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UV STERILIZATION DEVICE FOR PERSONAL ITEM-RELATED INFECTION CONTROL DURING MEDICAL PRACTICE IN HEALTH FACILITIES.

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ABSTRACT.

Multidisciplinary design is one of the requirements for the award of a National Diploma in Biomedical Engineering considered with great importance by UBTEB to produce future employees who are competent enough to work for the betterment of Uganda's Health. As such students are required to design any medical equipment about the needs in the health environment.

This report is the record of what we did that includes identification of a real-life problem and an innovative solution to the problem. This was covered between August and November 2022.

The report consists of three chapters that altogether explain the public health need and impact, conception of the innovation, and project management. This entails identification of the need from the source, definition of the problem and the objectives of the project, product design specifications, various design alternatives and justification of the selected design alternatives, project work plan, and conclusion.

Public health need and impact which includes an introduction of the need, problem statement, and current solutions to needs, their impacts and gaps, and the project objectives.

Conception of the innovation and this includes; introduction of the innovation, product design specification/criteria for success, project idea generation, and project idea selection.

Introductions of engineering analysis of the proposed solution, its principle and mechanism of operation, and the material analysis and simulation of the proposed solution.

Keywords: Ultraviolet, Sterilization, Device, Personal, Item-Related, Infection, Control, Medical Practice, Health Facilities
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Introduction/background of the need

Medical equipment plays an important role in the health sector as far as the provision of health services is concerned. These include medical workers' items and other portable electronics such as smartphones, stethoscopes, watches, and eye goggles and are considered important in the epidemiology of transmission of healthcare-associated infections. Policymakers generally agree that the use of these personal items in healthcare settings can't and shouldn't be banned. But there aren't any useful guidelines on how to handle the germ threat. The Ministry of Health recommends only that facilities address "multi-use electronic equipment" in their infection control policies and procedures. The substance of those directives is left up to each health institution. But regulation remains virtually absent even in the operating room, where personal item use would seem to merit the tightest restriction. Facilities that lack an effective medical workers' item infection-control strategy may jeopardize their accreditation status. But it's tough to find a means of cleaning or disinfection that's effective, affordable, convenient, and safe for both people and electronics.

However, the problem is that 90 percent of healthcare personnel never clean their devices. In a day's work, a nurse or doctor's phone can be splashed, splattered, or smeared with wound drainage, blood, or god-knows-what other bodily dreck. Handling the device can transfer bacteria to the ears, nostrils, and hands. If the germs are lucky, they'll get to cross-contaminate something the provider later touches a nice fresh incision, a cozy catheter, or a warm ventilator tube, say. The constant handling of these personal items by users in hospitals makes it an open breeding place for the transmission of microorganisms, as well as healthcare-associated infections (HAIs). This is especially so with those associated with the skin due to the moisture and optimum temperature of the human body especially our palms [2 (Tagoe DN)]. These factors and the heat generated by mobile phones contribute to harboring bacteria on the device at alarming levels. When we consider a phone's daily contact with the face, mouth, ears, and hands, the dire health risks of using germ-infested personal items are obvious [3 (Singh A, 2014)]

Due to the negligence of medical workers to disinfect their items and reluctance to practice hand hygiene 3% of hospital patients per year in Uganda will develop a health-associated infection which is associated with significant morbidity, mortality, and hospital costs. In Uganda, bacterial infections alone were accountable for 26% of all admissions, 23% of all mortalities and 20% of all death in children under the age of 5 in 2018 (Ssekitoleko , RT,Oshabaheebwa, S.,Munabi,IG.,Tushabe, 2020) There's need to ensure that these personal items are being sterilized regularly by medical workers as they do their daily jobs to mitigate the potential risks associated with the increased use of personal items in the clinical environments.

General Objective

To reduce infections that are passed on through contact with the personal items of both medical workers and patients in the health environment.

Specific Objectives.

To design and construct a light low-cost portable disinfection box that can help disinfect all kinds of medical workers' items.
To sensitize health facility managers to make informed, credible investment decisions concerning the disinfection of medical workers' items.
To test the working of the designed device.

Conception of the Innovation.

This chapter introduces us to the product design specifications, the different project idea generation, and the formulae we used to come up with the final ideas.

Product design specification.

Technical specifications.

The device shall have a power consumption of;
Voltage 220-240v
Wattage 135W
Frequency 50-60 Hz

Shape and color.

The device shall have a rectangular shape with a black outer surface.
Internal reflecting sides, for maximizing reflections and giving effective 360-degree coverage.

