 mJ/cm^2, could kill almost all virus HCoV-OC43 (>99.3%).

Table 2 The test results for bacteria E. Coli

Continuous Exposure Test					Pulsed Cyclic Exposure Test				
Time (s)	Number of microbes (before treatment)	Number of microbes (after treatment)	% Reduction	LOG_{10} Reduction	Time (s)	Number of microbes (before treatment)	Number of microbes (after treatment)	% Reduction	LOG_{10} Reduction
0.2	$3.2X10^5$	74.3	99.977	3.63	0.1X1	$1.93X10^4$	26.3	99.864	2.87
0.5	$3.2X10^5$	19.33	99.994	4.22	0.1X2	$1.93X10^4$	18.3	99.905	3.02
1.0	$3.2X10^5$	0.67	99.9998	5.68	0.1X5	$1.93X10^4$	3	99.984	3.81

Table 3 The test results for bacteria S. aureus

Continuous Exposure Test					Pulsed Cyclic Exposure Test				
Time (s)	Number of microbes (before treatment)	Number of microbes (after treatment)	% Reduction	LOG_{10} Reduction	Time (s)	Number of microbes (before treatment)	Number of microbes (after treatment)	% Reduction	LOG_{10} Reduction
0.5	$3.43x10^4$	$1.2x10^3$	96.4	1.4	0.1x1	$6.9X10^4$	ND	ND	ND
1	$3.43x10^7$	3.5X10	99.999898	6.0	0.1X5	$6.9X10^4$	91	99.87	2.9
5	$3.43x10^9$	4.3	99.99999	8.9	0.1x10	$6.9X10^4$	6.3	99.99	4.0

Table 4 The test results for virus HCoV-229E

Continuous Exposure Test					Pulsed Cyclic Exposure Test				
Time (s)	Number of microbes (before treatment)	Number of microbes (after treatment)	% Reduction	LOG_{10} Reduction	Time (s)	Number of microbes (before treatment)	Number of microbes (after treatment)	% Reduction	LOG_{10} Reduction
0.3	$9.28x10^5$	$1.36x10^5$	85.3	0.8	0.1x4	$1.36X10^6$	$1.36X10^5$	90	1
1.5	$9.28x10^5$	$6.3x10^3$	99.3	2.2	0.1X12	$1.36X10^6$	$2.0x10^3$	98.85	2.8
7.5	$9.28x10^5$	9.3	99.999	5.0	0.1x30	$1.36X10^6$	9.3	99.9993	5.2

Table 5 The test result for virus HCoV-OC43

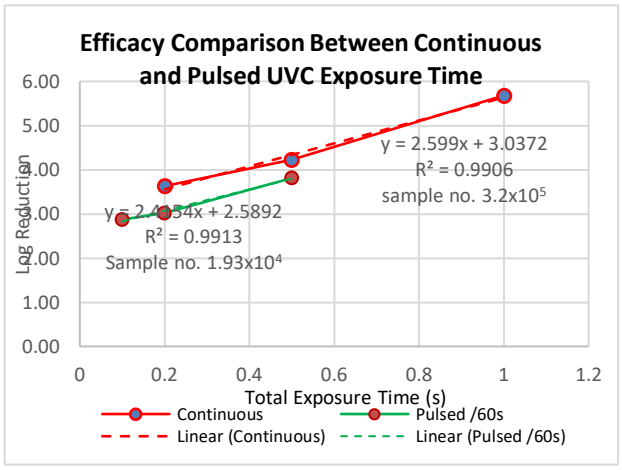
Pulsed Cyclic Exposure Test				
Time (s)	Number of microbes (before treatment)	Number of microbes (after treatment)	% Reduction	LOG_{10} Reduction
0.1x4	$4.3X10^7$	$2.9X10^5$	99.3	2.2
0.1X12	$4.3X10^7$	$9.3X10^3$	99.978	3.7
0.1x30	$4.3X10^7$	9.3	99.9998	6.7

4 THE RESULTS AND DISCUSSION

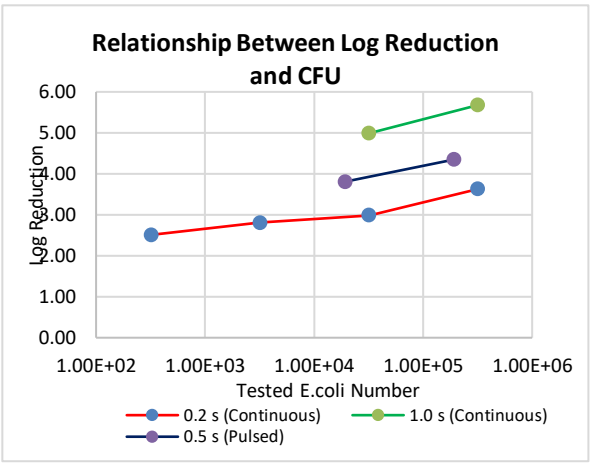
Using the experimental results provided above, we are able to examine the relationship between pulsed and cyclic exposure on the tested pathogens.

