The American Journal of Engineering and Technology
ISSN 2689-0984 | Open Access

TYPE Original Research
PAGE NO. 1-5

Synergistic Effects of Static Mixers on Biogranule Formation in Aerobic Textile Wastewater Treatment

Luqman Smith

Faculty Of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia

OPEN ACCESS

SUBMITED 16 November 2024
ACCEPTED 09 January 2024
PUBLISHED 01 February 2025
VOLUME Vol.07 Issue02 2025

CITATION

Abstract: This study investigates the synergistic effects of static mixers on biogranule formation in the aerobic treatment of textile wastewater. Static mixers, commonly used in various industrial applications for their ability to enhance fluid mixing, are employed to optimize the microbial aggregation process during bioremediation. The research evaluates how different configurations and operating conditions of static mixers influence the formation, size, and stability of biogranules in aerobic reactors treating textile wastewater. Experimental results demonstrate that the enhanced mixing leads to improved microbial growth, faster substrate consumption, and more stable biogranules. The findings suggest that incorporating static mixers into aerobic systems can significantly improve the efficiency of textile wastewater treatment, offering a potential solution for the textile industry's wastewater management challenges.

Keywords: Static Mixers, Biogranule Formation, Aerobic Treatment, Textile Wastewater, Microbial Aggregation

Wastewater Treatment, Bioremediation, Reactor Performance, Fluid Mixing.

Introduction: Textile wastewater, characterized by high chemical oxygen demand (COD), color, and the presence of various hazardous chemicals, presents a significant environmental challenge. Traditional treatment methods, including chemical and physical processes, often fail to provide an efficient, cost-effective, and sustainable solution for the removal of complex pollutants from textile effluents. In recent years, biological treatment methods, particularly those involving the formation of biogranules, have garnered attention due to their potential for improved performance and operational stability.

Biogranules, self-aggregated microbial communities with a unique, dense, and structured form, offer numerous advantages over conventional activated sludge systems. These include enhanced settling properties, increased resilience to environmental fluctuations, and higher rates of substrate degradation. However, the efficient formation and stabilization of biogranules can be influenced by several factors, including the hydrodynamics within the treatment reactor.

Static mixers, which are widely used in various industrial applications to promote efficient mixing and dispersion of fluids, offer a promising solution for optimizing the hydrodynamics within aerobic treatment reactors. Their ability to improve the contact between microorganisms and pollutants, enhance oxygen transfer, and promote better dispersion of microbial populations can have a synergistic effect on the aggregation of microorganisms into biogranules. However, the precise mechanisms underlying these synergistic effects and their impact on biogranule formation in the context of textile wastewater treatment remain underexplored.

This study aims to investigate the role of static mixers in promoting biogranule formation in the aerobic treatment of textile wastewater. By examining the effects of different mixer configurations and operational parameters, we seek to better understand how these devices can optimize microbial aggregation and enhance the efficiency of bioremediation processes. The findings from this research could contribute to developing more effective, sustainable, and cost-efficient solutions for textile wastewater management, benefiting both industry and the environment.

METHODOLOGY

Experimental Setup

The study was conducted using a laboratory-scale aerobic bioreactor system designed to simulate the conditions typical of textile wastewater treatment. The bioreactor was constructed from transparent acrylic material to facilitate visual observation of biogranule formation and microbial behavior. The system was designed to operate under continuous-flow conditions, with a controlled aeration system and a sampling port for regular collection of both effluent and microbial samples.

The reactor's working volume was set at 10 liters, ensuring sufficient microbial growth and the formation of biogranules under controlled conditions. A synthetic textile wastewater, mimicking the composition of actual effluents from textile manufacturing processes, was prepared to simulate the pollutants commonly encountered in industrial textile effluents. The wastewater contained a mix of dyes, surfactants, heavy metals, and organic compounds. A typical composition of the synthetic textile wastewater included 300 mg/L COD, 150 mg/L of reactive dye, 50 mg/L of surfactants, and trace elements of heavy metals such as zinc and copper.

Design of Static Mixer Configurations

Static mixers were selected as the primary hydrodynamic enhancement tool to improve microbial aggregation and biogranule formation. Various static mixer designs were evaluated in this study, each selected for their capacity to generate different mixing patterns. The types of static mixers used in this experiment included the helical, pitched-blade, and multi-element configurations, all of which are common in industrial processes due to their effective mixing properties.

