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Evaluation of Titanium Dioxide Modified Biochar in a Moving Bed Biofilm Reactor for Wastewater Treatment

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Abstract: Wastewater treatment is essential for reducing environmental pollution and improving effluent quality. Conventional biological treatment technologies, including the Moving Bed Biofilm Reactor (MBBR) are widely used for organic pollutant removal; however, their performance depends on wastewater characteristics, biofilm development, and operating conditions. The present study evaluates the potential application of titanium dioxide (TiO₂)-modified rice husk biochar in an MBBR system for wastewater treatment. The proposed approach combines the adsorption properties of biochar with the potential photocatalytic activity of TiO₂ to enhance contaminant removal. A laboratory-scale reactor with a working volume of 15 L was used to investigate treatment performance under controlled operating conditions, with a conventional MBBR serving as the control. Wastewater samples were collected from selected sources including a sewage treatment plant, a milk-processing facility, and industrial sources. Treatment performance was assessed primarily through biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved solids (TDS). The study also considered the influence of reactor configuration, carrier characteristics, aeration, sunlight exposure, and biofilm development on treatment performance. The principal evaluation outcomes are the comparative removal efficiencies of BOD, COD, and TDS in the conventional and TiO₂-modified biochar systems. This investigation provides a basis for assessing the practical applicability of TiO₂-modified biochar in hybrid biological treatment and for identifying the operational and material-related factors requiring further investigation. Further quantitative validation is necessary to establish the magnitude of performance improvement, material stability and suitability for practical wastewater treatment applications.

Keywords: TiO₂-modified biochar, rice husk biochar, moving bed biofilm reactor, wastewater treatment, biochemical oxygen demand, chemical oxygen demand, total dissolved solids.

I. INTRODUCTION

The treatment of wastewater is important for environmental protection because inadequately treated effluent can introduce organic matter dissolved substances and other contaminants into water bodies. The nature and concentration of pollutants vary according to the source of wastewater. [1] Consequently, the selection of a suitable treatment process depends on following factors such as the wastewater composition along with effluent quality, working conditions, and available resources. Biological treatment is commonly used in india to reduce biodegradable organic matter. In this system, microorganisms breaks organic compounds into a new biomass. The Moving Bed Biofilm Reactor is a technology in which microorganisms grow on carrier elements that move within the

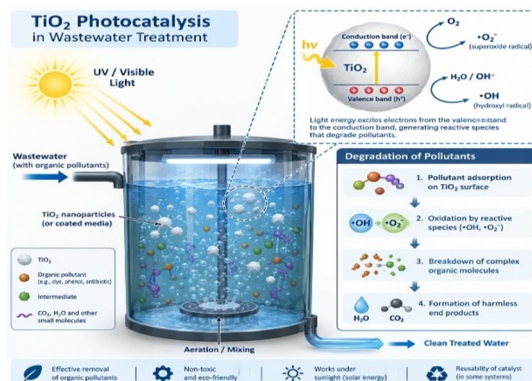


Figure 1. TiO₂ Photocatalysis in wastewater Treatment

reactor. The movement of carriers encourages contact between wastewater and attached biomass while the surface provide protected areas for biofilm development. Basically MBBR technology identifies carrier properties, HRT, aeration, organic loading, and biofilm characteristics as key factors that influences treatment performance. Although conventional MBBR systems can effectively reduce organic pollution but their performance is not uniform across all wastewater types. factors such as High pollutant loading, variable composition of wastewater , and unsuitable operating site conditions can affect biological activity and treatment efficiency.[2] This has encouraged researchers to use modified carriers and combined treatment approaches intended to improve contaminant contact as well as maintain biofilm activity and to remove pollutants that are not removed through biological treatment alone.

Biochar is a best example for advanced titanium Dioxide based wastewater Treatment it is produced by heating biomass in the absence of oxygen [pyrolysis]. it is used for the removal of various organic and inorganic contaminants whereas Titanium dioxide (TiO_2) is a semiconductor material widely studied for photocatalytic applications. Combining TiO_2 with biochar may bring together adsorption and photocatalytic functions. However, the effectiveness of this system depends on the composite's preparation, light exposure, contaminant type, and material stability.

Such system may combine biological degradation with additional adsorption.

