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## An Investigation of the Effectiveness of a Sterilization Device Using Heat and Ultraviolet Light Radiation



**Abstract:** - Background: Paper papers and banknotes are known to be possible vectors for infections, and the incredible COVID-19 pandemic has highlighted the critical necessity for efficient sterilization procedures. This research attempts to create a hybrid sterilization device that utilizes heat and ultraviolet (UV) light radiation. It employs the Design Science Research Method (DSRM) to tackle this urgent requirement.

**Methodology:** The study follows the six-step DSRM framework, which begins with problem and motive identification, then defines solution aims, designs and constructs the device, and lastly assesses the system to prove its effectiveness. UV port, heat drawer, and control panel are the three primary components that constitute the prototype. To determine the effectiveness of the treatment, relevant microbiological strains, such as fungi, Gram-negative and Gram-positive bacteria, and other viruses were exposed to pre-contaminated papers at different intervals to heat and ultraviolet light.

**Results:** The sterilization device that was developed displayed noteworthy effectiveness in withholding microbial contamination from paper documents. The device's effectiveness in sterilizing paper materials and ensuring their safe handling was demonstrated through an analysis of CFU reductions, which indicated a significant decrease when compared to untreated controls. A better result was seen when heat and ultraviolet light radiation were used together in a hybrid method.

**Conclusion:** The study shows a brand-new hybrid sterilization device designed specifically for paper documents. This meets an urgent need that has become even more important since the COVID-19 pandemic. The heat-UV radiation from this gadget eliminates bacteria, lowering the risk of sickness and making paper goods safer. The DSRM framework can help to construct an organized strategy for conceiving, creating, and assessing innovative solutions to real-world problems.

**Keywords:** Hybrid steriliser, Microbial strains, COVID-19 pandemic, Heat and UV radiation, CFU reduction.

### Introduction

In the wake of the devastating COVID-19 pandemic, every feasible measure of defence had to be taken to keep the populace safe. Many pieces of evidence show that papers can spread infectious germs like viruses and bacteria (1-7). Contamination can occur directly from infected people touching papers or indirectly from inanimate objects in the environment. According to a recent study, the coronavirus can survive for twenty-four hours on surfaces like cardboard and paper (2). This could potentially provide sufficient time for the virus to diffuse among university staff and students, thereby accelerating the rate of virus transmission. A machine that sterilizes papers used by students and staff might make it less likely that the virus will stay on the paper for longer.

Paper documents are widely used by everyone, with papers being the primary instruments for educational institutions and used in tests, documentation, and student record keeping. Additionally, hospitals use paper for many types of paperwork and records, including patient reports, files, and any notes that are connected. Cash, newspapers, and books are also handled and swapped every day. Paper-based tests and student papers could be a hidden source of infection in schools, as well as hospitals. It is important to keep contaminated paper documents moving and handled. Thus, paper documents can be a major way for pathogens to spread in both public and

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medical settings, which need control measures to lower the risk of any cases that might be linked, especially now that the world is more aware of the COVID-19 pandemic. Due to the widespread use of contaminated paper documents as infection vectors, rigorous control measures are needed after the COVID-19 pandemic.

Ultraviolet-C (UV-C) radiation has been widely recognized for its efficacy in sterilizing water, food, and medical equipment due to its ability to disrupt microbial survival by targeting their DNA (8-10). UV light has been shown in recent medical applications to reduce healthcare-associated infections, such as sterilizing medical equipment and hospital rooms (11-15). As its effectiveness rests on being directly exposed to the radiation, UV-C sterilization can only work on surfaces that are exposed to it. To eliminate germs from porous materials and tight areas, heat and UV-C radiation work synergistically (16, 17). As a result, there is a prospect of enhancing the safety of paper documents and other regularly handled items through the development of low-cost sterilization equipment that uses both heat and UV light.

Although conventional fluid disinfectants do not consistently succeed in sterilizing paper documents, the development of a cost-effective sterilization apparatus provides a glimmer of hope. The goal of this study is to meet that need by developing a device that can swiftly sterilize a large number of papers with heat and UV light. This device has the potential to significantly reduce the spread of infectious diseases that are typically linked with paper-based products, particularly in educational institutions where documents are issued regularly.

### Literature review

Among the many new applications of UV radiation that have emerged in response to the COVID-19 epidemic, the sterilization of N95 respirators and face masks is among the most notable (18-20). Thermal and radioactive decontamination methods are favoured over chemical sterilization agents since they can damage objects.

Since the COVID-19 pandemic began, researchers have been particularly interested in rhinovirus (RS) sterilization. Liao made use of five different sterilization processes to determine which one had the highest level of face mask filtration(6).

