Development of A Portable Ultraviolet Germicidal Irradiation System for Controlling Air Borne Infection

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***Abstract*— In order to ensure healthy indoor air quality, especially in densely populated and contaminated settings like that of hospitals, it is essential to focus on the prevention of airborne infections. A healthy air quality control system not only ensures the protection of the patients but also of the health care workers against hospital-acquired infections. The proposed UVC-FCU works on the principle of Ultraviolet germicidal irradiation (UVGI) and includes 2 integrated chambers wherein on one side of the chamber an air inlet and a fan coil unit (FCU) are assembled while on the other side an air outlet connected with activated carbon filter of special properties that allow it to remove volatile organic compounds (VOCs), odors, and other gaseous pollutants from the air. The portable FCU with UVGI air purifier has the advantages of not only removing large diameter suspended particles from the air, but also of effectively removing microbes including bacteria and viruses. Real-time disinfection of microbes in the air was achieved with controlled time intervention. The efficacy of the developed system was measured using standard microbiological procedures in a controlled environment of a Test Room. The proposed system was demonstrated to achieve a microbial load reduction of >90.**

Keywords*— Airborne infections, ultra violet germicidal irradiation (UVGI), fan coil unit (FCU).

I. INTRODUCTION

Ensuring environmental air quality is one of the first steps to prevent the onset of possible airborne infections in any given setting. Especially since the onset of the COVID 19 pandemic, many systems of air disinfection and purification have been developed and introduced. However, there is no comprehensive system that is currently available, that can accommodate a fan coil unit (FCU) with optimum intensity of an ultraviolet C (UVC) device for air borne infection control in the indoor area with a fully protected shield ensuring safety from direct exposure to UVC rays. The covid 19 pandemic has increased the demand for a more sustainable and indigenously developed disinfection system. Ultraviolet germicidal irradiation (UVGI) is an excellent rapidly growing chemical free technology that can be exploited to achieve this goal. The morbidity due to air-borne infections and the additional healthcare costs associated with the hospital acquired infections are a burden to the patients and pose a risk to the healthcare workers. UV irradiation is highly efficient for the removal of microbial growth in any medium. UV disinfection has been a validated technology for the disinfection of

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pathogens on surfaces, as well as in air [1]. Over the UVC range of 254 nm, a more detrimental effect on microbial cells occurs because the intercellular components of microbes (e.g., RNA, DNA, and proteins) can sensitively absorb UVC photons [2,3]. A particular spectrum of UV radiation between 200 and 280 nm known as the UVC spectrum, has been employed extensively as the germicidal range of UV radiation. Absorbed UVC photons cause critical damage to the genomic system of microorganisms (nucleic acid and microorganismal proteins), preventing them from replicating and surviving [4,5]. UV disinfection is an energy-based process, where the inactivation ratio is determined by the applied UV dose via the disinfecting unit. UVC energy is generated by germicidal lamps that kill or inactivate microorganisms by emitting radiation predominantly at a wavelength of 253.7 nm [6]. For UV-induced reactions, the most accurate fashion to report the kinetic data is as a function of UV dose rather than time. The disinfection of bio-contaminated air and surfaces could be considered more straightforward and predictable applications of UV radiation 7]. However, to achieve a valid inactivation value, e.g., 99.99%, by a UV air or surface disinfector, multiple factors are involved, which can be grouped into two categories: inherent microbial characteristics and target medium characteristics. The individual human microbiome, ventilation, outdoor air, Air conditioning systems, and foliage all contribute to the airborne particulate burden. [8] The potential for indoor air tobe a vehicle for the spread of infectious pathogens has led to the development of UVGI methods used for decontamination.

In this study, we describe the development of a portable UVC air disinfection system with an integrated UVGI unit and an FCU for removal of the air particulate matter to achieve prominent levels of air borne infection control namely the UVC-FCU system. This study was conducted as a part of infection control in a tertiary care hospital with inputs from clinical engineers and microbiologists.