Performance of device

The device is intended to kill about 99.5 % of the bacteria and viruses found on the surfaces of the items. This will lower the chances of cross-infections among medical workers themselves and between medical workers and patients.

Sterilizing duration

The device shall take a minimum of 10 minutes to kill the germs that will have been carried with the items. This time is to be managed by the medical worker operating this equipment since it won't have an automated sterilization duration.

Weight.

The device shall be relatively light in weight and it's estimated to weigh less than 10kg thereby portraying portability and easiness in terms of transportation from one place to another.

Safety.

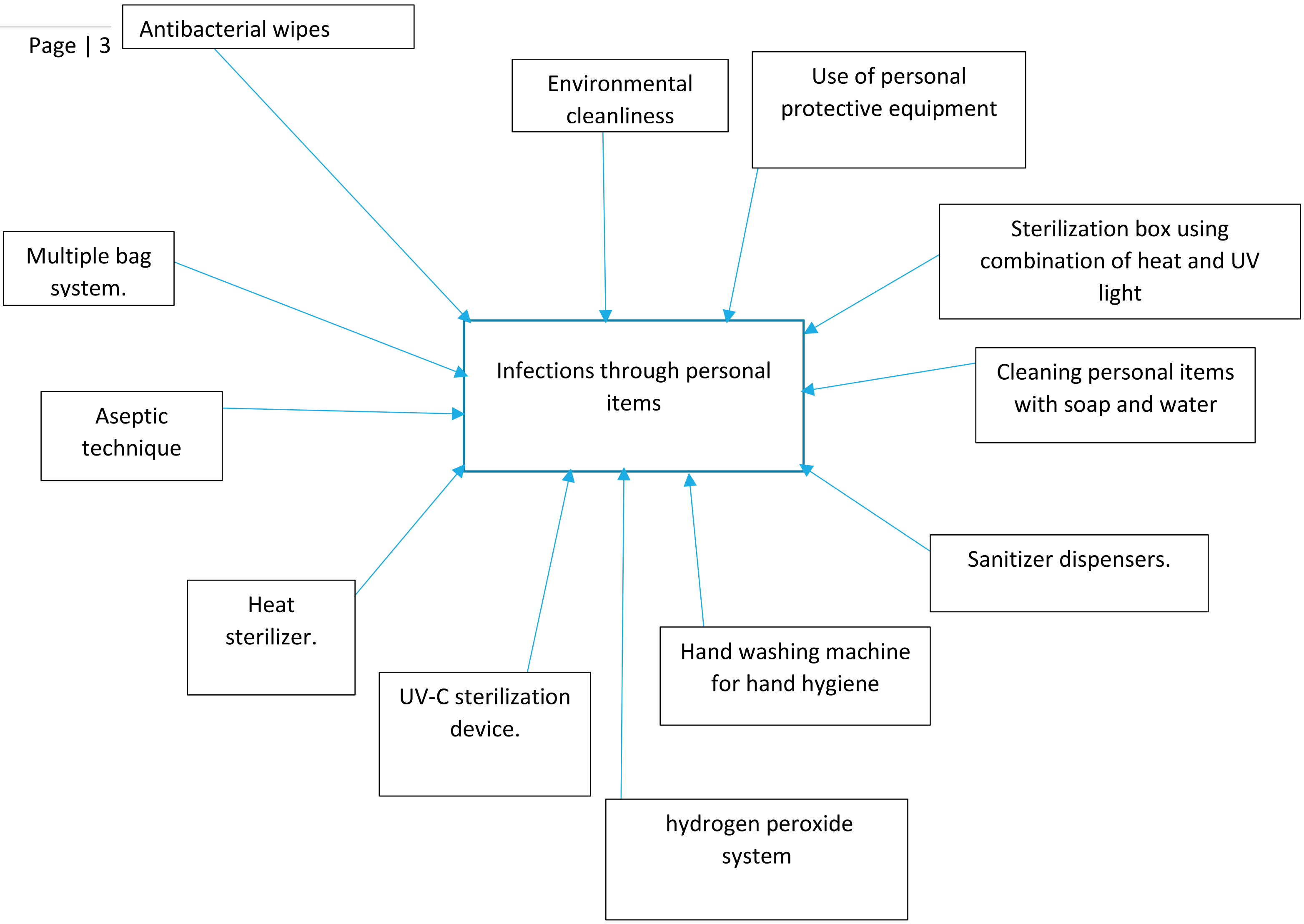
The device shall be properly enclosed with magnetic doors to prevent the escape of ultraviolet light rays to the surroundings.
Since the material used is wood which is a good insulator, it's expected to be safe from electrical shocks that may be brought due to voltage drops due to poor grounding.