The test for bacteria E. coli was designed to compare the disinfection efficacy for both continuous and pulsed modes. The log reduction with exposure time for both modes is shown in Figure 7 (a). The red line represents the continuous result and green line represents the pulsed cyclic result. The dotted lines are linear trendlines for both conditions. Both results have a linear relation with time (doses). That means the disinfection efficacy increases with dose. However, by comparing the disinfection efficacy at the same time points (same dose, 0.5 and 1.0 s), it seemed the log reduction of the continuous mode test was higher than that of pulsed cyclic mode. What caused this difference? During the testing processes, because these two mode tests were independently conducted, the colony forming unit (CFU) and number of pathogens in the samples were different. Based on these test results, there is a significant effect on the disinfection efficacy depending on CFU of the pathogens. Figure 7 (b) shows some comparison between the test results with CFU. In general, it did not matter whether it was a continuous mode test or pulsed cyclic mode test; the log reductions always increase as the CFU increases. That means that in Figure 7 (a), because the initial number of pathogens (3.2×10^5) applied in the continuous mode test is much higher, the initial number of pathogens (1.93×10^4) in the pulsed cyclic mode test the higher log reduction of continuous exposure is because of the higher initial pathogen number.

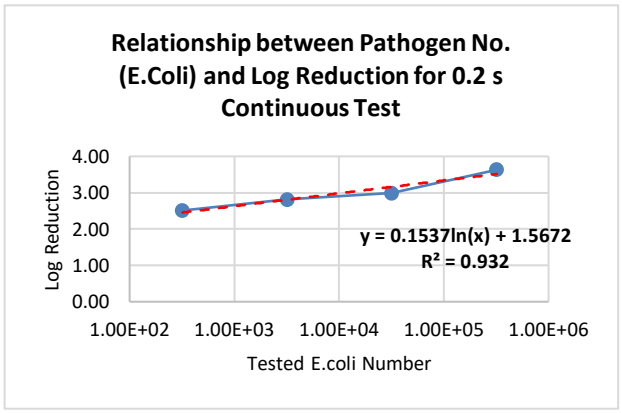
Figure 7 (c) shows the relationship between log efficacy with tested CFU. Using at least regression method, a linear trendline equation was obtained: $y=0.1537\ln(x)+1.5672$. The log reduction with the exact same pathogen number (1.93×10^4) used in pulsed cyclic was calculated. The log reductions of continuous mode tests for 0.5s and 1.0s were calculated according to the proportion of 0.2s. After correcting the log reductions, Figure 7 (d) shows the corrected disinfection efficacy comparison between the two modes. It seemed the two lines were very close for both test modes. Therefore, there isn’t significant disinfection difference for the continuous mode and pulsed cyclic mode.



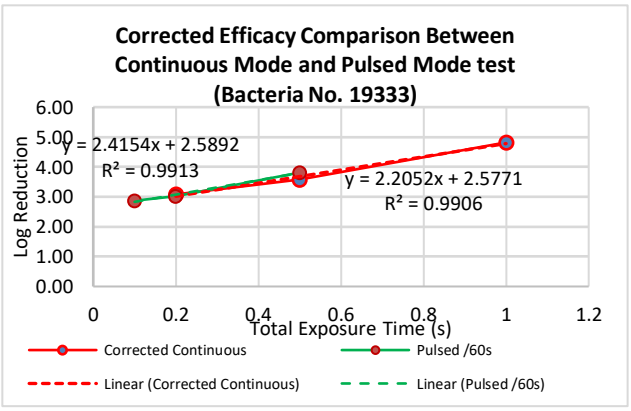
(a)



(b)



(c)



(d)

Figure 7 The relation of disinfection efficacies between continuous exposure and pulsed cyclic exposure

Usually, the logarithmic reduction of 1 (log reduction=1) means 10% of pathogens survived, i.e. 90% of pathogens were inactivated. D_{90} dosage means the dose can achieve 90% disinfection efficacy. For 2, 3, 4 log reduction, mean 99%, 99.9% and 99.99% of pathogens were inactivated, respectively. Similarly, D_{99}, D_{999}, D_{9999} dosages represent doses needed to achieve 99%, 99.9% 99.99% inactivation of pathogens, respectively. In this work, D_{99} was calculated based on test results of UofT under the zone with UVC intensity 3.78 mW/cm^2. And it will be used to evaluate the disinfection efficacy of this UVC device for various pathogens. The higher the D_{99} dosage, the longer the UVC exposure needed for the handrail surface.

Table 6 shows the tested dose and D_{99} for 4 pathogens. The dose equals the intensity (3.78mW/cm^2) times the total exposure time. Based on these dosages, the D_{99} can be easily obtained when log reduction equals 2. D_{99} dosage for virus HCoV-229 is the highest. That means it will take longer to inactivate HCoV-229E using this UVC device. Based on these tests, the bacteria E.coli is easiest to inactivate.