Scientific attention has been notably devoted to the sterilization of rhinovirus (RS). The COVID-19 pandemic has also brought to light the need for modern sterilization technology that takes an appropriate approach. Liao investigated how well face mask filtration worked with five different sterilization procedures. UV germicidal irradiation, 75% alcohol, home or diluted chlorine-based solution, steam, and heat with humidity were tested. Additionally, decontaminating methods that can be applied to sterilize face masks were summed up as follows: dry heat, UV germicidal irradiation, and vaporized hydrogen peroxide(11). The International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) in India developed COVID-19 sterilization systems, which Sarada studied(21). ARCI disinfected surfaces with dry heat, chemicals, and physical means.

Cadnum published a system for decontaminating SARS-CoV-2 and microorganisms with ultraviolet (UV) type C technology. The effectiveness of ultraviolet light (UV-A) and ultraviolet light (UV-C) in completely inactivating SARS-CoV-2 was compared (22). The results demonstrated that UV-C is more effective at inactivating viruses. According to Cheon, UV radiation plus a gentle heat treatment kills *E. coli* O157:H7 more effectively than UV radiation alone (9).

### Materials and methods

The Design Science Research Method will be employed to carry out the design method in this study by sanitary requirements(23). This device effectively reduces bacteria by combining UV light and heat approaches. Heat treatment and different dosages of UV-C radiation are used to cure papers. A comparison is made between treated and control papers to evaluate reductions in the overall bacterial count and the eradication of highly harmful microorganisms. The effectiveness of the device in cleaning documents is determined through data analysis.

### Design and Implementation

In this investigation, the design and performance of the UV-C irradiation system were centered on the UV-C source's critical component for optical power generation. The ultraviolet (UV) spectrum, which includes the germicidal effects of light on many different kinds of living things, operates between 200 and 300 nanometers in wavelength. UV radiation causes irreversible injury to cells via photochemical reactions (24).

The cell is the fundamental structural component of living organisms. This harm includes gaps in the structures of RNA and DNA, changes to proteins, and other parts of the cell. Ultraviolet light's pervasive effects on microbes interfere with their typical activities, ultimately leading to their demise.

Mercury lamps with low pressure that release radiation at a wavelength of 253.7 nm are the main UV light sources used in the present study (25-27). To generate the UV radiation required for sterilization, these lamps—especially their ozone-free versions—are crucial.

### Device prototyping

In consideration of various utilization scenarios and to optimize the efficacy of disinfection procedures, two prototypes of the paper sterilization device were created.

The primary objective of the prototype, which is illustrated in **Figure 1**, was to facilitate the disinfection of exam papers submitted by students promptly while also being able to accommodate a substantial quantity of papers. Thermal inner trays and a front-facing port with the capacity to accommodate seven stacks of papers, each containing a maximum of 50 pages, are among its remarkable aspects.



*Figure 1: Front-end design and the internal paper tray for the prototype.*

The second prototype, which is shown in **Figure 2**, experienced optimization to enable quicker disinfection of smaller volumes of documents that are frequently handled in academic institutions, government offices, and medical centers. There are two primary ports and keys on the side for manual adjustment, making it easy to operate.

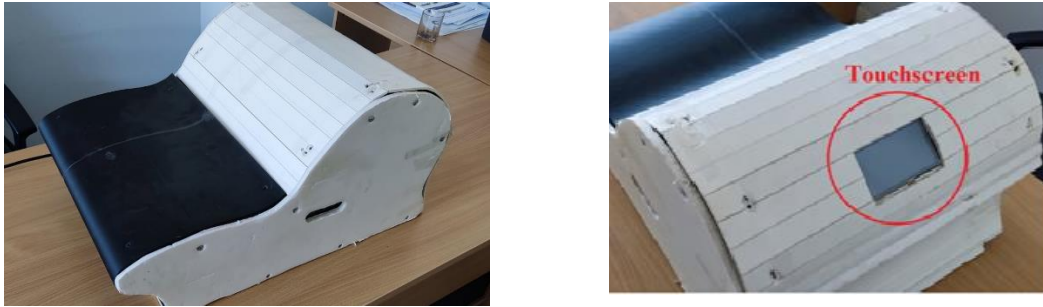


*Figure 2: External design of the second prototype*

Thermal treatment and ultraviolet-C light are the two disinfection procedures used by both prototypes. An adjustable thermal pull-and-push roller can disinfect a small stack of papers in under two minutes using the thermal method, which may reach temperatures of up to 90°C. Furthermore, individual papers are disinfected on both surfaces in under one minute using UV-C radiation. To disinfect larger stacks of papers at a controlled temperature of 75°C for around 45 minutes, manual entry is another option.