The present research focuses on evaluating TiO_2 -modified biochar in an MBBR system using BOD, COD, and TDS as the main water quality parameters . The aim is to assess its practical contribution in day to day life under defined operating conditions and identify whether the combined approach can be used over conventional biological treatment.[3]

II. LITRETURE REVIEW

Biase et al. (2019) examines the development of MBBR technology for municipal wastewater treatment including carrier properties, biofilm development, organic content removal. The research concluded that carrier characteristics and reactor operating conditions are important for effective treatment. [1]

Mahto and Das (2022) discusses the role of bacterial biofilms and extracellular polymeric substances in MBBR systems. The study discussed how the carrier surface and biofilm structure influence treatment performance. This is relevant to the present study because the introduction of a modified material must be assessed not only for its pollutant removal properties but also for its compatibility with microbial growth. [2]

Biochar is a carbon-rich material produced through the thermal conversion of biomass under limited oxygen conditions. Biochar based materials have been investigated over past years for removing organic pollutants, heavy metals and nutrients from water.

Chemosphere in 2020 discussed its applications in industrial, municipal, as well as in stormwater treatment. The writer identified engineered biochar as a way to modify surface properties and potentially improve its suitability for particular contaminants. [3]

Amdeha's (2023) examined biochar-based nanocomposites for industrial wastewater treatment. It highlighted the importance of biochar dosage, initial pollutant concentration, pH, treatment time, interfering ions, and regeneration. These factors are relevant when evaluating a modified biochar in a reactor rather than assuming that material performance in a laboratory batch test will transfer directly to continuous biological treatment.[4]

Liu et al. (2024) reviewed TiO_2 biochar-based photocatalysts and discussed preparation methods, adsorption, photocatalytic performance and the factors affecting material efficiency. The authors also identified challenges related to composite stability, recovery, light utilization, and scale-up. [5]

Saidulu et al. (2021) compared research trends and treatment mechanisms across MBBR, membrane bioreactor, and hybrid moving-bed membrane systems. Their study showed that treatment performance varies with process configuration and pollutant type. [6]

Madan et al. (2022) observed advances in hybrid MBBR-based biological treatment and discussed the development of systems intended to improve organic matter and nutrient removal. recent reviews identifies carrier other factors such as modification, aeration, hydraulic retention time, and hybridization as important areas for further future research. [7]

In 2026, research on biochar-based catalysts continued to examine combinations of adsorption and catalytic processes for wastewater treatment. However, findings from photocatalytic systems cannot be directly treated as proof of improved biological performance. A dedicated MBBR experiment is needed to establish whether TiO_2 -modified biochar improves parameters such as BOD, COD, or TDS removal under the specific conditions being investigated.

III. RESEARCH GAP

The reviewed literature establishes two relevant areas of research: MBBR technology for biological wastewater treatment and TiO_2 -biochar composites for adsorption and photocatalytic applications.

A specific experimental evaluation is needed to establish how TiO_2 -modified biochar performs when used in an MBBR system. the effects on BOD, COD, and TDS should be evaluated under comparable operating conditions. The material should also be assessed for compatibility with biofilm development, stability during operation, and potential release of particles into the treated water.

IV. AIM AND OBJECTIVES

A. Aim

To evaluate the performance of TiO_2 -modified biochar in a Moving Bed Biofilm Reactor for wastewater treatment, focusing on BOD, COD, and TDS reduction.

B. Objectives

- To evaluate the treatment performance of a conventional MBBR as a control.
- To investigate the performance of an MBBR using TiO_2 -modified biochar under comparable operating conditions.
- To measure BOD, COD, and TDS before and after treatment.
- To calculate pollutant-removal efficiencies and compare treatment conditions.
- To examine the stability and practical limitations of the modified material.

V. METHODOLOGY ADOPTED

A. Wastewater Sampling

Biochar should be prepared or obtained using a reproducible procedure.[4] Biochar Used in this lab Experiment was same as the quantity of titanium Dioxide (approx. 25 kg). The first step of the research was wastewater sample collections . wastewater samples are collected from different sources such STP Baldev Nagar ambala . Vita Milk Plant Baldev Nagar ambala and factories and plants near Lalru.

