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Optimizing Sequencing Batch Reactor (SBR) and Constructed Wetland Technologies

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ABSTRACT

Urbanization and industrialization bring economic growth but also pose significant challenges, particularly in environmental sustainability and public health. One pressing issue in developing regions is the inadequate infrastructure for wastewater treatment, which leads to environmental degradation and health risks. The Yamuna Expressway Industrial Development Authority (YEIDA), responsible for managing the development along the Yamuna Expressway in Uttar Pradesh, India, faces the challenge of balancing economic growth with sustainable development. This research investigates the implementation of a Sequencing Batch Reactor (SBR) Sewage Treatment Plant (STP) for the village of Abadi in Jewar Banger, under the jurisdiction of YEIDA, to address wastewater management issues in the area. The study explores the application of SBR technology, known for its operational flexibility, cost-effectiveness, and environmental sustainability, to provide efficient wastewater treatment in regions with growing populations and industrial activities. The research outlines the design and implementation of an integrated system combining SBR and submerged constructed wetlands, along with UV disinfection to ensure the effective removal of pollutants. This holistic approach aims to improve sanitation, public health, and environmental sustainability in the village. The study will also assess the operational efficiency, pollutant removal capabilities, and long-term sustainability of the system, offering a model for future infrastructure projects in similar regions. By focusing on the specific needs of resettled populations and leveraging advanced wastewater treatment technologies, this research contributes to sustainable urbanization and highlights the importance of incorporating community-specific solutions in infrastructure planning.

Keywords: Sequencing Batch Reactor (SBR), Wastewater Treatment, Nutrient Removal, Industrial Wastewater, Energy Efficiency

INTRODUCTION

Urbanisation and industrial development have both positive and negative impacts. While they bring economic benefits, they also present challenges in terms of environmental sustainability and public health. In numerous developing regions, the rapid growth of cities surpasses the progress made in constructing necessary infrastructure, such as waste-water treatment facilities. Environmental degradation and public health issues can arise from the insufficient management of sewage and industrial effluents, which is a common consequence of this imbalance. Yamuna Expressway Industrial Development Authority (YEIDA), like many other organisations, is facing the challenge of finding a balance between economic growth and sustainable development.

Yamuna Expressway Industrial Development Authority (YEIDA) was created to manage and govern the Yamuna Expressway Industrial Development area, which includes multiple districts in Uttar Pradesh, India. The main goal of the Authority is to support and promote the organised growth of industrial, residential, and commercial areas along the Yamuna Expressway. This Expressway is a major infrastructure project that links Greater Noida with Agra.

The primary objective of this Expressway is to improve connectivity and stimulate economic activities, while also encouraging sustainable urbanisation in the region. Yamuna Expressway Industrial Development Authority (YEIDA) is responsible for the development of new townships, industrial clusters, and commercial hubs. This requires a strong infrastructure to accommodate the increasing population and industries. Ensuring the rehabilitation and resettlement of villages affected by these developments is a vital aspect of Yamuna Expressway Industrial Development Authority (YEIDA)'s responsibilities. Abadi in Jewar Banger is a village where the Authority is dedicated to providing necessary amenities, such as an efficient sewage treatment system, to ensure the well-being of its residents.

REVIEW OF LITERATURE

The treatment of wastewater, particularly in complex and high-strength waste streams, is a critical aspect of modern environmental engineering. Over the years, various biological and chemical processes have been developed to address the challenges posed by pollutants such as organic compounds, nutrients, and pharmaceuticals. This literature chapter explores several advanced treatment methodologies, with a primary focus on anaerobic and aerobic systems, including Sequencing Batch Reactors (SBR), Anaerobic Sequencing Batch Reactors (AnSBR), and other innovative technologies such as non-thermal plasma and solar photocatalytic systems.

Ahmadi et al. (2023) investigated the enzymatic biodegradation of amoxicillin (AMX) in wastewater using a catalase-positive bacterial consortium stimulated by hydrogen peroxide (H2O2) in a sequential batch reactor. The bacterial consortium, including species such as Pseudomonas spp., Bacillus spp., and Klebsiella oxytoca, was acclimatized to AMX over a 12-day period. The study achieved a remarkable AMX removal rate of 99.6% after 25 days. However, when the initial AMX concentration was increased, the removal efficiency decreased to 90.3%. The enzymatic degradation process followed the Michaelis-Menten model, showing a high correlation ($R^2 = 0.999$), and produced a sludge volume index of 71 mL/g with a total solid content of 10.2 g/L. The results demonstrate the system's effectiveness in removing high concentrations of AMX from wastewater, highlighting the key role of the bacterial species in the degradation process.[22]