II. METHODOLOGY

This study involved the evaluation of an indigenously developed system for environmental decontamination that works on the principle of the bactericidal nature of UVC rays. A four-walled room was identified for the experimental setting, as the Test Room. A known amount of non-pathogenic Gram-positive bacteria isolated from the environment was introduced into the atmosphere of the Test Room in a controlled manner. Briefly, 0.5 McFarland's standard of the bacterial inoculum was prepared in normal saline. 20ml of thisinoculum was aerosolized and introduced into the test room using an aerosol injector. Subsequently, a 0^{th} hour sample of the Test Room air was sampled using an Air sampling system. The proposed System consists of a controlled UVC unit and air flow adjustment with an electronic control system. A high intensity UVC lamp (75 W) is connected to an electronic choke and the choke is connected to the controller. The UVC-FCU system operates with the FCU and UVC unit by the controlled air flow speed and switching mechanism of a microcontroller.

III. PROPOSED SYSTEM

The system is developed as a portable system with 4 castor wheels and a locker mechanism. Each user can adjust the position of the unit with the controller and manual moving mechanisms. The air purification technology employs the methods of using a shielded UV-C (100-280 nm) lamp to continuously purify the air. The unit is an enclosed air disinfection device incorporated inside a fan coil unit and light fixture, here an internal fan pulls air into a reflective, aluminum-covered chamber housing a UV-C lamp. A filter rated to remove large dust and debris is in line just before the UV-C chamber to prevent loss of efficacy over time from dust accumulation. The effectiveness of this developed system depends on the strength of the radiation and the exposure time. This technology can be applied indoors in the hospital rooms/wards and in air handing plants, stand alone in-room with recirculating units etc. UVC lamps are shielded by the module to reduce the collection of dirt on their surface thus extending their optimum efficiency.

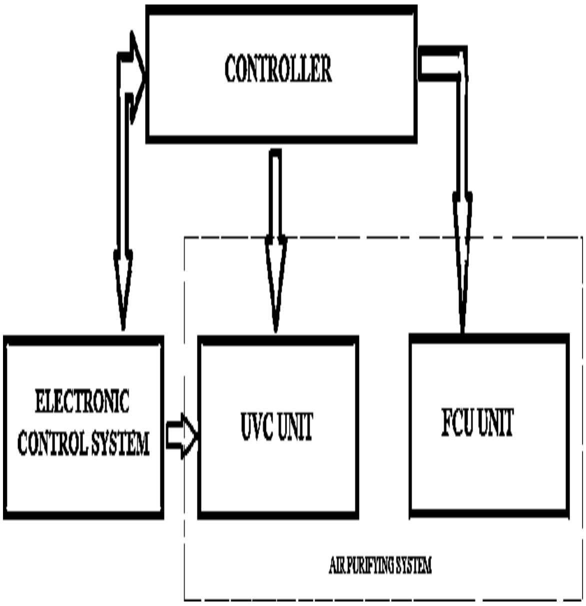

Fig.1. Block diagram of the proposed system

A. HARDWARE COMPONENTS

1.. FAN COIL UNIT

The FCU uses UVGI technology to irradiate viruses and bacteria. The FCU-UVC assembly unit is located in the enclosedhousing section.800 CFM FCU provides enough air changes perhour to disinfect the indoor air as part of the room air distribution. FCU operated directly in the air stream and with features of high output, UV-C lamps and the developed system does not allow the UVC Light to fall on the human body. Hence, this unit ensures safety during its operation. UVC-FCU work in the Main Power supply with AC 100-240V Input range, 50/60 Hz. The FCU has

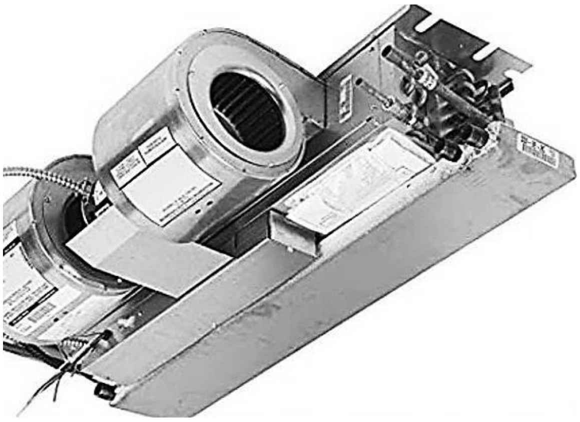

Fig.2.Fan coil unit

the capacity of 800 cubic feet per minute (cfm/min). The FCU can be operated with low, medium and high-speed options. A pre-filter has been connected to the air inlet so that large diameter particles can be filtered here and microbial decontamination with the UVC photonis mainly focused inside the housing. The exposed UVC light is designed to be placed inside the FCU. It gives the advantage of maximum safety to the user.