Sales

Since the current sterilization technologies range between hundreds of thousands to millions, we intend to come up with a cost-friendly product whose prices will range between Ugx.80 000 to Ugx.150000.

Project idea generation.

As a group, we generated ideas for the problem of the risk of exposure to infections through personal items of medical workers through brainstorming. Each member was allowed to jot down any solution to the problem and we came up with 12 solutions as shown in Figure


Antibacterial wipes
Environmental cleanliness
Use of personal protective equipment
Multiple bag system.
Sterilization box using combination of heat and UV light
Infections through personal items
Cleaning personal items with soap and water
Aseptic technique
Sanitizer dispensers.
Heat sterilizer.
Hand washing machine for hand hygiene
UV-C sterilization device.
hydrogen peroxide system

The UV Sterilization box

The UV Sterilization box performs disinfection of microbes to prevent cross infections by producing Ultraviolet C radiations of 265nm for peak germinal action. The protons of the UV C light are incredibly energetic and therefore destroy viruses and bacteria by using the light to target proteins and genetic materials (DNA and RNA). These irradiations of UV-C speed up the cross-linking of this genetic material, which reduces the ability of the genetic material to participate in healthy replication. Hence, the intended personal item to be sterilized is placed in the box, and with power connected to the device, sterilization occurs inside the box through UV-C rays continuously bouncing against the walls and base of the box (and the lid), covering any object placed in the box with UV light in its entirety. Thus, killing any pathogens or viruses that may be living on it. The sterilization process is complete after a minimum of 10 minutes. After successful, the UV Sterilization box can be disconnected from the power source and the object can be removed from the box.

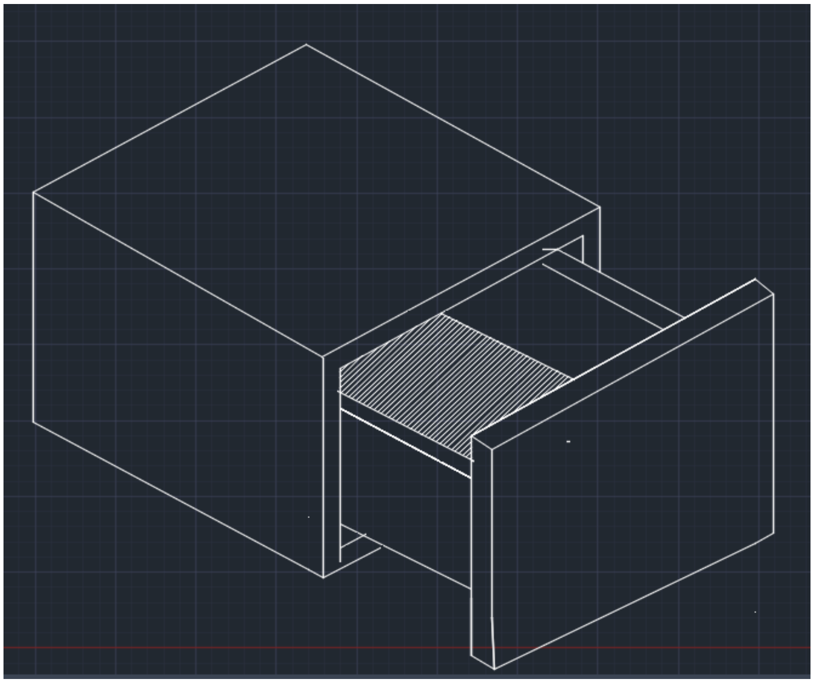


Figure 1 shows an ultraviolet disinfection unit using UV-C light

The hydrogen Peroxide System

The hydrogen peroxide system has a chamber that is evacuated and hydrogen peroxide solution is injected from a cassette and is vaporized in the sterilization chamber to a concentration of 6 mg/l. The hydrogen peroxide vapor diffuses through the chamber (50 minutes), exposes all surfaces of the load to the sterilant, and initiates the inactivation of microorganisms. An electrical field created by a radio frequency is applied to the chamber to create a gas plasma. Microbicidal free radicals (e.g., hydroxyl and hydroperoxyl) are generated in the plasma. The excess gas is removed and in the final stage (i.e., vent) of the process the sterilization chamber is returned to atmospheric pressure by the introduction of high-efficiency filtered air. The by-products of the cycle (e.g., water vapor, oxygen) are nontoxic and eliminate the need for aeration. Thus, the sterilized materials can be handled safely, either for immediate use or storage. The process operates in the range of 37-44°C and has a cycle time of 75 minutes. If any moisture is present on the objects the vacuum will not be achieved and the cycle aborts. Therefore, the hydrogen peroxide system is used for materials and devices that cannot tolerate high temperatures and humidity, such as some plastics, electrical devices, and corrosion-susceptible metal alloys.