B. Reactor Setup

A 15 Litre lab scale Reactor was made using 5 mm Thick acrylic sheet with 40-45% carrier fill ratio. this technique is also known as Bench scale simulation. [5]A Total of five reactor setup were made. Three Reactors for powder form , one for film and one controlled reactor. In case of TiO_2 powder treatment, There is no preconditioning of media was required. However, in the case of TiO_2 -coated media, a preconditioning period of Ten days was needed to allow biofilm formation before treatment. Photocatalysis was carried out using natural sunlight between 10:00 AM and 3:00 PM during which absorption was measured using a UV visible spectrometer Model name Shimadzu UV-1800 to ensure consistent exposure throughout the experiment. The reactor setup remained the same for both powder and coated TiO_2 forms with the key difference being the method of TiO_2 application. are conducted in seprate Reactors. In Case of coated media trials, no powder was added only the pre-coated biofilm carriers were used for the treatment process. [6]

The reactor setup for both film process and and powder process is shown in Figure 5.1 and Figure 5.2

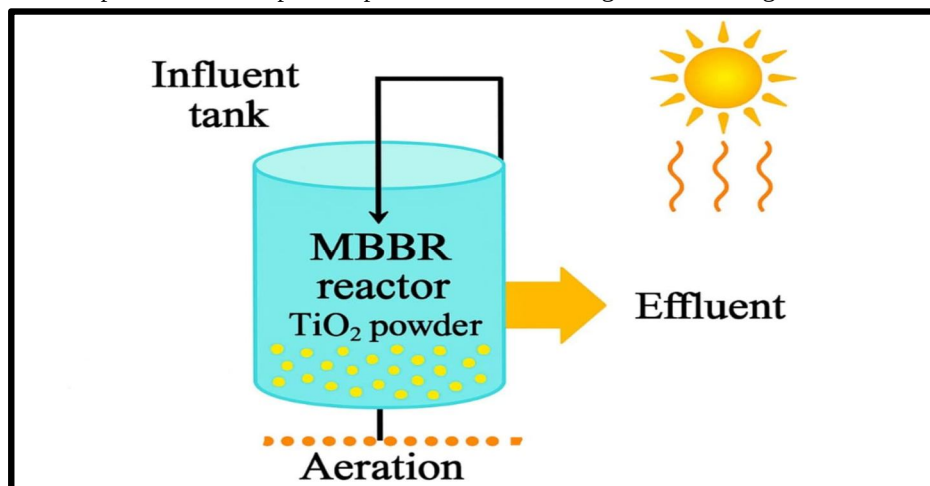


Figure 5.1 TiO_2 Powder Reactor Setup

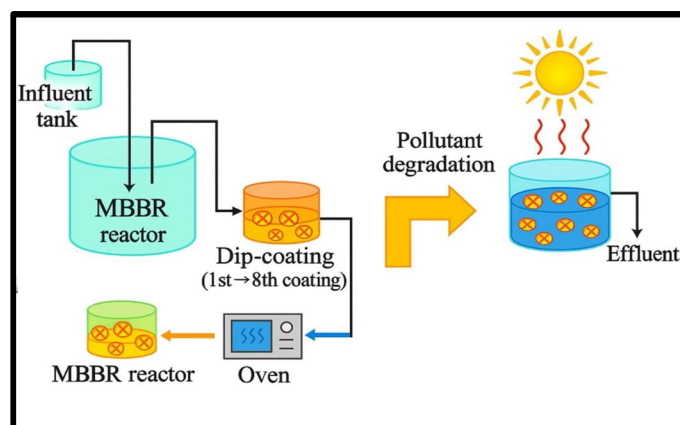


Figure 5.2 TiO₂ Film Reactor Setup

C. Photo catalytic Treatment

Titanium Dioxide (TiO₂) was added in powder form ranging from 25 kg relative to the volume of the reactor. Continuous aeration was provided using diffusers at 1.5 L/min, ensuring DO >2 mg/L

D. Sample Testing

Samples are collected after testing and send to lab for BOD, COD and TDS calculation

E. After Treatment Procedures

Results were recorded and compared with the untreated controlled samples and with proper precautions. Residual TiO₂ and treated wastewater were handled as per CPCB guidelines to ensure safe disposal. [7]

VI. CONCLUSION

TiO₂-modified biochar presents a potential material for investigation in MBBR-based wastewater treatment because it combines the adsorption characteristics of biochar with the potential photocatalytic properties of titanium dioxide. Existing literature supports the investigation of TiO₂ biochar composites for pollutant removal and establishes the importance of carrier properties and biofilm development in MBBR systems.