A better form of the machine, shown in **Figure 3**, was made so that it could clean more papers in less time and partially automatically. Optimized for efficiency and longevity, this variant boasts a carbon fiber shell insulated with rock wool.

In terms of functionality, the device can accept two sizes of paper: A3 and A4 size. There are two options to disinfect papers: using a heated drawer or a UV-C exposure system. An electronic control circuit has been developed to control all parameters, and all setting parameters can be readjusted from a Graphical User Interface (GUI) supported by a touch screen of type Nextion“NX8048T050” of size 5" inch as shown in **Figure 3**. The electronic circuit and the touchscreen have replaced all wiring and the manual control systems have been. Thus, the assembly time and the error for similar devices will be less.



*Figure 3: External design of the third prototype*

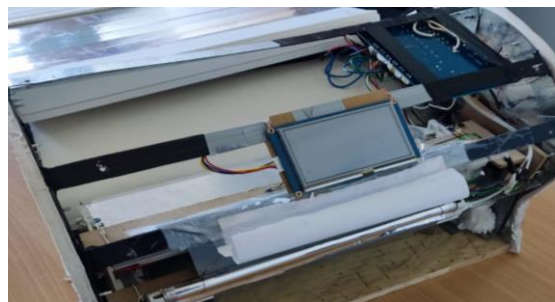
The device provides two options for disinfection—a heated container or an ultraviolet-C exposure system—and can accommodate both A3 and A4 paper sizes. An electronic control circuit that is connected to a touchscreen GUI makes it easier to modify parameters and improves the user experience. The heat drawer, shown in **Figure 4**, can sterilize stacks of paper with the help of a stainless-steel tubular heater pipe. It has digital temperature control and safety features like a mechanical thermostat and an electromechanical locker.



*Figure 4: Large stake drawer in the third prototype*

As seen in **Figure 5**, the UV exposure system makes use of 254 nm UV-C radiation emitted by Philips lamp tubes and internal heaters. The pace and orientation of the paper roller are regulated by a 360° servomotor, which guarantees consistent UV light exposure. Particularly when handling thermal paper, the heat function can be deactivated as necessary.

The goal of these prototypes is to offer efficient and user-friendly solutions for paper sterilization in different environments through methodical design and implementation.



*Figure 5: The UV exposure system*

### **Bacterial inoculum preparation**

Procurement of bacterial isolates was conducted through the American Type Culture Collection (ATCC). *Escherichia coli* (ATCC35218), *Proteus mirabilis* (ATCC7002), *Pseudomonas aeruginosa* (ATCC27853), *Staphylococcus aureus* (ATCC25923), *Candida albicans* (ATCC14053) were among these microorganisms. Their clinical importance in the development of infectious diseases was an important consideration in the selection of these strains.

To obtain new cultures, individual colonies of each bacterial strain were subsequently inoculated onto nutrient broth agar plates (BD Bioscience, CA, USA) and incubated at 37°C overnight. Once the incubation stage was up, individual colonies were transferred into a sterile 10 ml nutrient broth and left to incubate for an additional 2-3 hours at 37°C. The remaining testing conditions were standardized by adjusting the resultant bacterial suspension to a 1.0 McFarland standard, which corresponds to a density of about  $3.0 \times 10^8$  CFU/ml.

### **Testing the sterilization effect of the UV plus heating chamber in the device for single paper format**

The device's UV plus heating chamber was tested for its sterilization effectiveness in a single paper format using standard bacterial vaccines that were diluted in sterile phosphate-buffered saline (PBS). The bacterial suspension was applied on single sheets of paper (10 X 10 cm) and then allowed to air-dry within biosafety cabinets. The UV and heating chamber of the device were then used to expose the contaminated papers to different durations (18, 28, 38, and 48 seconds). Treatment procedures were carried out after the device had been allowed to reach the target temperature and UV light intensity for ten minutes. After the papers had been treated, they were transferred to sterile containers, submerged in sterile PBS, and any residual viable bacteria were extracted using pipetting. Following this, 100 microliters of the suspension were distributed onto sterile nutrient agar plates to conduct a bacterial colony count. The following formula is used to compute the total number of colonies seen and is given as CFU/ml:

- The total CFU/ml= the number of colonies counted X Total dilution factor.
- Log<sub>10</sub> in CFU/ml was subsequently calculated and compared to untreated control.