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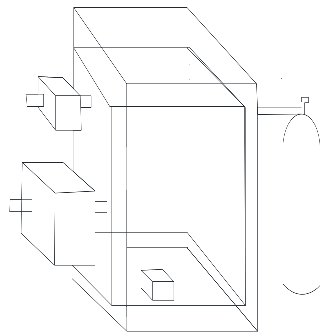

Figure 3 shows a hydrogen peroxide disinfection unit

Heat Sterilizer

In this case, a heat source such as a filament bulb of high power ratings e.g. 50W and above is housed within a box which prevents heat loss to the surrounding. The induced heat from the bulb kills about 95% of the microbes that are carried along with the medical workers' equipment.

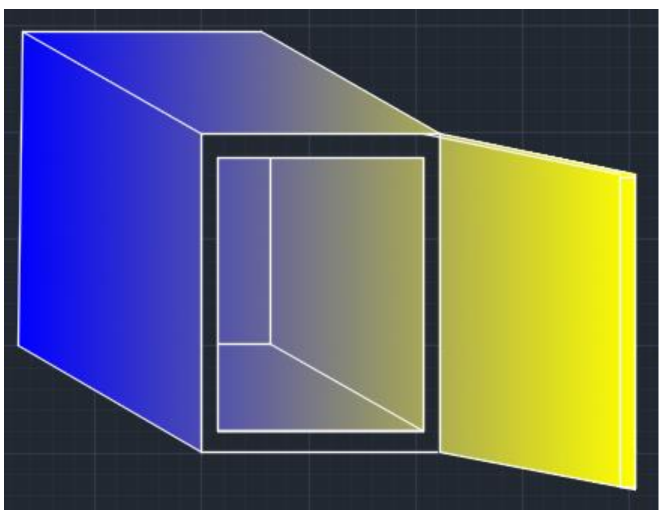

Figure 2 shows a heat sterilization unit

Idea Generation.

Our idea selection was through the weighted criteria assessment having scores awarded after intensive research and the goal of the weighted scoring approach was to derive quantitative value for each of the three innovative solutions brought up by the team. This was meant to help us use those values to determine which of the solutions the team can prioritize majorly based on the choices of the client and the product design specifications.

First, the team came up with the elements to be considered for the ideal selection which included and were ranked 1, 2,3,4,5, and 6 respectively. The weights for each element were calculated using the formula. A scale was developed as shown in the details below;

0-poor, 2-fair, 4-good, 6-quite good, 8-very good, 10-excellent

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Project Idea Selection

The weighted criteria assessment that the team came up with is shown in Table 1

Specification	Rank	Weight (W1)	UV sterilization Box	Hydrogen peroxide system	Sterilization using heat
Ability to sterilize all types of equipment	1	92	9.2 (10)	7.36(8)	4.6(5)
Low purchase cost	2	75	5.25(7)	1.5(2)	6(8)
Portability	3	58	5.22(9)	1.16(2)	4.06(7)
Time for use	4	42	3.36(8)	0.42(1)	1.68(4)
Power consumption	5	25	2.25(9)	0.75(3)	1.75(7)
Weight.	6	8	0.64(8)	0.32(4)	0.64(8)
		Total	25.92(51)	11.51(20)	12.73(39)

Table 1 shows weighted criteria. $-\left[\frac{i-.5}{n}\right]; n = 6$

Based on the weighted criteria shown above the solution of the use of a UV sterilization box to curb the risks of exposure to infections through personal items of medical workers takes position number one This is because the UV sterilization box has the highest overall scores of 25.92(51) compared to that of the other technologies of sterilization using heat having a score of 12.73(39) and hydrogen peroxide system which scored 11.51(20).

Conclusion

Based on the outcome-weighted criteria assessment, the UV-C sterilization device is the innovative solution the group would take for execution in Multidisciplinary Design 2.