2. *AIR SAMPLING SYSTEM*

The air sampling system presents the status of microbial count within the real time area of air samples. In theair sampling system, the percentage reduction of bacterial andfungal colony forming unit (CFU) counts after overnight incubation of the sampled culture plate, was analyzed. The percentage reduction of the microbe's calculation was performed based on the below-given Equation.

Percent Reduction of microbial load = (A-B) * 100 /A

Where A is the number of viable microorganisms before intervention and B is the number of viable microorganisms afterthe intervention [1]. A colony

Fig.3. Petri dish Air sampling system

forming unit count that exceeds the thresholdprompts an evaluation of cleaning practices, personnel work practices, operational procedures, and air-filtration effectiveness. In the direct compounding area (InternationalOrganization for Standardization [5] classification),1 CFU/m3 bacteria or fungus is considered actionable.

3. ULTRA-VIOLET GERMICIDAL IRRADIATION(UVGI) UNIT

Ultraviolet energy inactivates viral, bacterial and fungal organisms so they are unable to replicate and potentially cause disease. When the process is applied in a given location, it has generally been referred to as ultraviolet germicidal irradiation. The entire UV spectrum is capable of inactivating microorganisms, but UV-C energy (wavelengths of 200 – 280 nm) provides the most germicidal effect with 265 nm being the optimum wavelength for damaging DNA and RNA [11].
UVC lamp in the system has the power of 75 W in the germicidal luminaires with quartz glass UV-C185–254-nm light.In addition to generating UV-C in the germicidal band close to 253 nm. The majority of modern UVGI lamps create UV-C energy with an electrical discharge through a low-pressure gas (including mercury vapor) enclosed in a soft glass or quartz tube, similar to fluorescent lamps. 95% of the energy produced by these lamps are emitted at the near-optimal wavelength of 253.7 nm. Greater doses' wavelengths comprise photons that are most energetic photochemically active optical spectrum

B. FINAL PROTOTYPE

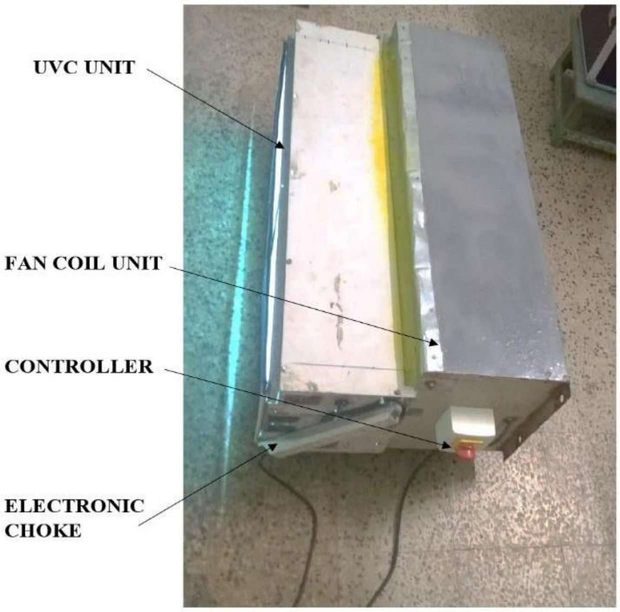

Fig.4. Final Prototype

The portable FCU- UVGI system has been fabricated with the features of microbial disinfection performance of UVGI Technology with optimum air changes provided by FCU. The Controlled and safe operating of the device is ensured by the system. The working prototype needs sophisticated fabrication and incorporation of state-of-the-art electronics to make it industry ready. The air purification technology

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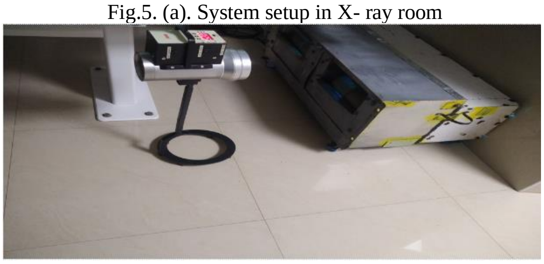
employs the method of using a shielded UV-C (75 W) lamp to continuously purify the air. The unit is an enclosed air disinfection device incorporated inside a fan coil unit and light fixture, where an internal fan pullsair into a reflective, aluminum-covered chamber housing a UV-Clamp.

