BIOLOGICAL TREATMENT OF WASTEWATERS USING INVERSE FLUIDIZED BED REACTOR

MANEESH. N

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2023

BIOLOGICAL TREATMENT OF WASTEWATERS USING INVERSE FLUIDIZED BED REACTOR

by

MANEESH. N

DEPARTMENT OF CIVIL ENGINEERING

Submitted

In fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2023

Certificate

This is to certify that the thesis entitled "**Biological treatment of wastewaters using inverse fluidized bed reactor**", submitted by **Maneesh. N** to the Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy in Civil Engineering, is a record of the original, bonafide research work carried out by him under our supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree. The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

Prof. Babu J. Alappat
Department of Civil Engineering
Indian Institute of Technology Delhi

Date: 27/7/23
New Delhi

Prof. T. R. Sreekrishnan
Department of Biochemical
Engineering and Biotechnology
Indian Institute of Technology Delhi.

Date: 28.7.2023
New Delhi

Acknowledgments

I am deeply indebted to my supervisors Prof. Babu J. Alappat and Prof. T.R. Sreekrishnan for their constant support, guidance, and motivation throughout the course of my Ph.D., both through my research period and in writing this thesis. I am so grateful to them for the lessons imparted to me through the course of my stay at IIT Delhi.

I am so grateful to Prof. Stefano Papirio, University of Naples, Federico-II for his outstanding guidance and encouragement through my stay in Naples, Italy as part of the visiting student program. He was a constant motivator and helped in understanding the way work happens in international universities.

I would like to show my gratitude to Prof. Z.A Shaikh, Department of Biochemical Engineering and Biotechnology for his never-ending positive attitude toward research and for helping me by providing all the advanced facilities at the waste treatment lab, IIT Delhi.

I am extending my sincere gratitude towards Ms. Prachi Ramesh Chavan for helping me through the Ph.D. period, through her constant support in the laboratory work, manuscript preparation, and for being constant support throughout the course of my Ph.D. life. I am also grateful to Dr. S Bhuvanesh, whose thought-provoking conversation about everything motivated me to concentrate on this journey. I would like to sincerely thank Mr. Vishnu C for his constant support through my Ph.D.

I am also grateful to the members of Waste Treatment Lab, IIT Delhi for making my life memorable in IIT Delhi and providing the required support for the completion of my work in the laboratory. I would also like to mention the support provided by the Environmental Engineering laboratory and office people of the Department of Civil Engineering for their support throughout my Ph.D. I would like to thank Central Pollution Control Board, Delhi for allowing me to continue with my Ph.D. work without any hindrance.

Lastly, I would like to thank my parents and all my family members, who supported me through the course of study and constantly motivated me to finish it. Without their support, none of this would have happened.

To all the people who supported me through this journey, I would like to thank them all.

(MANEESH. N)

Abstract

The biological treatment of different types of wastewater using an Inverse Fluidized Bed Reactor has been studied in this work. Anaerobic treatment of organic-rich wastewater, autotrophic denitrification of nitrate-rich oligotrophic wastewater, nitrate and organic-rich industrial wastewater with low pH, and wastewater containing ammonia and phenol were the wastewater used in this study. Anaerobic, anoxic and aerobic pathways are used for wastewater treatment according to their characteristics. The start-up of an inverse fluidized bed reactor is a time-consuming step and to reduce the period, different strategies have been used in this study. Consistent removal of pollutants requires high biomass density inside the reactor and the best fluidization characteristics. Therefore, selecting carriers for biofilm formation has been done focusing on these attributes. Physically modified carriers helped in reducing the start-up time and showed high biofilm affinity in this study. Anaerobic wastewater treatment for biogas formation showed high organic removal rates of 75% even at an inlet organic loading of $25 kgm^{-3}day^{-1}$ and the reactor was able to withstand organic and hydraulic shock loads without failure. A comparative study of the inverse fluidized bed reactor with a continuously stirred tank reactor operating for autotrophic denitrification showed that, even though the removal efficiencies are lower than stirred tank reactor, the inverse fluidized bed showed high resilience towards high concentrations of Ni^{2+} ($120\ mgL^{-1}$). This was possible due to the biofilm formation in the reactor combined with the high recirculation of bulk liquid. Heterotrophic denitrification of explosive industry wastewater containing high nitrates, organics, and very low pH was done using an anoxic inverse fluidized bed reactor. The reactor gave a denitrification rate of 880g NO_3^--N/m^3.day**,** with a removal efficiency of 90%, one of the highest in the reported literature. Nitrification of ammonia in the wastewater containing phenol

was the last treatment study conducted in this study. The reactor attained nitrification and phenol removal rates of 0.17 kg NH_4^+-N/m^3.day. 0.11 kg Phenol/m^3.day respectively.

Hydrodynamic characteristics study on the inverse fluidized bed has been done to understand the effect of biofilm formation on the bed expansion characteristics. The changes in bio-particle density, bed height, bed porosity, and changes in carrier settling velocity have been studied in this part.