SELECTED INNOVATION

Introduction

The UV-C Sterilization device is based on Ultraviolet Germicidal Irradiation (UVGI) which is a disinfection method that uses short-wavelength germicidal ultraviolet (ultraviolet C or UV-C) radiation of wavelength approximately 254nm, which has been proven to be effective against viruses, bacteria, and other pathogens by damaging their genetic material and obstructing pathogenic multiplication, leaving them unable to perform vital cellular functions. The device will be used to disinfect personal items of medical workers in health facilities as these items are exposed to microbes during medical practices leading to their cross-contamination and resulting in possible infections. These personal items include mobile phones, wallets, keys, paperwork, masks, goggles, stethoscopes, and any other small objects that can transmit microorganisms and pathogens.

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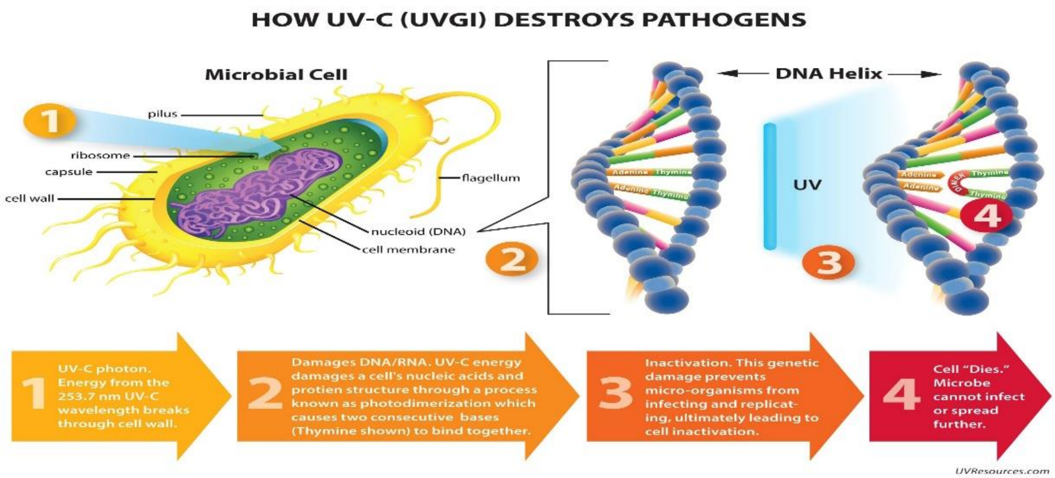
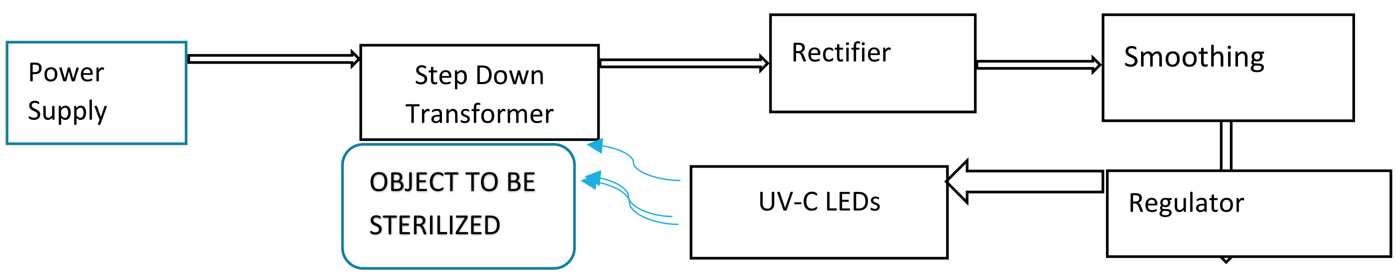
Working Principle

Disinfection with UV-C is based on the fact that UV-C radiation can damage the DNA or RNA. This is achieved by UV C photon energy produced by the device of wavelength approximately 253.7 nm. This highly energetic UV light can induce the formation of pyrimidine dimers when it breaks through the cell wall [2] and other damages to the DNA which can inhibit the multiplication of cells such as bacterial and fungal cells. Similarly, the UV light can damage the RNA of viruses leading to their inactivation.



Block Diagram



Working Mechanism

The step-down transformer converts the AC mains supply of 230V to 12V AC. A 1A fuse is in between the bridge rectifier and the transformer to stop the flow of current that is drawn through the 1A circuit. The bridge rectifier generates a rectified DC that is smoothened using a 470µF Capacitor. So, the output of the 470µF capacitor is 12V unregulated DC.

This DC is then given as an input to the IC 7805 voltage regulator. After that, this regulator changes regulated 5V DC, and the output p is attained at its o/p terminals. It gives a constant regulated output of 5V which can be used to give input to the UV-C LEDs. Here the 5V is used to bias the UV-C LEDs through a resistor.