Christiaens et al. (2022) explored amyloid adhesin production in activated sludge using lab-scale reactors operated in sequencing batch mode. The study examined how various feeding regimes influenced the microbial community and amyloid distribution. Results showed that lab-scale reactors produced more amyloids than full-scale systems, with the distribution of amyloids transitioning from clustered to dispersed under continuous aerobic feeding conditions. Despite this shift, the dispersed amyloids did not negatively impact bioflocculation performance. Additionally, the abundance of denitrifiers increased with more continuous feeding, and Zoogloea and Candidatus Competibacter were identified as potential amyloid producers. Thioflavin T (ThT) staining confirmed increased amyloid adhesin production, and the microbial community dynamics were found to influence nitrogen removal efficiency. The study highlights how feeding regimes can significantly affect both amyloid production and microbial community composition in activated sludge, without detrimentally affecting sludge performance.[23]

Fan et al. (2021) conducted a study on achieving enhanced biological phosphorus removal (EBPR) by utilizing waste activated sludge (WAS) as a carbon source. The researchers enriched Tetrasphaera bacteria, achieving a 91.9% abundance in a sequencing batch reactor. This approach not only resulted in complete removal of PO4 3−-P but also significantly improved sludge reduction, with an efficiency rate of approximately 44.14%. The study revealed that Tetrasphaera outperformed traditional methods by better hydrolyzing slowly biodegradable organics, leading to more efficient resource utilization. Additionally, the findings highlighted that cell death and lysis contributed to the observed sludge reduction. By leveraging WAS as a carbon source, the process also led to reduced operational costs in wastewater treatment systems. The research clarified the mechanisms behind phosphorus removal and sludge reduction, offering a sustainable approach to improving wastewater treatment processes.[24]

Jagaba et al. (2024) compared two kinetic models, the Modified-Kincannon and Grau second-order models, with the Grau model showing a higher correlation for COD removal. The granulation process significantly influenced the microbial community dynamics, with high influent strength not reducing heterotrophic activity. The hybrid-SBR system maintained an average COD removal efficiency of 97.9%, although increasing cycle time resulted in a modest performance decline. This system effectively treated HSDW with minimal sludge production and energy consumption, highlighting the importance of cycle duration and OLR in SBR design for water purification and reuse, which is critical in addressing water scarcity issues.[25]

Kim et al. (2011) carried out a comparative study on the co-digestion of sewage sludge using a Thermophilic-Phase Anaerobic Sequencing Batch Reactor (TPASBR) system, The thermophilic stage significantly improved the system's stability and methanogen performance, making TPASBR more effective than conventional systems, though further optimization and economic analysis are recommended for practical implementation.[26]

Kumar et al. (2022) studied the anaerobic treatment of dye-bearing water, focusing on Acid Red 3BN dye (AR3BNDW) and mixed dye water (MDW). The treatment was conducted using a sequential batch reactor (SBR) with microorganisms sourced from maize processing wastewater treatment. The study achieved significant reductions, with AR3BNDW showing 87% color reduction and 82.8% chemical oxygen demand (COD) reduction, while MDW showed 84.5% color reduction and 79.42% COD reduction. The initial hours of treatment exhibited higher reduction rates, and the optimal hydraulic retention time (HRT) was determined to be 2.5 days. The pH decreased initially but later stabilized at 6.7. The second-order Grau model provided a good fit for the reductions observed. The anaerobic SBR was found to be effective in degrading dye-bearing water, and the treated water was deemed suitable for discharge or irrigation purposes.[27]

Sadaf et al. (2022) conducted a study focused on the treatment of slaughterhouse wastewater using the Sequencing Batch Biofilm Reactor (SBBR) system. The research tested various aeration cycles and hydraulic retention times (HRT) to optimize pollutant removal. Post-anoxic phase denitrification proved to be more effective than pre-anoxic, contributing to enhanced treatment performance. The optimal operating conditions for COD removal were found to be at 5200 mg/L with an 18-hour HRT. Additionally, the use of recycled biocarriers within the SBBR system shows promising results for potential commercialization, suggesting that this technology could be widely adopted for slaughterhouse wastewater treatment.[28]

Overview of the SBR process:

- Waste-water is added to the SBR tank, maintaining a suitable balance of food and microorganisms.
- During the process of aeration, pollutants like ammonia and BOD are broken down by microorganisms. The effectiveness is influenced by the mass of the sludge and the duration of aeration [5].