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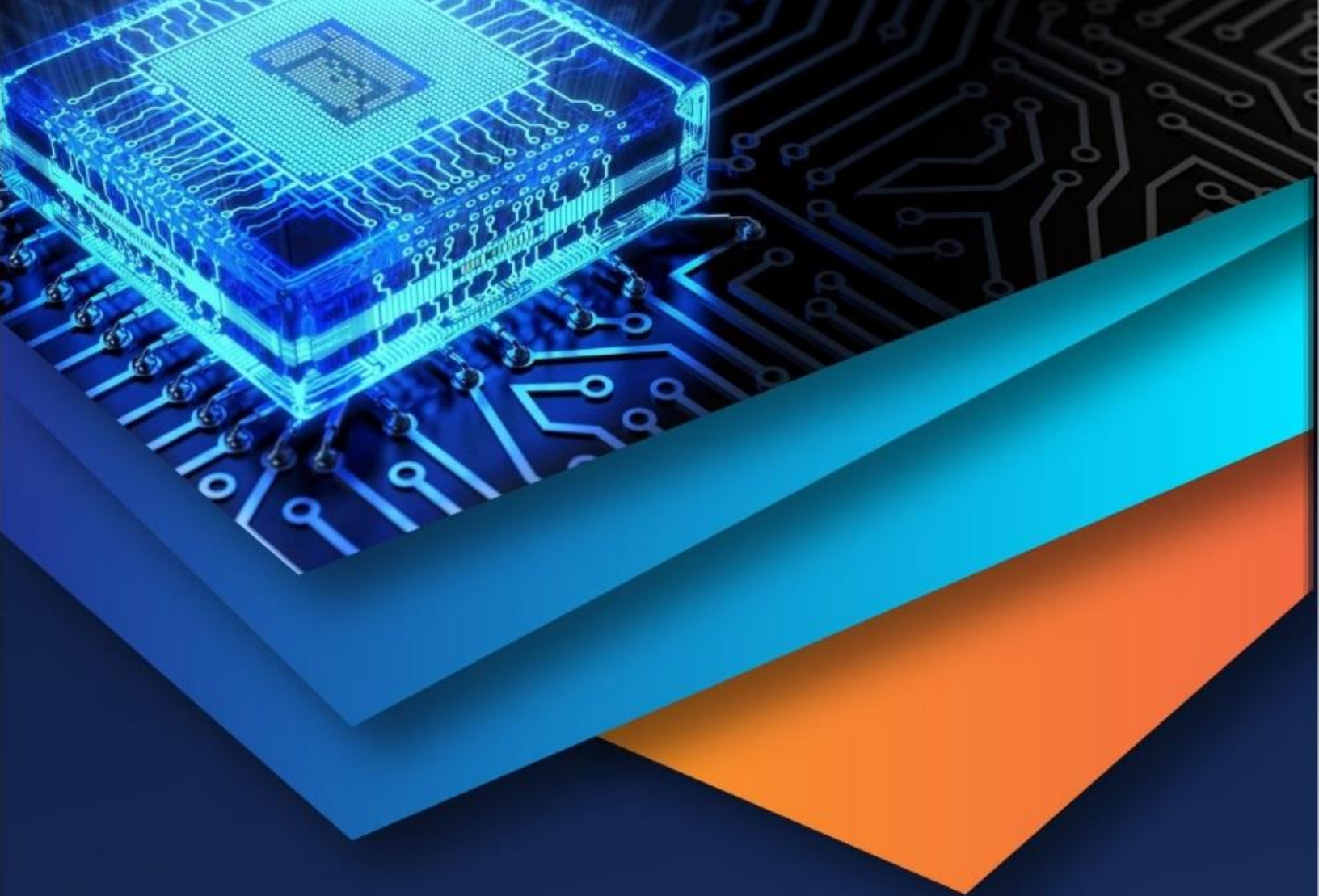


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