A CUBOID CHAMBER DESIGN FOR RADIATION-BASED SARS-COV-2 DISINFECTION

W. N. I. Yalagama

179454F

Master of Science in Materials Science

Department of Materials Science and Engineering

Faculty of Engineering

University of Moratuwa

Sri Lanka

May 2024

A CUBOID CHAMBER DESIGN FOR RADIATION-BASED SARS-COV-2 DISINFECTION

W. N. I. Yalagama

179454F

Thesis submitted in partial fulfillment of the requirements for the degree

Master of Science in Materials Science

Department of Materials Science and Engineering

Faculty of Engineering

University of Moratuwa

Sri Lanka

May 2024

DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date: May 2024

The above candidate has carried out research for the PhD/MPhil/Masters thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Dr. D.A.S. Amarasinghe

Signature of the Supervisor: Date: May 2024

FOREWARD

In the wake of unprecedented global challenges brought along by the COVID-19 pandemic, I am honored to present this thesis, titled "A Cuboid Chamber Design for Radiation-Based SARS-CoV-2 Disinfection." Although the work was conceived and executed during the rough times, its completion and presentation to the university mark a significant milestone in our collective journey toward combating this brutal virus. Throughout the development of this project, we confronted numerous obstacles aggravated by the collapse of the global supply chain and stringent import restrictions imposed by the country. These constraints posed additional challenges to our design process, compelling us to rely solely on locally available resources and materials. In the face of these limitations, we demonstrated resourcefulness and ingenuity, leveraging the assets accessible to us to devise an innovative solution to combat the spread of COVID-19.

As we navigate through this period of uncertainty and disruption, the urgency to develop innovative solutions has never been more pronounced. This project represents not only a response to the immediate necessities of the pandemic but also a testament to our resilience and adaptability in the face of adversity. Despite the challenges posed by the pandemic, we remained steadfast in our commitment to advancing scientific knowledge and contributing to the global effort to control the spread of COVID-19. The design of the disinfection chamber for SARS-CoV-2 arose from a confluence of necessity, ingenuity, and unwavering determination. Informed by the latest advancements in UV-C technology and rigorous empirical analysis, this work embodies our collective resolve to address pressing public health concerns and mitigate the impact of the pandemic on our communities.

As I stand on the precipice of presenting this thesis to the university, I am reminded of the invaluable support and guidance my mentors, colleagues, and loved ones extended to me. Their unwavering encouragement and expertise have been instrumental in shaping this project and bringing it to completion. It is my sincere hope that the findings and insights presented herein will contribute to the ongoing discourse surrounding COVID-19 mitigation strategies and inspire further innovation in the field of disinfection technology. In closing, I extend my heartfelt gratitude to all those who have supported and contributed to this endeavor, and I invite you to join me in embracing the spirit of resilience, collaboration, and determination that has defined our response to the COVID-19 pandemic.

ACKNOWLEDGEMENTS

First, I would like to express my sincere gratitude to the Department of Materials Science and Engineering for accepting this research. It is Dr. D.A.S. Amarasinghe, my supervisor who was behind me and keeping me in the track and enlightening me with precious advises not only for this research but also for other projects, especially during 1st wave of COVID-19 pandemic. His guidance, effort and continuous supervision made this research a successful one.

I must express my gratitude to Dr Prasanna Premadasa, the Dean, Faculty of Technology, General Sir John Kotelawala Defense University who helped with the biomedical, electrical and electronics aspects as the co-partner of the project. His will to support the country during the pandemic was tremendous. And, I would also be grateful to Dr. Santha Rahubadde, the Head of the Department of Mathematics, Faculty of Engineering, General Sir John Kotelawala Defence University for helping me with the mathematical software application. His eager to help others is grateful.

And also, I would like to thank Mr. V. Sivahar, Head of the Department of Materials Science and Engineering, the programme coordinator Prof. (Mrs.) A.S. Galhenage, the all-academic staff and non-academic staff for the guidance and kind support throughout the period.

ABSTRACT

Ultraviolet germicidal irradiation (UVGI) has long been recognized as a potent disinfection technology, but its prominence surged during the COVID-19 pandemic as an effective solution for air disinfection. This revival was fueled by its notable advantages over chemical and traditional disinfection methods. UVGI stands out for its residue-free nature and the absence of harmful substances, making it an environmentally friendly option. Additionally, UVGI effectively targets a broad spectrum of pathogens, including the resilient SARS-CoV-2 virus, without fostering microbial resistance. Thus, adequately designed UVGI irradiation systems hold immense promise for indoor air disinfection compared to conventional methods.

Numerous studies affirm the effectiveness of UVGI radiation at $253.7nm$ in neutralizing the SARS-CoV-2 virus when administered at the appropriate dose, dependent on factors such as airflow and UV intensity. Our primary objective was to ensure that every air molecule passing through the disinfection system receives sufficient UV light to deactivate viruses, thereby ensuring system reliability. Design parameters were meticulously chosen based on the UV light photons required to deactivate 99.9% of the SARS-CoV-2 virus, with stringent precautions taken to mitigate UV light leakage, which poses risks to human health.

This study proposes a novel conceptual design of a cuboid chamber utilizing the Line Source Spherical Emission (LSSE) model to analyze irradiance variations based on a chosen coordinate system.

The selection of the 64T5 HO G5 Philips TUV T5 double-ended UV-C (germicidal) lamp was led by considerations of market availability and cost-effectiveness. Through simulations employing the LSSE model with varying point source numbers, we comprehensively examined irradiance variation at $253.7nm$, producing informative graphs.

The investigation unveiled that with an average airflow velocity of $202.027\ cm/s$, the proposed chamber geometry ensures that every bit of air passing through receives a UV dose sufficient for effectively deactivating 99.9% of the SARS-CoV-2 virus. This finding highlights the usefulness of our design in delivering thorough disinfection to safeguard indoor environments.

Keywords: Irradiance modelling, **UV dose, Air-disinfection, germicidal**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
COVID-19	Coronavirus Disease 2019
DI	Diffuse Incidence
DNA	Deoxyribonucleic Acid
ESDE	Extense Source Superficial Diffuse Emission
ESSE	Extense Source Superficial Spherical Emission
ESVE	Extense Source Volumetric Emission
HAI	Healthcare-Associated Infection
LD	Lethal Dose
LED	Light-Emitting Diode
LSDE	Line Source Diffuse Emission
LSSE	Line Source Spherical Emission
LVREA	Local Volumetric Rate of Energy Absorption
PDI	Partially Diffuse Incidence
PyNNFV	Pyrimidine Dinucleotide Frequency Value
RH	Relative Humidity
RI	Radial Incidence
RMSrPE	Root-Mean-Squared Relative Prediction Error
RNA	Ribonucleic Acid
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
TDI	Diffuse Incidence
UV	Ultraviolet
UVGI	Ultraviolet Germicidal Irradiation

LIST OF NOTATIONS

l	Light intensity, $Jm^{-2}s^{-1}$
ρ	Cylindrical coordinate, m
z'	Linear source coordinate, m
N	Concentration of infective microbe or virus,
t	Time,
k	1^{st}-order inactivation constant, and
E	Fluence rate
N_0	Concentration of infective microbes or viruses before exposure to UV radiation
D	UV Dose
ν	frequency
T	Periodic time
λ	Wavelength
q	Energy flux density ($m^{-2}s^{-1}$)
μ	Attenuation coefficient (m^{-1})
q_λ	Radiant energy distribution
$S_{p,\lambda}$	Point source strength, W
$S_{L,\lambda}$	Line source strength, W