A filter rated to remove large dust and debris is in line just before the UV-C chamber to prevent loss of efficacy over time from dust accumulation. The device is developed with the principle of ultra violet germicidal irradiation and a standard ventilation air changing system. The fan coil unit provides sufficient air changes per hour(ACH) for fresh air in the room and the contaminated air is disinfected continuously by the UVC unit assembled inside the fan coil unit, which is controlled by the electronic choke and microcontroller. The operating time and safety use of the portableunit is controlled by the microcontroller. The device is Floor mounted and the system has been movable with 360-degree rotation on the floor and an operation control facility is available in the system. A Mechanically controlled switch is also provided in the system for the user requirements.

III. RESULTS

The developed Portable UVC-FCU air disinfection system was tested for efficacy in the earlier described Test Room. The system is implemented in various positions in the Hospital environment like Imaging room, CT -X ray complex, Intensive care critical wards, patient waiting areas to check the efficacy of the product. Also, the air- sampling was done in various places check the microbial count after and before the system implantation. Fig. 5. Shows the various placements of the implemented unit in hospital environment to ensure the disinfection property of the developed system.

Fig.5. (a). System setup in X- ray room



(b)

(c)

Fig.5 (b) ,5(c) CCU Room

Using the air sampling system, notable reduction of microbial colony count was noted after just 30 minutes of intervention itself. A representative image of a nutrient agar plate showing microbial growth after air sampling is given in figure 6. The figure 7 clearly shows that with the portable UVC-FCU system significantly reduced the microbial contamination in Test Room. The Test Room simulated a contaminated air environment in a hospital setting. The Table 1 gives the air sampling results before and after intervention using the developed UVC-FCU system. The UVC intensity and positioning of UVC lamps in the system allowed for the maximum disinfection rate within short period of time. Here, due to the limitations of achieving controlled environments for studying viruses, the study did not involve data.

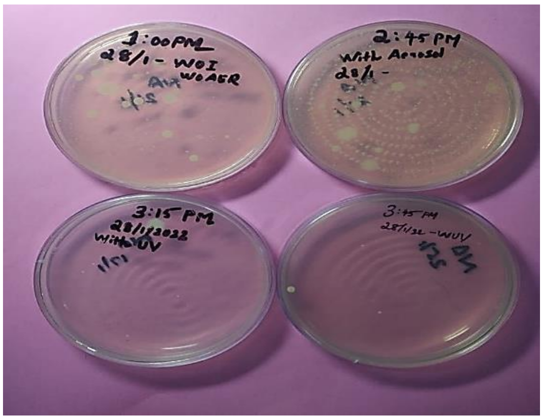
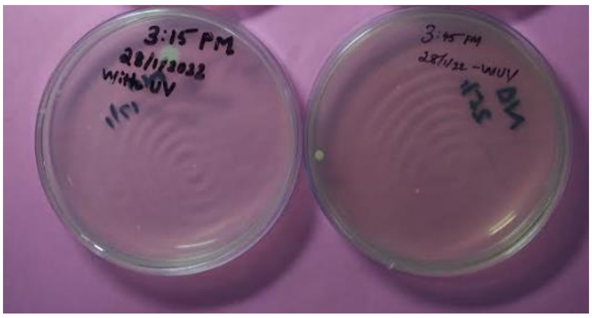


Fig.6. Nutrient agar plate showing bacterial growthafter air sampling from the Test Room



(a)

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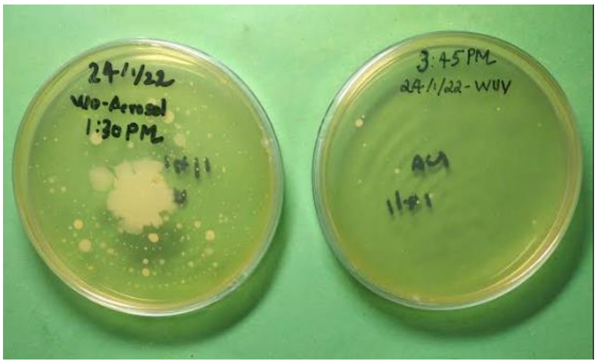

