

Declaration

I hereby declare that the work presented in this Thesis titled *Design, Development, and Characterization Studies of Non-Thermal Non-Equilibrium Plasma Systems for Indoor Air Quality* submitted to the Indian Institute of Technology Jodhpur in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out under the supervision of Professor Ram Prakash. The contents of this thesis in full or in parts, have not been submitted to, and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.

Ram Avtar
P19PH008

Certificate

This is to certify that the thesis titled *Design, Development, and Characterization Studies of Non-Thermal Non-Equilibrium Plasma Systems for Indoor Air Quality*, submitted by *Ram Avtar* (P19PH008) to the Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Ram Prakash
Ph.D. Thesis Supervisor

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Ram Avtar
Ph.D. Student

List of Publications

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1. **Jangra R**, Ahlawat K, Dixit A, Prakash R (2023) Efficient deactivation of aerosolized pathogens using a dielectric barrier discharge based cold - plasma detergent in environment device for good indoor air quality. **Scientific Reports** 13 1–14.
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2. **Jangra R**, Ahlawat K, Prakash R (2023) An SDBD Plasma-based Source for Efficient Degradation of VOCs in an Enclosed Environment. **Physics Letters A** 490 129184.
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3. **Jangra R**, Ahlawat K, Mohan MK, Prakash R (2024) Indoor air disinfection by non-thermal atmospheric pressure plasma: a comparative study of performance in low and high humidity environments. **Physica Scripta** 99 085612.
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4. **Jangra R**, Ahlawat K, Prakash R (2024) Investigating the Role of Active Air Ions and Hydroxyl Radicals on the Eradication of ESKAPE Bacteria using Non-equilibrium Atmospheric Air Cold Plasma. **IEEE Transactions on Radiation and Plasma Medical Sciences**.
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2. Ahlawat K, **Jangra R**, Ish A, et al (2024) A dielectric barrier discharge based low pressure narrow band far UV-C 222 nm excimer lamp and its efficiency analysis. **Physica Scripta** 99 025018.
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3. Ahlawat K, **Jangra R**, Prakash R (2024) Environmentally Friendly UV-C Excimer Light Source with Advanced Oxidation Process for Rapid Mineralization of Azo Dye in Wastewater. **ACS Omega** 9, 15615–15632.
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4. Ahlawat K, **Jangra R**, Prakash R (2024) Accelerated mineralization of textile wastewater under 222 nm irradiation from Kr/Cl₂ excilamp: an environmentally friendly and energy efficient approach. **Scientific Reports** 14, 1-18.
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5. Ahlawat K, **Jangra R**, Prakash R (2024) Degradation of Carbamazepine and Sulfamethoxazole in Water by Dielectric Barrier Discharge Plasma Coupled with Far UV-C (222 nm) System" **Environmental Science: Water Research & Technology**.
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6. Gadodia V, Ahlawat K, **Jangra R** et al. (2024) Potential use of DBD based 222 nm exciplex light source for milk sterilization and its comparative analysis with 253 nm UV-light and conventional pasteurization. **Journal of Food Measurement and Characterization** 18 1-12.
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7. Ahlawat K, **Jangra R**, Ish A, et al (2023) Analysis of a UV photocatalytic oxidation-based disinfection system for hydroxyl radicals, negative air ions generation and their impact on inactivation of pathogenic micro-organisms. **Review of Scientific Instruments** 94 104103.
<https://doi.org/10.1063/5.0151619>
8. Ahlawat K, **Jangra R**, Chaturvedi S, et al (2022) Photocatalytic oxidation conveyor “PCOC” system for large scale surface disinfection. **Review of Scientific Instruments** 93 074101.
<https://doi.org/10.1063/5.0082222>
9. Pandey S, **Jangra R**, Ahlawat K, et al (2023) Selective generation of nitrate and nitrite in plasma activated water and its physicochemical parameters analysis. **Physics Letters A** 474 128832.
<https://doi.org/10.1016/j.physleta.2023.128832>
10. **Ahlawat K**, Jangra R, Gadodia V et al. (2024) Efficacy Analysis of 222 nm Far UV-C Radiation on Degradation of Organic Micropollutants in Water. **Radiation Effects and Defects in Solids**.
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11. **Ahlawat K**, Yadav P, Gadodia V, Jangra R, Prakash R (2024) Surface Modification of Banana Fibres using DBD Plasma based KrCl* and XeI* Exciplex Sources. **Fundamental Plasma Physics** 12 100068.
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1. **Ramavtar Jangra**, Kiran Ahlawat, Ram Prakash “Deactivation efficiency analysis of airborne microorganisms using a dielectric barrier discharge (DBD) based plasma system” presented **Poster** in the **XXXV International Conference on Phenomena in Ionized Gases (ICPIG-2023)** held at Egmond Aan Zee, The Netherlands during 9-14 July 2023.
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7. Kiran Ahlawat, **Ramavtar Jangra**, Ram Prakash “Photo-degradation of brilliant red 5B dye under DBD plasma based far UV-C 222 nm light using an advanced oxidation process” presented **Orally** in the **National Symposium on Gaseous Discharges (NSGD-2023)**, held at Pondicherry, India during 9-11 August 2023.
8. **Ramavtar Jangra**, Kiran Ahlawat, Ram Prakash “Application of DBD Air Plasma for Indoor Particulate Matter Removal” presented **Poster** in the **38th National Symposium on Plasma Science and Technology (Plasma-2022)**, held at Dehradun, India during 4-8 December 2023.
9. Kiran Ahlawat, **Ramavtar Jangra**, Vigyan Gadodia, Ram Prakash “Wastewater treatment using an Indigenous plasma DBD based 222 nm far UV-C excimer lamp” presented **Orally** in the **38th National Symposium on Plasma Science and Technology (Plasma-2022)**, held at Dehradun, India during 4-8 December 2023.
10. **Ramavtar Jangra**, Jyoti Verma, Chandra Prakash, **Kiran Ahlawat**, Ambesh Dixit, Ram Prakash “Optimizing Nanostructure Materials based Large Scale Packed Bed Plasma Reactor: Understanding the effect of Plasma-Catalysts” presented **Poster** in the **10th PSSI - Plasma Scholars Colloquium (PSC-2024)**, held at New Delhi, India during 4-6 July 2024.
11. Kiran Ahlawat, **Ramavtar Jangra**, Ram Prakash “DBD-Based Planar 222 nm Kr/Cl₂ Excilamps: Effective for Surface Sterilization” presented **Orally** in the **10th PSSI - Plasma Scholars Colloquium (PSC-2024)**, held at New Delhi, India during 4-6 July 2024.