**Testing the sterilization effect of the heating chamber in the device for stack format:**

A modified version of the same procedure was utilized to examine the sterilizing effect of the thermal chamber in the stack format device. The apparatus involved contaminating stacks of ten papers, each measuring 10 x 10 cm, which were then air-dried and subjected to varying exposure times (5, 10, 20, and 40 minutes) within the thermal chamber. Rolling the treated stacks into sterile cups, immersing them in sterile PBS, and finally pipetting them for bacterial extraction was the next step. Finally, by using an L-shaped glass rod, 100µl of the suspension was spread across the surface of a sterile nutrient agar plate after being inoculated. The total number of colonies observed is calculated in the following formula and expressed as CFU/ml:

- The total CFU/ml= the number of colonies counted X Total dilution factor.
- Log<sub>10</sub> in CFU/ml was subsequently calculated and compared to heat untreated control stack.

**Results**

1. Significant reduction in bacterial count by integrated UVC-heat chamber at the lowest speed of 48 seconds.

The two-chambered apparatus was specifically engineered to process single paper formats. Papers are exposed to UV-C and heat sources on a belt in the first chamber, like photocopiers. The purpose of this exposure process is to ensure that the documents are completely sterile before their removal from the chamber. This study evaluates the device's sterilization effectiveness in this chamber and determines the best speed or duration for maximal sterilization power.

A standardized inoculum was used to contaminate standard paper with clinically important ATCC bacterial isolates, including gram-positive and gram-negative strains and fungi. The subsequent calculation determined the reduction in CFU/ml in comparison to the untreated control samples. As seen in **Figure 6**, microbial growth decreased at all speeds and exposure durations.

Microbial growth was lowest at 45 rpm and 48 seconds. Everything except *Pseudomonas aeruginosa* isolates, which were reduced by 4 logs at all speeds, was reduced by more than 8 logs. These results show that the integrated UVC heat chamber is very good at killing bacteria on paper substrates. For most of the bacteria isolates that were tried, the lowest speed showed the best sterilization performance.

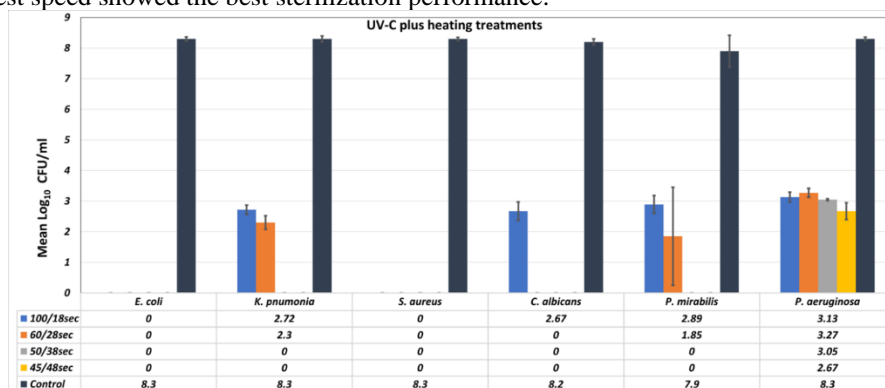


Figure 6: UV-C and varied heating speeds treated a paper contaminated with different bacteria (coloured graph). Mean log<sub>10</sub> CFU/ml, error bars standard deviation of 3 experiments. This table shows the mean Log<sub>10</sub> CFU/ml for each microbial strain treated at varied speeds/times.

2. Reduction in bacterial count achieved by the heating chamber of the device.

The second chamber of the devices has only a heating source. A different sterilization approach was expected to be needed for stacks of sheets since UV radiation cannot penetrate solid layers. This chamber saves time by sterilizing several papers at once, such as exam documents or cash. The device's sterilization efficiency in this chamber and the optimal sterilization period will be assessed in this investigation.

A standardized vaccine was used to contaminate stacks of 10 paper pieces with ATCC bacterial isolates, as in the prior experiment. In comparison to untreated control samples, the decrease in CFU/ml was approximated. The results show that all 75°C heating treatments decrease microbial isolate growth (Figure 7). Optimal microbial growth decrease was seen at 20 and 40 minutes of heating treatment, resulting in more than 8 logs for all isolates except *Pseudomonas aeruginosa*, which reduced 7.