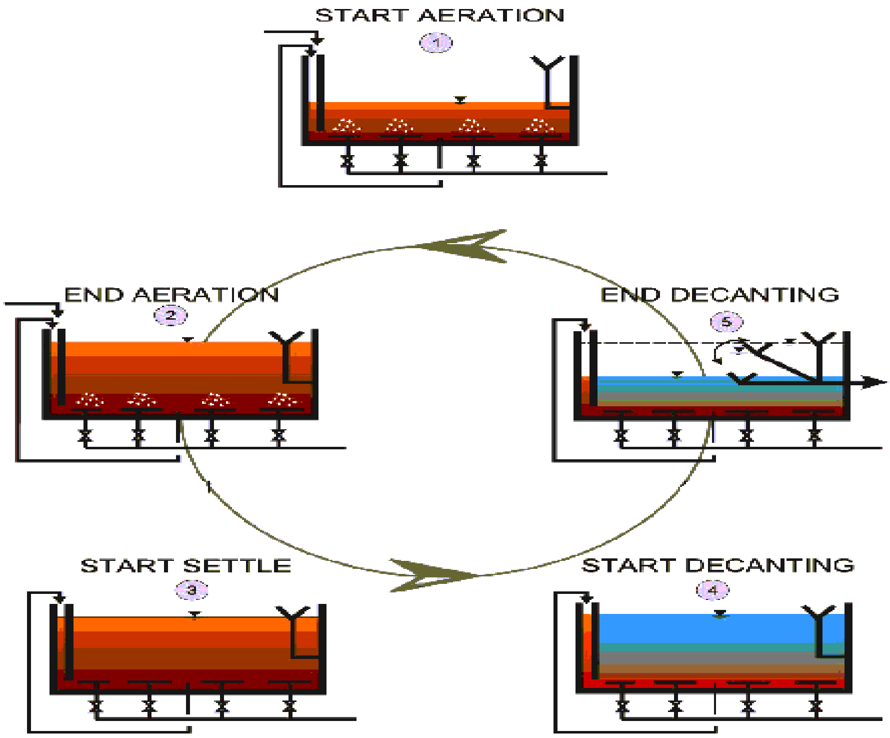

Figure 1: SBR Process

- Settling occurs when aeration is halted, which enables the sludge to gradually settle at the bottom of the tank.
- Effluent is removed from the tank without disturbing the settled sludge during the decanting process.
- The waiting period that takes place between filling cycles.
  Excess sludge is removed from the system once it exceeds the threshold limit through a process known as sludge wasting.
- Efficient purification of waste-water is ensured through a systematic sequence of actions.

CONCLUSION

Sequencing Batch Reactor (SBR) technology continues to demonstrate its versatility and effectiveness as a wastewater treatment method, capable of addressing the complex demands of both municipal and industrial effluents. Its ability to customize treatment processes within a single reactor cycle makes it particularly suited to environments with fluctuating wastewater characteristics. Despite the challenges associated with its operation, including the need for skilled personnel and the management of operational issues like foaming and sludge bulking, SBR technology remains a valuable tool in modern wastewater management.

As environmental regulations become more stringent and the need for sustainable treatment solutions grows, SBR technology is poised for further advancements. Future developments are likely to focus on enhancing energy efficiency, integrating real-time monitoring and automated control systems, and improving nutrient and pollutant removal capabilities. By addressing these areas, SBR technology will continue to evolve, playing a critical role in the future of wastewater treatment and contributing to the broader goals of environmental protection and resource recovery.

REFERENCES

[1]. Q. Zhao et al., "Comparison study on enhancement of phosphorus recovery from low-strength wastewater treated with different magnesium-based electrochemical constructed wetland," J. Environ. Manage., vol. 345, 2023, doi: 10.1016/j.jenvman.2023.118840.

[2]. C. Wang et al., "Strengthen high-loading operation of wastewater treatment plants by composite micron powder carrier: Microscale control of carbon, nitrogen, and sulfur metabolic pathways," Sci. Total Environ., vol. 904, 2023, doi: 10.1016/j.scitotenv.2023.166593.

