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Effectiveness & Efficiency of UV-C Lights at Killing Bacteria

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This project focuses on utilizing UV-C light for disinfection to provide a safer environment by eliminating bacteria and viruses on surfaces. The circuit is adaptable by changing the number of LEDs, including a 12-volt battery, with a driver and potentiometer ensuring the correct current to supply maximum LED efficiency. Initial results for the design showed nearly total bacterial disinfection with minimal exposure, confirming the UV-C design's effectiveness. The adjustable testing apparatus, made by 3D printing technology, allows precision testing and different configurations, effectively killing bacteria on surfaces with specific LED setups.

Background

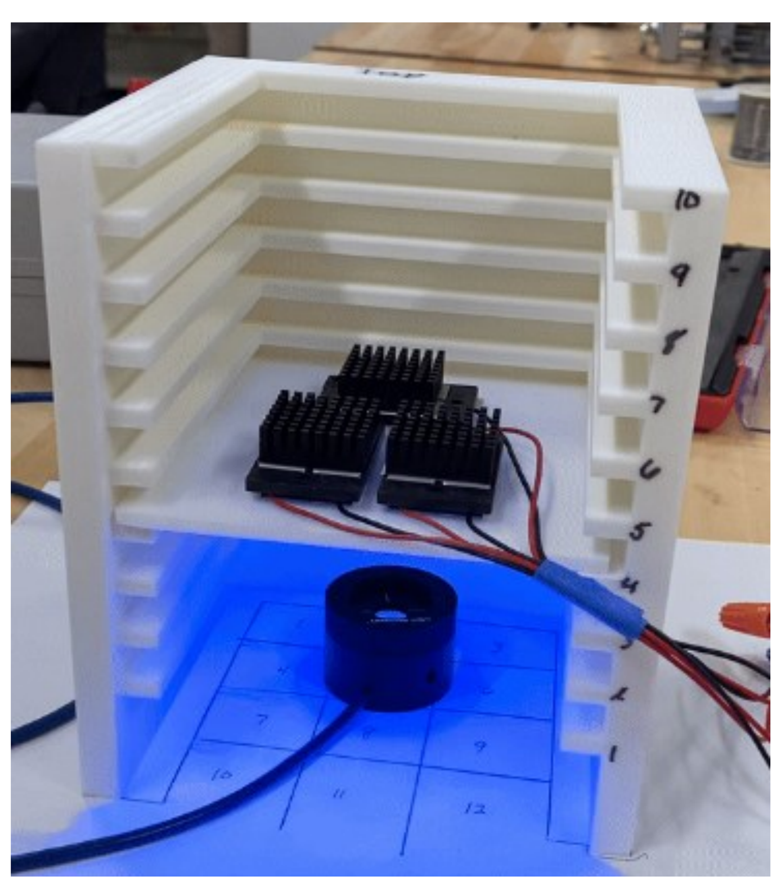
The COVID pandemic raised concerns about disinfection methods to reduce bacteria and provide a safer and healthier environment for humans. Various disinfection techniques have been used to prevent the further transmission of viruses and bacteria. Ultraviolet light or UV light is a widely used method due to its high effectiveness, non-chemical treatment, and ease of installation and maintenance. UV light is electromagnetic radiation with wavelengths between 100-400nm. It has three primary types: UV-A, UV-B, and UV-C, with UV-C having the shortest wavelength of 200-280nm. For a long time, UV light has contributed its benefits in disinfecting surfaces, the environment, and products against human pathogens. This project will explore the effectiveness of UV-C lights in killing bacteria by conducting different variable testing. Specific factors will be determined if they impact the effectiveness of UV-C lights.

Design

The testing apparatus for the UVC LED disinfection method was designed to be completely adjustable, with features like variable height slots and removable LED trays allowing the team to test multiple configurations for maximum efficiency. The UV tray features a customized cutout for each LED, ensuring precise and accurate measurements between the LED and the testing surface. 3D printing technology also allowed the team to produce multiple iterations for each part of the testing apparatus, proving very useful in the trial-and-error process of building the ideal prototype. The UV-LED circuit design uses a 12-volt battery to power the lights. An LED driver is included in the circuit to ensure the correct current goes through our LEDs when the switch is on. For each LED to supply maximum intensity or disinfection, a 400-500 [mA] current must go through each LED. The design is adaptable to include multiple LEDs if there is a need for more UV-C cover area. A potentiometer is used to adjust the voltage and current supplied by the driver for each LED.

Power Meter Testing

Using a Newport 1815-C Light Meter with an 818-UV sensor attachment, the power output of the UVC LED was able to be measured. The power output of the UVC LED helps us understand the time it takes for the LED to kill bacteria effectively, and knowing and understanding how we can best optimize things like the distance to the light will be crucial in the design of our system. One of the main variables we tested was the distance from the source to the target, and we did this in two different ways, horizontally and vertically. We moved the LEDs up and down vertically using slots on our testing box and horizontally by marking out a grid where we placed the light sensor. Unsurprisingly, we noticed that the closer the sensor was to the LED, the higher the power output was. However, when we changed the number of LEDs to two, we noticed a strange trend and decided to test whether putting the sensor directly under one LED would be better than putting it between them. We found much better results when placing the sensor directly under one of the LEDs than between the two. One of the last variables we tested was whether the reflectivity of the inside surface made a big difference in the effectiveness of the LEDs. We tested this by using the box's base white surface, aluminum foil to get an extremely reflective surface, and a black surface with a low reflectivity. The procedure for testing the LEDs using the power meter is simple. First, we randomly select which zone to be in for whatever variable we are changing (height, grid zone, etc). Then, once we are ready, we turn on the LED and let the sensor soak in the light for 10 seconds. After 10 seconds, we collect the data, measure it, and repeat the steps until all zones have been tested.