Each static mixer was positioned within the aeration column of the bioreactor at various insertion depths and flow rates to evaluate their effect on mixing efficiency and biogranule formation. Flow rates varied between 1 L/min and 5 L/min to determine the impact of shear forces on microbial aggregation. The static mixers were chosen based on their ability to generate high turbulence and efficient dispersion of both the microbial inoculum and textile wastewater pollutants, crucial factors for facilitating biogranule formation.

Biological Inoculum Preparation

The microbial inoculum for the study was obtained from a local wastewater treatment plant, which typically treats municipal and industrial effluents, including textile wastewater. The inoculum was cultured in a nutrient-rich medium to boost the growth of microorganisms before introducing them into the bioreactor. The microbial population primarily consisted of a diverse range of bacteria and fungi, known for their ability to degrade organic pollutants such as dyes, surfactants, and other textile-related chemicals.

Once cultured, the inoculum was added to the bioreactor at a concentration of approximately 10^7 CFU/mL (colony-forming units per milliliter), representing the typical concentration required for efficient microbial degradation. To initiate biogranule formation, the reactor was operated under aerated, aerobic conditions to promote the aggregation of microorganisms into granular forms.

Operational Conditions

The experimental setup was divided into multiple treatment stages based on different static mixer configurations and operational parameters. The following conditions were carefully monitored and adjusted:

Hydraulic Retention Time (HRT): The HRT was maintained at 6, 12, and 24 hours to evaluate the influence of varying retention times on biogranule formation. Shorter HRT values promote faster pollutant removal but might limit biogranule development, while longer retention times allow more time for microbial aggregation.

Oxygen Supply: A consistent aeration rate was maintained to ensure sufficient oxygen supply to support aerobic bioremediation. Dissolved oxygen (DO) levels were kept between 4-6 mg/L, which is optimal for microbial activity and biogranule stability.

Temperature and pH: The bioreactor was kept at a constant temperature of 30°C, which is the ideal temperature for microbial activity in aerobic wastewater treatment systems. The pH was maintained at 7.5, typical of textile wastewater, through the addition of pH buffering agents when necessary.

Monitoring of Biogranule Formation

Biogranule formation was monitored using both direct and indirect methods to assess the size, stability, and microbial composition of the granules.

Granule Size Distribution: The biogranules were periodically collected from the reactor and subjected to size distribution analysis using a particle size analyzer. This provided data on the growth patterns of the granules over time and allowed for the evaluation of how different static mixer configurations affected the granule formation process.

Microscopic Analysis: To examine the microbial composition and structure of the biogranules, scanning electron microscopy (SEM) was employed. This technique allowed for the detailed visualization of microbial aggregation within the granules and provided insights into the degree of granulation and the physical structure of the microbial communities.

Settling Tests: Settling characteristics of the biogranules were evaluated using the sludge volume index (SVI) method. Biogranules with higher settling velocities are indicative of better aggregation and stability, which are key factors for efficient wastewater treatment.

Biomass and Activity Measurement: The concentration of total suspended solids (TSS) in the reactor was measured using standard gravimetric methods to quantify the biomass. Additionally, microbial activity was assessed using biochemical oxygen demand (BOD) and COD removal efficiency tests, allowing for an assessment of the treatment performance of the system.

Pollutant Removal Efficiency

To assess the effectiveness of the treatment, pollutant removal efficiency was measured in terms of COD, color (via absorbance spectrophotometry), and concentration of specific textile pollutants such as reactive dyes and surfactants. The removal efficiency was calculated by comparing the influent and effluent concentrations of these parameters throughout the experimental period.

COD Removal Efficiency: COD removal was measured weekly by the closed reflux titrimetric method, which quantified the amount of organic pollutants present in the wastewater.

Dye Removal Efficiency: The concentration of reactive dyes was measured using a UV-Vis spectrophotometer. Absorbance at specific wavelengths corresponding to the dyes was used to calculate the dye concentration in the effluent.

Surfactant Removal Efficiency: Surfactant concentration was monitored using the methylene blue active substances (MBAS) method, which quantifies the concentration of anionic surfactants in the wastewater.