The UV-C LED produces a pre-selected wavelength from a small amount of electricity. The LED then emits UV-C photons that are reflected and directed with the help of aluminum foils to the viruses, bacteria, and other pathogens on the surfaces of objects placed within the sterilization chamber that penetrate the cells and damage the nucleic acid in the microorganism's DNA. As these cells cannot replicate, it renders the harmful microorganism inactive. As a result, UV-C LEDs allow for high-intensity radiation to kill the bacteria in seconds.

Engineering Calculations

In air and surface disinfection applications, the UV effectiveness is estimated by calculating the UVdose that will be delivered to the microbial population. The UV dose is calculated as follows:

UV dose $\mu Ws/cm^2$ = UV intensity $\mu W/cm^2$ × exposure time (seconds)

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The UV intensity is specified for each lamp at a distance of 1 meter. UV intensity is inversely proportional to the square of the distance so it decreases at longer distances. Alternatively, it rapidly increases at distances shorter than 1m. In the above formula, the UV intensity must alwaysbe adjusted for distance unless the UV dose is calculated at exactly 1 m (3.3 ft) from the UV-C LED. Also, to ensure effectiveness, the UV dose must be calculated at the end of lamp life (EOL is specified in number of hours when the lamp is expected to reach 80% of its initial UV output) andat the furthest distance from the lamp on the periphery of the target area.

Dosages for a 90% kill of most bacteria and viruses range from 2,000 to 8,000 µW·s/cm2.

The details for the UV-C sterilization box are shown below

- Our UV- C LED is with 28 µW/cm2,
- The UV band used 253.7 nm (UV C),
- The distance to the target is 10 cm max.

As UV intensity is inversely proportional to the square of the distance, and our distance is 0.3 in comparison to 1 m, the formula to apply is the following*:

UV dose $\mu Ws/cm^2$ = UV intensity $\mu W/cm^2 \times$ exposure time (seconds)/ $(0.3)^2$Applying our figures, we get the following formula:

UV dose $\mu Ws/cm^2 = 28 \times$ exposure time (seconds) / 0.01

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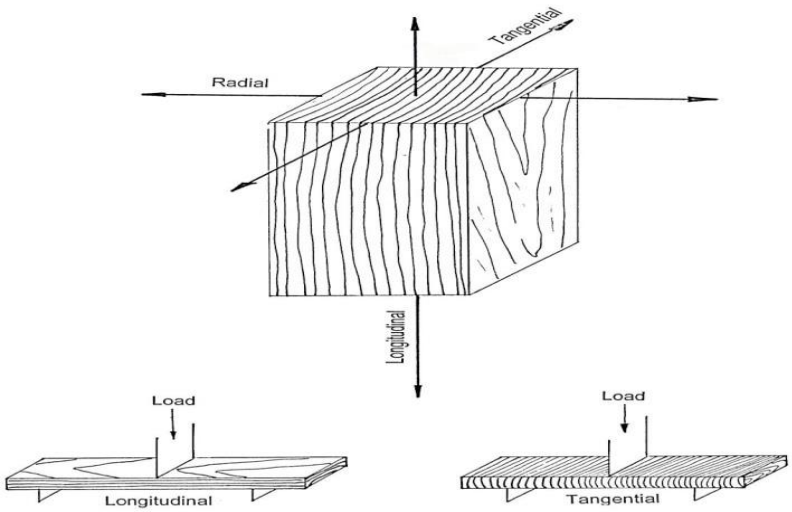

Figure 1. Orthotropic structure of wood.

Elastic materials easily stretch under an applied load. However, they return to their original conditions once the load is released. In contrast, plastic materials stay in the stretched condition even if the load is released after a long

An exposure for 10 mins, or 10 x 60 = 600 seconds, results in:

UV dose $\mu Ws/cm^2 = 12\times 600 / 0.09 = 168{,}666$ µW·s/cm2, which is far above the required dose.

*Note: The fact that the UV-C sterilization box is closed and has a reflective surface which the power of theradiation and compensates for the 80% expected intensity drop of the UV-C LED at the end of its life.

Material analysis and justification

Wood as Casing of the Ultraviolet Sterilization Device

Electrical property

In terms of the electrical properties, the wood forms an excellent electrical insulator in the absence of moisture, with resistivity in the order of 1017 ohms at room temperature making it suitable for use as the casing for the electronic components present in the ultraviolet sterilization device.

Viscoelasticity

In contrast to metals and plastics, wood is an orthotropic material, meaning its properties will be independent in three directions – longitudinal, tangential, and radial, as illustrated in Figure 1. Another unique property of wood is its viscoelasticity, which can be described as having both plastic and elastic characteristics when exposed to a certain deformation

period. The behavior of wood products is between the above two types of conditions.

