

**Biodegradation of Congo red dye in moving and packed
bed bioreactors: Process optimization and kinetic
modeling**



**Thesis submitted in partial fulfillment
for the Award of Degree**

DOCTOR OF PHILOSOPHY

By

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Dedication

I dedicated this Ph.D. thesis to the 140 crore Indians who paid the cost of this study; I am greatly indebted to them and also thanks to nature for always creating a positive environment for me.

CERTIFICATE

It is certified that the work contained in the thesis entitled " **Biodegradation of Congo red dye in moving and packed bed bioreactors: Process optimization and kinetic modeling**" submitted by **Kanhaiya Lal Maurya** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

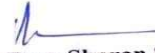
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DECLARATION BY THE CANDIDATE

I, **Kanhaiya Lal Maurya**, certify that the work embodied in this Ph.D. thesis is my bonafide work carried out by me under the supervision of **Dr. Ankur Verma** and co-supervision of **Prof. Ram Sharan Singh** from **July 2018 to July 2023** at the Department of Chemical Engineering & Technology, Indian Institute of Technology (BHU), Varanasi, India. The matter embodied in this Ph.D. thesis has not been submitted to award any other degree/diploma. I declare that I have faithfully acknowledged and given credit to the research workers whenever their works have been cited in the text and the body of the thesis. I further declared that I have not willfully lifted some other work, paragraph, text, data, results, etc., reported dissertations, thesis, etc., or available at websites and included them in this Ph.D. thesis and cited as my work.


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ACKNOWLEDGEMENT

This is a great opportunity to owe immense gratitude to my esteemed supervisor **Dr. Ankur Verma** and co-supervisor **Prof. Ram Sharan Singh**, of the Department of Chemical Engineering and Technology, Indian Institute of Technology, BHU, Varanasi, India.

I also would like to thank my RPEC committee member, **Prof. Vikash Kumar Dubey** (Department of Biochemical Engineering, Indian Institute of Technology (BHU), Varanasi), for providing me guidance along the way.

I would like to express my sincere gratitude to **Prof. Ram Sharan Singh** for his advice and support throughout my doctoral work. He always made time to listen and provide prudent advice whenever I needed it.

I owe my thanks to **Prof. M. K Mondal**, Head of the Department of Chemical Engineering, for encouraging and providing all facilities to carry out my research work.

I am thankful to **Dr. Ravi Kumar Sonwani** and **Dr. Ganesh Swain** for their sincere guidance, co-operation, and motivation during the entire thesis work. I am grateful to all my lab-mates, namely **Ms Nidhi Dubey, Ms Mona Viswkarma, Mr. Mohit Kumar, Mr. Himanshu Tiwary, Mr. Pranjal Tripathi, Ms. Nidhi Agnihotri, Mr. Bhanu Prtap, Vivek Kumar Jaiswal, Mr. Prmanand Maurya, Mr. Rohit Kushuwaha**, for helping me during the entire thesis work. I would like to express my most heartfelt and cordial thanks to my friends **Mr. Mohit Kumar, Mr.**

Shakti Priyadarsan, and **Mr. Bhanu Pratap**, who have always been a source of inspiration for me and stood by my side at the most challenging times.

I am also thankful to **Mr. Birendra Yadav**, **Mr. Ajay Kumar Pandey**, **Mr. Sudhir Kumar**, **Mr. Ajay Yadav**, and **Mr. Rakesh Kumar** for their assistance during my research work.

I gratefully acknowledge the **Ministry of Education of India, MoE (India)** for granting financial support and Indian Institute of Technology, BHU, Varanasi, India, for providing a laboratory facility to carry out the research work.

I am highly thankful to my parents **Mr. Ram Kumar Maurya** and **Mrs. Shobha Devi**, and my sibling **Mr. Munna Lal Maurya**, **Mr. Babban Lal Maurya**, **Mr. Madan Lal Maurya**, **Ms. Suman Maurya**, for inspiring me to carry out my research work.