Above: Power Sensor testing with 3 LEDs and Adjustable 3D Design

Power Output Distribution, Height	
Tray Slot	Avg Power (mW)
9	14%
8	16%
7	19%
6	23%
5	26%
4	34%
3	42%
2	55%
1	100%

Above: Power Distribution of different heights

Power Output Distribution, Aluminum Foil

29%	44%	30%
59%	100%	42%
61%	77%	51%
40%	50%	41%

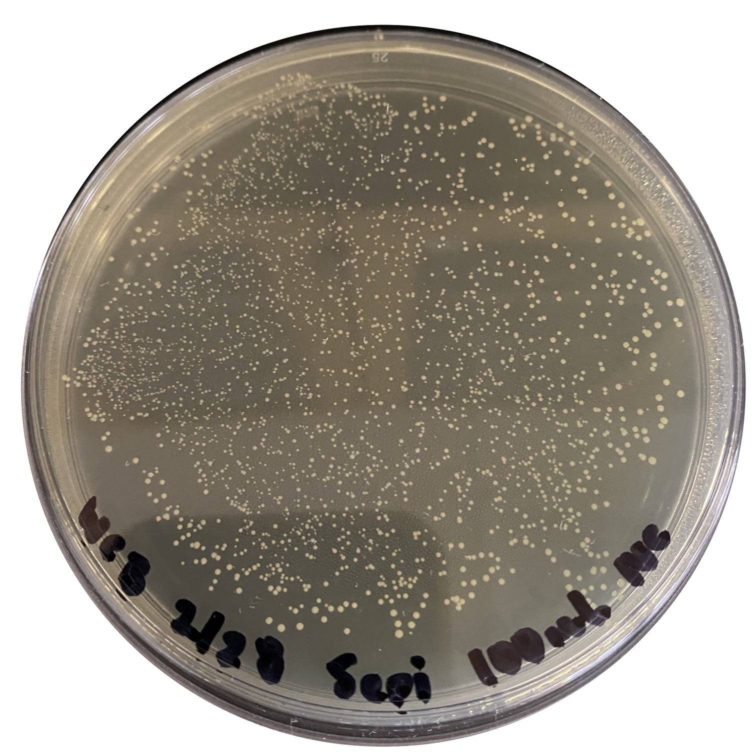
Above: Power Distribution of different zones

Bacteria Testing

The bacteria testing not only allowed for the testing of the efficacy of designs for different amounts of time but also confirmed the accuracy of the power meter testing. All bacteria testing was conducted using agar plates with Staphylococcus epidermidis. This pathogen is commonly found on surfaces and provides a minimal safety risk, as it is classified as a Biosafety Level 1. For each bacteria test, a control streak plate was prepared first. Then, another plate with 50-250 CFU of bacteria was prepared and placed under the testing apparatus. The bacterial lawn was subsequently exposed to the UVC LED for 3, 5, or 10 seconds. After the disinfection process, the plate was incubated for 24 hours. The test's efficacy was determined by comparing the control bacterial lawn with the disinfected lawn and counting the colony left after disinfection. The calculations to find the efficacy of that test are as follows:

$$\frac{\textit{Number of Bacteria Colonies on Disenfected plate}}{\textit{Total number of colonies on control plate}} * 100 = \textit{Efficacy}\ \%$$

Through the bacteria testing, the best and worst design configurations based on the conclusions from the power meter testing were tested. This provided confirmation that the variables in the design impact efficiency. Overall, the bacteria testing was successful in determining the effectiveness and efficiency of testing the disinfection power of a UVC LED on bacteria.



Left: Control Plate for Bacterial Testing

Right: Disinfected Bacterial Lawn (2 LEDs 3 Seconds)

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Results

The testing procedures that were conducted using the Newport power meter helped the team to determine the ideal LED configuration that would eliminate bacteria in the most efficient manner. All the data compiled from the power meter testing was then validated using actual bacteria testing. The results proved the team's original hypothesis, which stated that UVC light would successfully disinfect the bacteria on the testing surface. Through optimization, the team worked towards reducing the exposure time needed to achieve significant bacterial reduction. The team first achieved nearly total bacterial disinfection using a setup of 2 and 3 LED down to a 3-second exposure time, proving the success of these configurations. Additional testing was conducted, reducing the number of LEDs and the exposure time with each iteration. The team determined that a setup with 1 LED was most effective at vertical tray "2" and horizontal zone "5", achieving 100% bacterial disinfection down to 10 seconds of exposure.

Influence of Testing Variables on UVC Disinfection

Variable	Importance
Light Zone (Grid)	HIGH
Tray Number (Vertical Height)	HIGH
Number of LEDs	MEDIUM
Total Power through LEDs	HIGH
Angle of LEDs	MEDIUM
Effects of Ambient Light	LOW
Reflective Surface (Aluminum Foil)	LOW

Bacteria Disinfection using UVC

Time (s)	Efficacy		
	1 Light	2 Light	3 Light
3	98%	100%	100%
5	98%	100%	100%
10	99%	100%	100%