

## **Dedication**

*I dedicated this Ph.D. thesis to the 130 crore Indian who paid the cost of this study, I am greatly indebted to them*

## CERTIFICATE

It is certified that the work contained in the thesis titled “**Process Design and Optimization of Bioreactors for the Treatment of Aromatic Hydrocarbon and Dye using Isolated Bacterial Species**” by **Ravi Kumar Sonwani** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy, and SOTA for the award of Ph.D. Degree.

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## DECLARATION BY THE CANDIDATE

I, **Ravi Kumar Sonwani**, certify that the work embodied in this Ph.D thesis is my own bona fide work and carried out by me under the supervision of **Prof. B. N. Rai** and co-supervision **Dr. Ravi P. Jaiswal** from **July 2016 to December 2020**, at the Department of Chemical Engineering & Technology, Indian Institute of Technology (Banaras Hindu University), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraph, text, data, results, etc. reported in the journals, books, magazines, reports, dissertations, thesis, etc., or available at websites and have not included in this thesis and have not cited as my own work.

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## List of Abbreviations and Symbols

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<b>Abbreviation</b>	<b>Nomenclature</b>
AHCs	Aromatic hydrocarbons
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)
IATP	Integrated aerobic treatment plant
ILR	Inlet loading rates (mg/L.d)
LDPE	Low-density polyethylene
LDPE-PP	Low-density polyethylene-polypropylene
MAH	Monocyclic aromatic hydrocarbon
MBBR	Moving bed biofilm reactor
OVAT	One variable at a time
PAH	Polycyclic aromatic hydrocarbon
POP	Persistent organic pollutant
PBBR	Packed bed bioreactor
PP	Polypropylene
PUF	Polyurethane foam
PUF-PP	Polyurethane foam-polypropylene
RE	Removal efficiency (%)
RSM	Response surface methodology

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<b>Symbol</b>	<b>Nomenclature</b>
$K_B$	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)
$S_0$	Inlet concentrations of substrate (mg/L)
$S_e$	Out 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)
$\mu$	Specific growth rate of microorganism (per day)
$\mu_{max}$	Maximum specific growth rate of microorganism (per day)

## PREFACE

Industrialization is one of the key aspects of the growth and economic development of any country. The industries such as petroleum, textile, pulp and paper, pharmaceutical, and leather have enormous economic significance due to their involvement in vibrant production output and employment generation. One of the sectors causing excessive environmental concerns is the petroleum and textile industries since they release toxic pollutants such as aromatic hydrocarbons (AHCs) (e.g., benzene, toluene, naphthalene, benzo[a]pyrene), surfactants, heavy metals, dyes, etc. Given their carcinogenic and mutagenic nature, AHCs and dyes reveal direct or indirect health risks to human and aquatic life. The harmful concern of these pollutants (AHCs and dyes) has motivated researchers to develop cost-effective, environmentally benign, and efficient treatment technologies to remove/treat them. In this direction, biodegradation is acknowledged as an eco-friendly and economical approach than physicochemical methods. Although there are lots of research works going on in the field of biodegradation but slow degradation rate is a major challenge.

In the last few decades, it has been observed that the bioreactors (both suspended-growth and attached-growth) play a significant role in the treatment of wastewater which is discharged from various industries, including refineries, textile, leather, and pharmaceuticals. However, the application of continuous bioreactors (specially packed bed bioreactor and moving bed biofilm reactor) is the under-explored area for the biodegradation of Congo red (dye) and naphthalene (AHC). Also, very limited attention has been given to the design and optimization of bioreactors by response surface methodology. The biodegradation rate can also be improved by using acclimatized and isolated potential bacterial species from pollutants-contaminated sites. The main objective of the work is to isolate the dyes and AHCs degrading bacterial species and

used in bioreactors for the effective degradation of dyes and AHCs. The experiments were designed and optimized by response surface methodology to enhance a greater yield with fewer experiments. The performance of the continuous bioreactors was evaluated at various inlet loading rates. The kinetic parameters were evaluated by various substrate growth and inhibition models.

The present study is divided into **7 chapters**. **Chapter 1** contains the introduction of dyes and aromatic hydrocarbons, treatment methods, and bioreactors and their types. **Chapter 2** deals with the literature review on the biodegradation of dyes and aromatic hydrocarbons, research gaps, and the objective of the research work. **Chapter 3** describes the enrichment and isolation procedure of potential bacterial species. Process parameters were optimized by surface response methodology. Further, the performance of an integrated aerobic treatment plant was evaluated at different inlet loading rates. The external mass transfer (EMT) aspect of naphthalene degradation in packed bed bioreactor has been described in **Chapter 4**. **Chapter 5** describes the comparative study of modified carriers in moving bed biofilm reactor for wastewater treatment. In **chapter 6**, the biodegradation of Congo red dye in a moving bed biofilm reactor has been studied. The summary and scope of the future work are described in **Chapter 7**.