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List of Abbreviations and Symbols

Abbreviation	Nomenclature
AHCs	Aromatic hydrocarbons
ACB	Activated carbon biochar
BFR	Bio carrier filling ratio
BOD	Biochemical oxygen demand (mg/L)
CCD	Central composite design
COD	Chemical oxygen demand (mg/L)
DO	Dissolved oxygen (mg/L)
EC	Elimination capacity (mg/L.d)
HRT	Hydraulic retention time (d)
ILR	Inlet loading rates (mg/L.d)
LDPE-PP	Low-density polyethylene
MBBR	Moving bed biofilm reactor
OVAT	One variable at a time
PAH	Polycyclic aromatic hydrocarbon
PBBR	Packed bed bioreactor
PP	Polypropylene
PUF	Polyurethane foam
PUF-PP	Polyurethane foam-polypropylene
RE	Removal efficiency (%)
RSM	Response surface methodology
SA	Sodium Alginate

Symbol	Nomenclature
K_B	Saturation constant (mg/L.day)
K_i	Substrate inhibition constant (mg/L)
K_s	Half-saturation rate constant (mg/L)
Q	Volumetric flow rate (mL/h)
S	Substrate concentration (mg/L)
S_i	Inlet concentrations of substrate (mg/L)
S_f	Effluent concentrations of substrate (mg/L)
t	Time (day)
U_{max}	Maximum substrate removal rate (mg/L.day)
V	Bioreactor volume (L)
X	Biomass concentration (mg/L)
μ	Specific growth rate of microorganism (per day)
μ_{max}	Maximum specific growth rate of microorganism (per day)

Preface

Industrialization has improved the living style and economic prospects of the people as well as the country. In the meantime, the toxic pollutants (mainly phenol, phenolic derivatives, dyes, polycyclic aromatic hydrocarbons, etc.) are discharged to the ecosystem by various industries like petroleum, pharmaceutical, paints, and pesticides, and cause environmental issues. The carcinogenic, mutagenic, and teratogenic properties of the pollutants make researchers to explore cost-effective and eco-friendly technology for the degradation of such pollutants. In this direction, the biodegradation process is preferred as an effective tool for the mineralization of xenobiotic compounds.

The adopted microorganisms which have a history of exposure to the contaminated site exhibit higher biodegradation rates than other microorganisms. Hence, the acclimatization and isolation of the potent microbial species can enhance the biodegradation rate. The real-time applications of various microorganisms and packing support have been widely studied for wastewater treatment. However, the continuous performance evaluation of attached-growth bioreactors, such as packed bed bioreactor (PBBR) and moving bed bioreactor (MBBR), are relatively less researched for such applications. The objective of this study is to evaluate the efficacy of the potential bacterial species isolated from a textile industry-contaminated site for the biodegradation of azo dye and its derivatives in the PBBR and MBBR. In addition, this study employed low-density polyethylene and polyurethane foam, a packaging waste, in bioreactors for the purpose of bacterial immobilization. Process optimize and kinetic study performs in this study.

The present thesis is categorized into **6 chapters**. **Chapter 1** embeds a general introduction (sources and toxic effect) of azo dye and its derivatives, treatment methods, various factors affecting the biodegradation process, and the objective of the thesis work. **Chapter 2** contains a detailed analysis of the literature review, and research gaps. **Chapter 3** Bioremediation of Congo red in an anaerobic moving bed bioreactor: Process optimization and kinetic modeling. **Chapter 4** Biodegradation of Congo red dye using *Lysinibacillus* species in a moving bed biofilm reactor: Continuous study and kinetic evaluation. **Chapter 5** Biodegradation of Congo red dye using polyurethane foam-based biocarrier combined with activated carbon and sodium alginate: Batch and continuous study in the PBBR. The conclusions of the thesis work and the scope for future work have been mentioned in **Chapter 6**