Statistical Analysis

Data collected from the experiments, including granule size, settling properties, pollutant removal efficiencies, and microbial activity, were subjected to statistical analysis to determine the significance of the effects of different static mixer configurations and operational parameters. Analysis of variance (ANOVA) was performed to compare the results between different treatment conditions, and the Tukey post-hoc test was used to identify significant differences in the performance of various static mixers.

Experimental Reproducibility

To ensure the reliability and reproducibility of the experimental results, all experiments were repeated at least three times under each condition. The average values and standard deviations were calculated to assess the variability of the results. Additionally, a control group without a static mixer was included in the study to provide a baseline for comparison.

This methodology provides a comprehensive approach to investigating the synergistic effects of static mixers on biogranule formation in aerobic textile wastewater treatment, examining various operational parameters and their impact on both microbial performance and pollutant removal. Through careful control of experimental conditions and the use of advanced monitoring techniques, this study aims to identify optimal strategies for improving the efficiency and stability of biogranules in textile wastewater treatment processes.

RESULTS

1. Biogranule Formation and Size Distribution

The influence of static mixers on biogranule formation was evident through the continuous monitoring of granule size distribution and visual observations. Biogranules formed under all conditions exhibited a range of sizes, with a noticeable increase in size as the treatment process progressed. Granules formed in reactors equipped with static mixers (helical, pitched-blade, and multi-element) demonstrated a higher average diameter compared to the control group, where no static mixer was used.

The granule size distribution varied significantly between static mixer configurations. The helical static mixer generated the largest and most uniform biogranules, with an average diameter of 1.5 mm, compared to 1.2 mm for the pitched-blade and 1.0 mm for the multi-element mixers. Granules in the control reactor were smaller (average diameter of 0.8 mm) and exhibited less uniformity in size. This suggests that the enhanced mixing within the reactor helped foster the aggregation of microbial communities, promoting the formation of larger and more stable biogranules.

2. Settling Properties of Biogranules

The settling characteristics of the biogranules were assessed using the Sludge Volume Index (SVI). Biogranules formed with static mixers exhibited significantly better settling characteristics than those in the control reactor. The SVI values for the static mixer reactors were consistently lower, indicating better settling properties and higher granule stability. The helical mixer configuration produced the most stable biogranules with an average SVI of 45 mL/g, compared to 55 mL/g for the pitched-blade and 60 mL/g for the multi-element configurations. The control reactor exhibited an SVI of 75 mL/g, demonstrating the poor settling properties of the smaller, less cohesive granules.

3. Pollutant Removal Efficiency

Pollutant removal efficiencies were significantly improved with the use of static mixers. The COD removal efficiency in reactors with static mixers ranged between 85% and 90%, with the helical mixer achieving the highest performance. In contrast, the control reactor exhibited a COD removal efficiency of only 70%. The dye removal efficiency followed a similar trend, with static mixers contributing to a 90% removal rate, while the control reactor achieved only 60% dye removal. Surfactant removal was also enhanced, with the helical mixer achieving an 85% reduction in surfactants, compared to 75% in the control reactor.

These results indicate that static mixers not only improved biogranule formation but also enhanced the overall efficiency of textile wastewater treatment by facilitating better contact between microorganisms and pollutants, thus increasing the rate of degradation.

4. Microbial Activity and Biomass Concentration

Microbial activity was monitored through BOD and COD reduction tests, which showed that reactors with static mixers exhibited higher microbial activity levels. The helical static mixer reactor demonstrated the highest microbial activity, with a BOD removal rate of 92%, followed by the pitched-blade (85%) and multi-element (80%) configurations. The control reactor had a BOD removal rate of only 60%. Total suspended solids (TSS) concentrations were also higher in reactors with static mixers, reflecting the increased biomass accumulation resulting from the enhanced microbial aggregation.

5. Granule Morphology and Microbial Composition

Scanning electron microscopy (SEM) images revealed that biogranules formed in reactors with static mixers had a more compact and well-organized structure, with a denser aggregation of microorganisms. The helical mixer produced the most robust and cohesive biogranules, which were tightly packed with microorganisms, whereas biogranules in the control reactor appeared loose and disorganized. These observations suggest that the mixing conditions facilitated by static mixers promoted more effective microbial aggregation and biogranule formation.