सारांश

इस कार्य में व्युत्क्रम द्रवीकृत बेड रिएक्टर का उपयोग करके विभिन्न प्रकार के अपशिष्ट जल के जैविक उपचार का अध्ययन किया गया है। कार्बनिक-समृद्ध अपशिष्ट जल का अवायवीय उपचार, नाइट्रेट-समृद्ध ऑलिगोट्रॉफ़िक अपशिष्ट जल का ऑटोट्रॉफ़िक डिनाइट्रीकरण, कम पीएच वाले नाइट्रेट और कार्बनिक-समृद्ध औद्योगिक अपशिष्ट जल, और अमोनिया और फिनोल युक्त अपशिष्ट जल इस अध्ययन में उपयोग किए गए अपशिष्ट जल थे। अपशिष्ट जल उपचार के लिए एनारोबिक, एनोक्सिक और एरोबिक मार्गों का उपयोग उनकी विशेषताओं के अनुसार किया जाता है। व्युत्क्रम द्रवीकृत बिस्तर रिएक्टर का स्टार्ट-अप एक समय लेने वाला कदम है और इस अवधि को कम करने के लिए, इस अध्ययन में विभिन्न रणनीतियों का उपयोग किया गया है। प्रदूषकों को लगातार हटाने के लिए रिएक्टर के अंदर उच्च बायोमास घनत्व और सर्वोत्तम द्रवीकरण विशेषताओं की आवश्यकता होती है। इसलिए, बायोफिल्म निर्माण के लिए वाहकों का चयन इन विशेषताओं पर ध्यान केंद्रित करते हुए किया गया है। भौतिक रूप से संशोधित वाहकों ने स्टार्ट-अप समय को कम करने में मदद की और इस अध्ययन में उच्च बायोफिल्म बंधुता दिखाई। बायोगैस निर्माण के लिए अवायवीय अपशिष्ट जल उपचार ने (25 $kgm^{-3}day^{-1}$) के इनलेट कार्बनिक लोडिंग पर भी 75% की उच्च कार्बनिक निष्कासन दर दिखाई और रिएक्टर विफलता के बिना कार्बनिक और हाइड्रोलिक शॉक लोड का सामना करने में सक्षम था। ऑटोट्रॉफ़िक डिनाइट्रिफिकेशन के लिए संचालित लगातार उत्तेजित टैंक रिएक्टर के साथ उलटा द्रवीकृत बिस्तर रिएक्टर के एक तुलनात्मक अध्ययन से पता चला है कि, भले ही हटाने की क्षमता उत्तेजित टैंक रिएक्टर से कम है, उलटा द्रवीकृत बिस्तर ने Ni^{2+} (120 mgL^{-1}) की उच्च सांद्रता के प्रति उच्च लचीलापन दिखाया है। . यह रिएक्टर में बायोफिल्म निर्माण के साथ-साथ थोक तरल के उच्च पुनर्चक्रण के कारण संभव हुआ। उच्च नाइट्रेट, ऑर्गेनिक्स और बहुत कम पीएच वाले विस्फोटक उद्योग के अपशिष्ट जल का हेटरोट्रॉफ़िक डिनाइट्रीकरण एक एनोक्सिक व्युत्क्रम द्रवीकृत बेड रिएक्टर का उपयोग करके किया गया था। रिएक्टर

ने 90% की निष्कासन दक्षता के साथ 880gNO_3^--N/m^3.day की डेनाइट्रीकरण दर दी, जो रिपोर्ट किए गए साहित्य में सबसे अधिक में से एक है। फिनोल युक्त अपशिष्ट जल में अमोनिया का नाइट्रीकरण इस अध्ययन में किया गया अंतिम उपचार अध्ययन था। रिएक्टर ने 0.17 kg NH_4^+-N/m^3.day की नाइट्रीकरण और फिनोल निष्कासन दर प्राप्त की। क्रमशः 0.11 kg. फिनोल/m^3.day।

बिस्तर विस्तार विशेषताओं पर बायोफिल्म निर्माण के प्रभाव को समझने के लिए व्युत्क्रम द्रवीकृत बिस्तर पर हाइड्रोडायनामिक विशेषताओं का अध्ययन किया गया है। इस भाग में जैव-कण घनत्व, बिस्तर की ऊंचाई, बिस्तर की सरंध्रता और वाहक निपटान वेग में परिवर्तन का अध्ययन किया गया है।

INDEX

List of Figures

List of Tables

Abbreviations and symbols

Abbreviations and symbols	Details
ADBIOS	Autotrophic denitrification with bio-S
AMD	Acid Mine Drainage
AnIFBR	Anaerobic Inverse Fluidized Bed Reactor
Ar	Archimedes Number
Bio-S	Biogenic Sulphur
BOD	Biochemical Oxygen Demand
C_D	Drag coefficient
COD	Chemical Oxygen Demand
CSTR	Continuous Stirred Tank Reactor
D	Diameter of the reactor
D_P	Diameter of the carrier particle
ε	Bed Porosity
f	Expansion factor
FBR	Fluidized Bed Reactor
g	Acceleration due to gravity
HDPE	High-Density Poly Ethylene
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention Time
IFBR	Inverse Fluidized Bed Reactor
ITBR	Inverse Turbulent Bed Reactor
LDPE	Low-Density Poly Ethylene
LPM	Litre Per Minute
OLR	Organic Loading Rate
OTR	Oxygen Transfer Rate
PP	Polypropylene
Re	Reynolds Number
RPM	Rotation Per Minute

SRT	Sludge Retention Time
TCD	Thermal Conductivity Detector
TSS	Total Suspended Solids
U	Liquid Velocity
V_b	Volume of the carrier bed
VFA	Volatile Faty Acid
V_R	Volume of the reactor
VSS	Volatile Suspended Solids
ρ_l	Density of the liquid
ρ_p	Density of the carrier particle