Strength

The most important fact about the strength of timber is that it is not the same in all directions. This is because wood is an anisotropic material hence the strength of wood is determined concerning the direction of the grain of the wood under load.

Besides grain, many other factors also influence the strength of timber. These are;

1. Density. The higher the density of timber, the greater will be its strength. This is because of the high density of thicker cell walls i.e., the greater amount of wood substance per unit volume.
2. Moisture content. The higher the moisture content, the lower the strength of the timber. This is because water in itself has no load-bearing capacity.
3. Its increased volume in the cell simply decreases the volume of the wood tissue. Moreover, the higher amount of water in the cells invites many fungal and insect growths which destroy the wood tissue. They tend to reduce the strength directly.

Tensile strength.

Wood is very strong to tensile forces acting parallel to grain but very weak when these forces are made to act perpendicular to the grain. Thus the tensile strength of some woods ranges from 500-2000kg/cm^2 for the same varieties when tested perpendicular to the grain.

Transverse or bending strength.

The most important use of timber as beams is based on the fact that wood has very high bending from 300 to 900km/cm^2 or more.

Cost

Wood, while not cheap is an economical option than other materials. It is more adaptable on-site and flexible in its use. Wood is available in a variety of types, products, and dimensions. It is also lighter in volume/weight, which amounts to cost savings.

Sustainability

Wood has been found to have the least impact on the environment when sourced sustainably. It uses fewer natural resources and does not release as many contaminants into the air and water.

Weight

Wood is relatively lightweight and can outperform materials like steel in terms of supporting its weight, so it is just as strong or strong in the casing of the device. The lightweight makes the device portable.

Maintenance

Due to its durable nature, hardwood timber is easy to clean, whilst scratches and dents can be fixed with ease.

Color

Wood can be painted to a desired color with easy without getting worn out after a long period.

Aluminum Foil as the Internal Lining for the Ultraviolet Sterilization Device

Corrosion resistance

The naturally occurring surface oxide on all aluminum in the presence of oxygen in the atmosphere acts as a shield and renders foil substantially corrosion-resistant. Aluminum is also chemically resistant in contact with substances in the pH range of 4 to 9.

Formability

Aluminum is very malleable and can be deformed considerably without losing its barrier integrity.

Hygiene

Foil is sterile following annealing, and does not harbor or support the growth of microbes that may be encountered by the foil material.

Opacity

Foil is a solid metal. It transmits no light and is a total barrier to light including the UV spectrum hence the ultraviolet light produced will be trapped within the device chamber.

Reflectivity

Aluminum foil reflects approximately 98% of radiant heat and light and therefore the UV light and heat produced by the UV LEDs will be effectively distributed.

Weight

At 6.35 µm foil weighs 17.2 g/m2 which contributes a very small mass to the device's total mass.