(b)

Fig.7. Nutrient agar plates showing bacterial growth reduction after UVGI intervention from the Test Room (a). Microorganism growth observation in Test room (b). Test result repeated to ensure the growth reduction

Table.1 indicates that the portable UVC FCU system reduced the microbial contamination in Test Room. On Day 1, after the introduction of the aerosol, the ambient microbial load was seen to be 1402 CFU. However, with just 30 minutes of intervention using the UVC_FCU system the count was reduced by 97%. Further, counts fell to 31 and 24 after 60 and 90 minutes of intervention, respectively, finally achieving 98.5% reduction at the end of 90 minutes. On Day 2 comparable results were obtained, as shown in Table 1. The percentage reduction in the microbes in the ambient air is shown in the graph suggests there is a surprising count reduction of microbes in the ambient air and the surroundings.

Time	Description of Technology	Numberof CFU (r)	% Reduction of Bacteria
24/01/2022			
Hour 0	With introduced bacterial load, without intervention	1402	N/A
Hour 0.5	UVC-FCU system	41	97
Hour 1	UVC-FCU system	31	98
Hour 1.5	UVC-FCU system	24	98.5
28/01/2022			
Hour 0	With introduced bacterial load, without intervention	583	N/A
Hour 0.5	UVC-FCU system	51	91.25
Hour 1	UVC-FCU system	48	92
Hour 1.5	UVC-FCU system	41	92.96

Table 1: Air sampling results obtained before &after intervention using the UVC - FCU system

However, it has been demonstrated in the literature that UVGI and the filter can reduce levels of suspended aerosols and particulates in the air and therefore, reduce the risk of SARS- CoV-2 virus transmission. In some viruses, such as the Influenza virus and SARS-CoV-2, the protein capsid is itself encased in a lipid envelope. Nonenveloped viruses are typicallymore UV resistant than enveloped viruses, since proteins and lipids of the envelope may be disrupted more easily than otherviral parts.

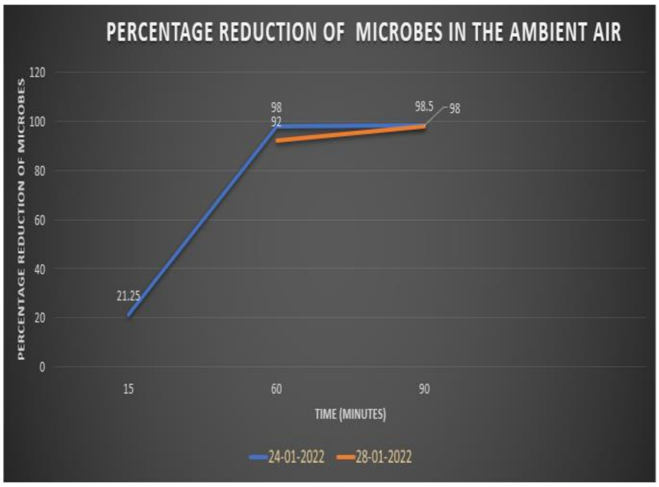

Fig.8. Percentage reduction of Microbes In the ambient air

Fig. 8. Represents the percentage of microorganism reduction after the UVC system implementation in the test room for 60- 90 minutes. It has been shown from the graph that, there is a promising reduction greater than 90 percentage. The efficiency of the system is validated through repeated experiments in different area and period of time.

V. CONCLUSION

The surge in the use of UVC sterilization devices for air and surface disinfection testifies to the fact that UVC technology is an effective and convenient disinfection method. Here, we developed a portable UVC air borne infection control unit - the UVC-FCU system and demonstrated its bactericidal efficacy using a Test Room. UVGI is a proven method that can destroy viruses, bacteria, and fungi, and since the system utilizes that technology. The UVC energy 254 nm has poor propagation to overcome this problem, the system is so designed with well geometric patterns to optimize the exposure of the air and maximum germicidal disinfection treatment for the circulating air for a healthy environment.

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