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List of Symbols

Symbol	Description
eV	Electron Volt
$^{\circ}C$	Degree Celsius
K	Kelvin
$\%$	Percentage
Hz	Hertz
kHz	Kilo-hertz
MHz	Mega-hertz
nm	Nanometer
μm	Micro-meter
mm	Millimeter
cm	Centimeter
m	Meter
W	Watt
V	Volt
kV	Kilo-volt
ft	feet
ns	Nanosecond
s	Seconds
min	Minutes
h	Hour
C	Coulomb
μ_e	Electron Mobility
ml	Milliliter
L	Liter
g	Gram
mg	Milligram
θ	Diffraction Angle
d	Lattice Spacing
λ	Wavelength
$\text{\AA}$	Angstrom
k	First-order Reaction Rate Constant
A	Ampere
mA	Milli-ampere
μM	Micro-molar
mM	Milli-molar
M	Molar
kb	Kilo-byte
C	Capacitance
f	Frequency
J	Joule

List of Abbreviations

<i>Abbreviation</i>	<i>Full form</i>
IAQ	Indoor Air Quality
NTP	Non-thermal Plasma
CP	Cold Plasma
UV	Ultraviolet
OES	Optical Emission Spectroscopy
MS	Mass Spectroscopy
DBD	Dielectric Barrier Discharge
CD	Corona Discharges
APPJs	Atmospheric Pressure Plasma Jets
GAD	Gliding Arc Discharge
RF	Radio Frequency
MD	Microwave Discharge
AC	Alternating Current
WHO	World Health Organization
IAP	Indoor Air Pollution
EPA	Environmental Protection Agency
VOCs	Volatile Organic Compounds
PM	Particulate Matter
HEPA	High-efficiency Particulate Air
PPM	Parts Per Million
PPB	Parts Per Billion
OSHA	Occupational Safety and Health Administration
PCO	Photocatalytic Oxidation
ROS	Reactive Oxygen Species
RONS	Reactive Oxygen and Nitrogen Species
RH	Relative Humidity
HH	High Humidity
LH	Low Humidity
TBCs	Total Microbial Counts
TFCs	Total Bacterial Counts
SDBD	Surface Dielectric Barrier Discharge
HEEs	Highly Energetic Electrons
IPC	In-Plasma Catalysis
PPC	Post-Plasma Catalysis
V-I	Voltage-Current
AIC	Air Ion Counter
TA	Terephthalic Acid
HTA	Hydoxy-terephthalic Acid
XRD	X-ray Diffraction
ICCD	International Centre for Diffraction Data
FWHM	Full Width of Half Maxima
UV-Vis	Ultra-Violet and Visible Spectroscopy
FESEM	Field Emission Scanning Electron Microscopy
XPS	X-ray Photon Spectroscopy
PDA	Potato Dextrose Agar

NA	Nutrient Agar
CFU	Colony Forming Unit
PFU	Plaque Forming Unit
ESKAPE	<i>Enterococcus faecium</i> , <i>Staphylococcus aureus</i> , <i>Klebsiella pneumoniae</i> , <i>Acinetobacter baumannii</i> , <i>Pseudomonas aeruginosa</i> , and <i>Enterobacter species</i>
HVAC	Heating, Ventilation, and Air Conditioning
CDC	Centre for Disease Control
EDX	Energy Dispersive X-ray
FNS	First Negative System
SPS	Second Positive System
BDE	Bond Dissociation Energy
APP	Atmospheric Pressure Plasma
NAI	Negative Air Ions
PAI	Positive Air Ions
NE-AACP	Non-equilibrium Atmospheric Air Cold Plasma
CB	Conductive Band
VB	Valence Band