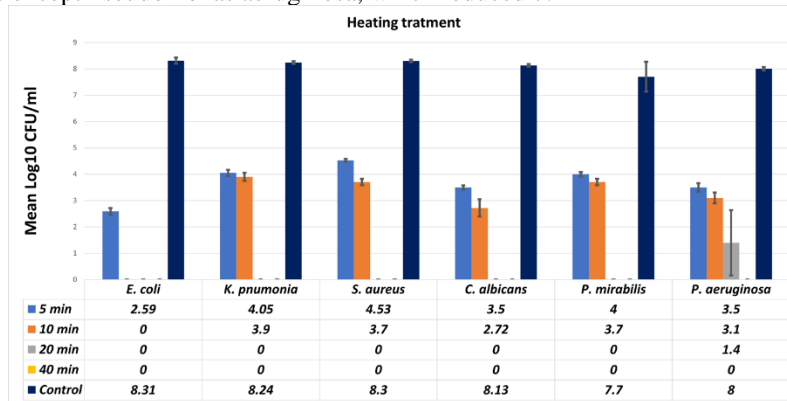


Figure 7: Heating treatment analysis: The color-coded graph shows 10 papers contaminated with different bacteria and heated at different times. Log10 CFU/ml mean, error bars standard deviation of 3 experiments. The table below the diagram displays the mean Log10 CFU/ml for each microbial strain treated at different speeds/times.

**Discussion**

The significance of proper sterilization procedures for personal protective equipment (PPE) like N95 respirators and face masks was highlighted by the recent COVID-19 pandemic (11-15). To decontaminate goods that can degrade if exposed to chemicals, radiation, and heat treatments are good alternatives to chemical sterilization agents. It is critical, however, to deal with the fact that pathogenic microbes, especially drug-resistant strains, can live on paper and spread disease in this way (1-7).

Our research tried to create an effective apparatus capable of disinfecting documents, whether they were stacked or used individually, as a response to this concern. A hybrid model was implemented, which integrated thermal treatment and UVC irradiation, with the dual purpose of applying pressure to contaminants and optimizing the disinfection procedure. We found that for single paper forms, this combination method drastically lowers the colony-forming units (CFU) of clinically relevant bacterial pathogens in about 45 seconds. Furthermore, comparable reductions in viable bacterial counts were achieved with the heating chamber component of our device, albeit at a higher temperature of 75°C and for extended treatment durations of 20 minutes.

There has been research on combined heat and UVC devices for a variety of uses, such as food and tiny objects disinfection (14). The significance of duration, temperature, and distance from the light source in attaining optimal sterilization outcomes has been emphasized in this research. Device design, wavelength setting, material characteristics, and the microbes under study are some of the variables that can affect sterilization treatments' effectiveness.

Importantly, our results indicate that maybe because of their porous structure, papers are less likely to be contaminated with microbes than other surfaces (28, 29). However, it is important to consider microbial variety when evaluating sterilization technologies, as our device did reduce *P. aeruginosa* viability, but not as much as other bacterial strains. The biofilm activity of *Paeruginosa* provides it with intrinsic resistance to heat and radiation; this strengthens the need for microbial agent-specific sterilization strategies (30).

The present investigation primarily examined bacterial pathogens; however, it is critical to recognize the constraints associated with sterilizing viral and spore-forming bacteria, which necessitate specialized facilities and safety protocols. While our device is effective against many microorganisms, it is considered low-level sterilization and is therefore ideal for lipid viruses like SARS-CoV-2. Further work is needed to confirm its efficacy against viruses and spore-forming bacteria.

**Conclusion**

In summary, our study introduces an innovative UV-C sterilization apparatus that combines UV-C radiation and heat to efficiently cleanse surfaces, specifically porous materials like paper-based products. The device's effectiveness in substantially decreasing the number of colony-forming units (CFUs) of clinically significant

bacterial pathogens, even at the lowest speed settings, has been established through experimental investigation. The combination of heat and ultraviolet-C radiation is a quick and efficient approach to sterilizing objects. The number of CFUs was 10 log lower in the treated group than in the untreated one.

Applications for the gadget are numerous and include government, academia, and healthcare. Addressing public safety concerns is important, as demonstrated by its potential efficacy in sterilizing letter envelopes that have been found to carry biological diseases in the past.

The device's efficacy against spore-forming bacteria and viruses needs more study. To prevent general infections, the device might be helpful. Subsequent research needs to examine the feasibility of integrating this technology into current sterilization procedures and its practical uses.

In summary, the study's findings demonstrate the effectiveness and use of this UV-C sterilizing tool. It is an inexpensive solution to safeguard everyone's health and halt the spread of harmful diseases.

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**Ethical Approval:** Not needed

**Data availability statement:** Data is available within the manuscript and will be provided at the editor's request.

**Author Contributions:** The authors have contributed to writing, designing, compiling, and editing the final manuscript.

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