[3]. H. S. Tran, N. T. T. Viet, T. H. Duong, L. H. Nguyen, and K. Kawamoto, "Autoclaved aerated concrete grains as alternative absorbent and filter media for phosphorus recovery from municipal wastewater: A case study in Hanoi, Vietnam," Environ. Technol. Innov., vol. 31, p. 103175, 2023, doi: 10.1016/j.eti.2023.103175.

[4]. H. Fernandes, M. K. Jungles, H. Hoffmann, R. V. Antonio, and R. H. R. Costa, "Full-scale sequencing batch reactor (SBR) for domestic wastewater: Performance and diversity of microbial communities," Bioresour. Technol., vol. 132, pp. 262–268, 2013, doi: 10.1016/j.biortech.2013.01.027.

[5]. T. Saeed, A. K. Yadav, R. Afrin, P. Dash, and M. J. Miah, "Impact of the electrode, aeration strategies, and filler material on wastewater treatment in tidal flow wetlands," Bioresour. Technol. Reports, vol. 24, 2023, doi: 10.1016/j.biteb.2023.101596.

[6]. X. Zou et al., "Shear bond strength in repaired concrete structures," Constr. Build. Mater., vol. 26, no. 1, pp. 1–8, Mar. 2020, doi: 10.1016/j.engstruct.2020.110746.

[7]. A. Singh, A. Srivastava, D. Saidulu, and A. K. Gupta, "Advancements of sequencing batch reactor for industrial wastewater treatment: Major focus on modifications, critical operational parameters, and future perspectives," J. Environ. Manage., vol. 317, p. 115305, 2022, doi: https://doi.org/10.1016/j.jenvman.2022.115305.

[8]. F. Rehman, A. Pervez, B. N. Khattak, and R. Ahmad, "Constructed Wetlands: Perspectives of the Oxygen Released in the Rhizosphere of Macrophytes," Clean - Soil Air Water, vol. 45, no. 1, 2016, doi: 10.1002/clen.201600054.

[9]. A. Stefanakis, "The Role of Constructed Wetlands as Green Infrastructure for Sustainable Urban Water Management," Sustainability, vol. 11, no. 24, p. 6981, 2019, doi: 10.3390/su11246981.

[10]. H. Wu et al., "A Review on the Sustainability of Constructed Wetlands for Wastewater Treatment: Design and Operation," Bioresour. Technol., vol. 175, pp. 594–601, 2015, doi: 10.1016/j.biortech.2014.10.068.

[11]. A. Stefanakis, "Constructed Wetlands for Sustainable Wastewater Treatment in Hot and Arid Climates: Opportunities, Challenges and Case Studies in the Middle East," Water, vol. 12, no. 6, p. 1665, 2020, doi: 10.3390/w12061665.

[12]. X. Wei et al., "Comparative study of efficiencies of purification of cadmium contaminated irrigation water by different purification systems," Sci. Total Environ., vol. 907, 2024, doi: 10.1016/j.scitotenv.2023.167941.

[13]. M.-K. Nguyen et al., "Occurrence, fate, and potential risk of pharmaceutical pollutants in agriculture: Challenges and environmentally friendly solutions," Sci. Total Environ., vol. 899, 2023, doi: 10.1016/j.scitotenv.2023.165323.

[14]. L. Jia, E. Gou, H. Liu, S. Lu, S. Wu, and H. Wu, "Exploring Utilization of Recycled Agricultural Biomass in Constructed Wetlands: Characterization of the Driving Force for High-Rate Nitrogen Removal," Environ. Sci. Technol., vol. 53, no. 3, pp. 1258–1268, 2019, doi: 10.1021/acs.est.8b04871.

[15]. Q. Cai, C. Lai, and P. Yang, "Biomass yield characteristics and removal kinetic model construction with mass transfer optimization of a moving bed and constructed wetland (MBCW) integrated bioreactor," Biochem. Eng. J., vol. 200, 2023, doi: 10.1016/j.bej.2023.109085.

[16]. N. Deng, "Assembly Processes of Rhizosphere and Phyllosphere Bacterial Communities in Constructed Wetlands Created via Transformation of Rice Paddies," Front. Microbiol., vol. 15, 2024, doi: 10.3389/fmicb.2024.1337435.

[17]. A. Adhikary, S. Mondal, J. Gantait, S. Pal, and S. Ghosh, "Evaluation of Lightweight Expanded-Clay Aggregates as Bed Material in Constructed Wetlands for Attenuation of Antibiotics," J. Environ. Eng. (United States), vol. 149, no. 11, 2023, doi: 10.1061/JOEEDU.EEENG-7368.