Circuit Diagram

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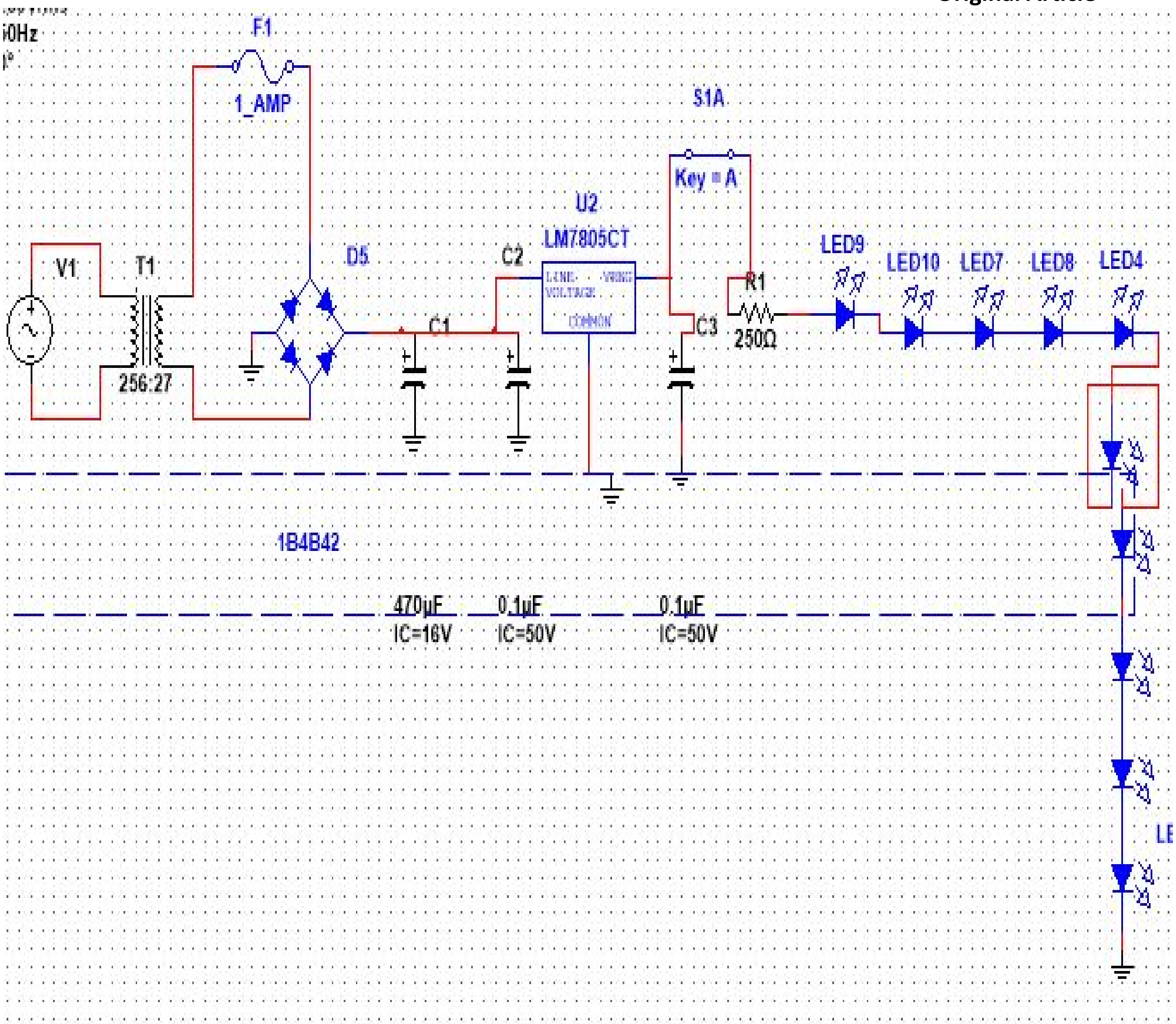

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Finished Prototype

Precautions.

Safety precautions

UVC is a low-penetrating form of UV compared to UVA or UV-B. Measurements of human tissue show that 4 to 7% of UVC (outer dead layer of human skin), thus minimizing the amount of and absorbed in the first 2 µm of the stratum corneum (along with a wide range of wavelengths, 250 to 400 nm) is reflected UVC transmitted through the epidermis. Exposure to ultraviolet energy may result in transient corneal inflammation, which can go unnoticed.

Workers expected to clean up broken lamps should be trained in proper protection, cleanup, and disposal.

No personnel should be subject to direct UV exposure, but if exposure is unavoidable, personnel should wear protective clothing (no exposed skin), protective eyewear, and gloves.

Care and maintenance.

Always clean the outer parts of the machine with foam.

Do not spill water on the surfaces of the machine.

Make the machine run 10 minutes before and after sterilization takes place.

Ensure carrying out preventive maintenance every 3 months to check the electrical components.

Grease the moving parts of the equipment.

Prospect

The device shall be equipped with a timer set, which would cut off the circuit to the UV clamp if the door was opened accidentally or intentionally during a disinfection cycle. An emergency stop button shall also be incorporated in the design in case of any other unexpected accident.

The device shall have a fixed UV-C light system on the lower side of the chamber that shall remain in the interior section of the box.

The device shall have an LCD to indicate the time that would decrease till the sterilization process is complete and the operation state of the machine of sterilization.

Challenges.

Acquiring some of the electronic components especially the UV–C LEDs was difficult due to their unavailability in most places of sale which caused a delay in the execution of the project. The group incurred extra costs in search of the devices.

Conclusion

The use of personal items by medical workers in healthcare facilities without disinfection is a major challenge that has contributed to the microbial contamination of other hospital surfaces leading to many hospital-acquired infections. The UV-C sterilization device will help disinfect most of the personal items owned by medical workers thereby reducing the rate of spread of hospital-acquired infections.

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List of acronyms and abbreviations

UV: Ultraviolet
HAI: Healthcare Acquired Infection
DNA: Deoxyribonucleic Acid
V: Voltage
W: Wattage
Hz: Hertz
Kg: Kilogram
Ugx: Ugandan shillings

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