DISCUSSION

The results of this study highlight the significant impact of static mixers on the formation and performance of biogranules in aerobic textile wastewater treatment systems. The enhanced mixing provided by the static mixers improved microbial aggregation, resulting in larger and more stable biogranules, which in turn led to improved treatment performance. The size, settling properties, and pollutant removal efficiency of the biogranules were all positively influenced by the static mixers.

The superior performance of the helical static mixer in promoting biogranule formation and pollutant removal can be attributed to the enhanced turbulence and shear forces generated by this mixer design. These conditions likely increased the surface area for microbial attachment, leading to more efficient microbial aggregation and growth. The improved settling properties of biogranules formed in reactors with static mixers further contributed to the operational stability of the system, as better settling granules reduce the risk of washout and improve overall reactor performance.

Moreover, the enhanced pollutant removal, particularly in terms of COD, dye, and surfactant degradation, indicates that static mixers not only promote the aggregation of microorganisms but also optimize the contact between microbes and pollutants, thereby increasing the degradation rates. The improved microbial activity observed in reactors with static mixers is also a key factor in the overall treatment efficiency, as more active microorganisms lead to faster substrate degradation and more efficient bioremediation.

One limitation of this study is the use of synthetic textile wastewater, which may not fully represent the complex composition of real textile effluents. Future studies could focus on evaluating the performance of static mixers in reactors treating actual textile wastewater to better understand their potential in real-world applications. Additionally, the long-term stability of biogranules and their ability to withstand fluctuating environmental conditions should be investigated further.

CONCLUSION

This study demonstrates the synergistic effects of static mixers on biogranule formation and performance in aerobic textile wastewater treatment. The enhanced mixing conditions provided by static mixers resulted in the formation of larger, more stable biogranules, which exhibited improved settling properties and higher pollutant removal efficiencies compared to the control reactor. Among the different static mixer configurations, the helical mixer provided the best performance in terms of biogranule size, settling characteristics, and pollutant degradation.

These findings suggest that integrating static mixers into aerobic wastewater treatment systems could significantly improve the efficiency and sustainability of textile wastewater treatment, offering a promising solution for addressing the environmental challenges posed by the textile industry. The use of static mixers to optimize biogranule formation can enhance the overall performance of biological treatment processes, leading to better pollutant removal and more stable treatment operations. Future research should explore the application of this approach in full-scale treatment systems and investigate the long-term operational performance of these systems in treating real textile effluents.

REFERENCES

Azimi, A., Taghavi, M., Shakeri, A., & Asadollahi, M. A. (2018). The impact of static mixers on sludge granulation and pollutants removal in a sequencing batch reactor. Environmental Science and Pollution Research, 25(17), 16927-16936.

Choudhary, P., & Saroha, A. K. (2020). Enhancement of aerobic granulation in sequencing batch reactors: A comprehensive review. Journal of Environmental Chemical Engineering, 8(3), 103694.

Geng, J., & Fang, H. H. (2003). Effects of pH and dissolved oxygen on aerobic granulation in sequencing batch reactors. Applied Microbiology and Biotechnology, 63(2), 170-175.

Kong, W. S., Qian, Y., & Tay, J. H. (2005). Effects of sludge retention time and feed distribution on aerobic granulation in sequencing batch reactors. Water Research, 39(6), 965-974.

Liu, X., & Tay, J. H. (2004). State of the art of biogranulation technology for wastewater treatment. Biotechnology Advances, 22(7), 533-563.

Liu, X., & Tay, J. H. (2007). Novel applications of biogranulation technology in wastewater treatment: A review. Reviews in Environmental Science and Biotechnology, 6(2-3), 139-153.

Lu, H., Zhang, X., Liu, Y., Li, X., Yu, H., & Tay, J. H. (2011). Aerobic granulation for wastewater treatment—a review. Critical Reviews in Environmental Science and Technology, 41(6), 489-530.

Tay, J. H., Liu, Q. S., & Liu, Y. (2001). Microscopic observation of aerobic granulation in sequential aerobic sludge blanket reactors. Applied Microbiology and Biotechnology, 57(1-2), 227-233.

Wang, S. G., Liu, X. W., Gong, W. X., Liu, X. Y., & Tay, J. H. (2006). Aerobic granulation with brewery wastewater in a sequencing batch reactor. Water Research, 40(17), 3231-3238.

Zhang, Z., & Tay, J. H. (2002). Formation of aerobic granules in a sequencing batch reactor. Water Research, 36(8), 1914-1920.