Table 6 Tested dosages and calculated D_{99} for 4 pathogens

Pathogens	Total Exposure Time	Log Reduction	The Percentage Reduction	Needed UVC Dose (mJ/cm^2)	Calculated D_{99} based on left side measured data	Percentage Reduction	Log Reduction	UVC D_{99} Dose (mJ/cm^2)
E.coli	0.1 s	2.86	99.86%	0.378		99%	2	0.264
S.aureus	0.5 s	2.8	99.84%	1.89		99%	2	1.35
HCoV-229E	1.2 s	2.8	99.85%	4.536		99%	2	3.236
HCoV-OC43	0.4 s	2.2	99.3%	1.512		99%	2	1.375

Table 7 shows the time the UVC device requires to inactivate 99% of the 4 pathogens. This has been used to estimate D_{99} for a 30m escalator handrail on a unit running at 0.5m/s. In this case the escalator needed 3 minutes running to inactivate 99% E. coli, 14 minutes for S. aureus and HCov-OC43, and 32 minutes for HCoV-229E.

Table 7 The required time of the UVC device to inactivate for 4 pathogens

Pathogens	Needed handrail running cycles to kill 99% of pathogens	Time/cycle (minute/cycle)	Time to kill 99% of pathogens (minutes)
E.coli	3	1	3
S. aureus	14		14
HCoV-229E	32		32
HCoV-OC43	14		14

5 CONCLUSIONS

The UVC distribution, intensity, and dose of the new UVC device on an escalator handrail surface was clearly analyzed by combination of a measurement and FEA simulation method. The relationship of intensity and dose between the simulated values and real (measured) values was developed. After analyzing the test results from UofT for bacteria E. Coli, the disinfection efficacy of the UVC device with pulsed cyclic exposure time didn't have a significant difference with the equivalent continuous exposure time. On the handrail surface, UVC intensity and dose distribution is not uniform. The top surface of the handrail is closer to the UVC device (LEDs), therefore it receives a higher dose of UVC and consequently the disinfection efficacy is higher on the top surface. D_{99} for 4 pathogens was obtained. It was found that the times required for inactivating 99% of various pathogens on the handrail top surface is different for each pathogen. For example, it needs a total of 3 minutes of escalator handrail cycling to kill 99% of E. coli; it needs 32 minutes of the handrail running (cycles) to inactivate 99% of CoV-229E; and it needs 14 minutes of the handrail running (cycles) to inactivate 99% of both S. aureus and CoV-OC43.

6 REFERENCES

[1] W. Kowalski, Ultravilot Germicidal Irradition Handbook, Springer, New York, 2009.

[2] https://www.amca.org/educate/articles-and-technical-papers/amca-inmotion-articles/uv-c-for-hvac-air-and-surface-disinfection-2.html

[3] M. Biasin, A. Bianco, G. Pareschi, A. Cavalleri, C. Cavatorta, C. Fenizia, P. Galli, L. Lessio, M. Lualdi, E. Tombetti, A. Ambrosi, E. M. A. Redaelli, I. Saulle, D. Trabattoni, A. Zanutta, & M. Clerici., "UV C irradiation is highly efective in inactivating SARS CoV 2 replication", March 18, 2021, Scientific Reports (nature.com)

[4] Yin R, Dai T, Avci P, Jorge AE, de Melo WC, Vecchio D, et al. Light based anti-infectives:Ultraviolet C irradiation, photodynamic therapy, blue light, and beyond. Curr Opin Pharmacol. 2013;13:731–62.

[5] Application Note: Disinfection with UV-C LEDs-Würth Elektronik.

[6] Selecting the UV LED Wavelength for Purification Applications — LED professional - LED Lighting Technology, Application Magazine (led-professional.com)

[7] COMSOL - Software for Multiphysics Simulation

[8] Raeiszadeh M, and Adeli B, "A Critical Review on Ultraviolet Disinfection Systems against COVID-19 Outbreak: Applicability, Validation, and Safety Considerations", ACS Photonics. 2020 Oct 14

BIOGRAPHICAL DETAILS

Qingping Guo is a senior product engineer at Draka EHC of Prysmian group. He received his PhD degree from University of Toronto in 2007. His job focuses on developing new products, new processes and toolings for polymer extrusion by using FEA simulation. He also did a lot research of polymer foaming and composites, and product testing. He published over 20 papers and hold 4 patents.

Benjamin Hatton is an Associate Professor in the Department of Materials Science and Engineering at the University of Toronto. His group investigates fabrication methods for surface topographies, antimicrobial materials, microfluidics, nano/micro porous layers, smart materials, non-fouling biomaterials, and bio-inspired materials. Prof. Hatton currently has 50 peer review publications, 15 patents (and applications).