Simultaneous Carbon and Nitrogen Removal in a Pilot-Scale Structured Bed Reactor with Intermittent Aeration: Real Domestic Sewage Treatment

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Highlights:

- The pilot-scale SBRIA effectively removes nitrogen and carbon, meeting environmental parameters in Brazil
- Intermittent aeration creates conditions for simultaneous nitrification and denitrification, resulting in efficient total nitrogen removal.
- The SBRIA operated stably with a 10-hour HRT and an aeration cycle of 3 hours (2 hours aerated, 1 hour non-aerated).

Keywords: Simultaneous carbon and nitrogen removal; Pilot-scale structured bed reactor with intermittent aeration, domestic sewage treatment

INTRODUCTION

Nitrogen removal from sanitary sewage is essential because the unregulated release of these compounds into water ecosystems causes severe environmental consequences, such as eutrophication. In developing nations like Brazil, treatment plants often prioritize the removal of organic matter, placing less emphasis on eliminating nitrogen compounds (Barbosa et al., 2024; Oliveira et al., 2022). Thus, to prevent pollution, meet environmental regulations and reduce operational costs, it is crucial to develop a bioreactor capable of simultaneously removing carbon and nitrogen in a single system.

The structured bed and intermittent aeration reactor (SBRIA) is an innovative and cost-effective technology (Barbosa et al., 2024; Oliveira et al., 2022). Despite promising results in nitrogen removal in bench-scale studies (Moura et al., 2018, Oliveira et al., 2022, Santos et al., 2016), SBRIA rarely has been explored at full scale. Therefore, investigating the operational parameters and dynamics of SBRIA at the pilot scale for sanitary sewage treatment is crucial. By addressing these challenges, this study contributes directly to the development of more efficient and scalable solutions for sanitary sewage treatment, aligning with sustainability and environmental regulations.

This study aims to explore the simultaneous removal of organic matter and nitrogen in SBRIA system, with the objective of advancing both its technological and commercial application.

METHODOLOGY

The pilot-scale SBRIA was operated at room temperature for 454 days following preliminary treatment at the Bortolan wastewater treatment plant in Poços de Caldas. The SBRIA was constructed as a cylindrical fiberglass vessel with a diameter of 1.8 m and a working height of 4.95 m. Inside, four 1.0 m modules containing 30x30 mm prismatic polyurethane foam structures were installed, achieving a working volume of 8.37 m^3 and a bed porosity of 66%. The reactor maintained a hydraulic retention time (HRT) of 10 hours, utilizing a 3-hour intermittent aeration cycle (2 hours aerated, 1 hour non-aerated).

Treated sanitary sewage samples were analyzed according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2023). Total nitrogen (Total-N) removal, nitrification and denitrification efficiencies were calculated using TKN (Total Kjeldahl Nitrogen) in the influent and effluent when available. If TKN data were not available or if NH_4^+ (ammonium) concentrations exceeded TKN values, calculations were based solely on NH_4^+ measurements. A post-sedimentation unit was simulated by measuring COD after allowing the sample to settle for 3 minutes (COD_sed removal) to estimate the improvement in COD removal.

RESULTS AND CONCLUSIONS

The observed mean efficiencies of Total-N removal, nitrification, denitrification, COD removal and COD_sed removal are presented in Figure 1. The Total-N removal efficiency achieved a mean value of 55 ± 23%, without requiring an external carbon source. The mean nitrification and denitrification efficiencies were 65 ± 24% and 82 ± 21%, respectively. While the denitrification efficiencies were similar to the mean values reported in bench-scale studies (Santos et al., 2016; Moura et al., 2018; Oliveira et al., 2022), the nitrification and total-N removal efficiencies were reduced. This indicates that upscaling led to changes in the quality of the final effluent, as also reported by Barbosa et al. (2024). Future work should prioritize refining operational strategies to improve nitrification performance while mitigating the negative impacts of upscaling the SBRIA. This would involve optimizing key parameters such as hydraulic retention time (HRT), aeration duration and aeration flow rates to optimize nitrification process without compromising denitrification efficiency. The same was observed for COD removal, which was 56 ± 23%. Hence, the use of a post-sedimentation unit can improve the SBRIA's performance in COD removal to 85 ± 15%, closer to the reported studies in bench-scale (Moura et al., 2018; Oliveira et al., 2022). In contrast to conventional activated sludge systems, SBRIA produces minimal solids, requiring a smaller clarifier, thereby maintaining low operational costs. The results demonstrate the significant potential of SBRIA for technological applications in wastewater treatment, particularly in the nitrification and denitrification stages. This method integrates both processes in a single reactor, improving treatment efficiency while reducing costs and optimizing space use. As a cost-effective technology, SBRIA is especially suited for developing countries like Brazil, as it enables efficient carbon and nitrogen removal with lower energy consumption and maintenance costs, key factors in wastewater treatment. However, further exploration of reactor operating parameters and biological interactions during the treatment process is essential to replicate the high removal efficiencies observed in bench-scale experiments and ensure consistent performance at larger scales.

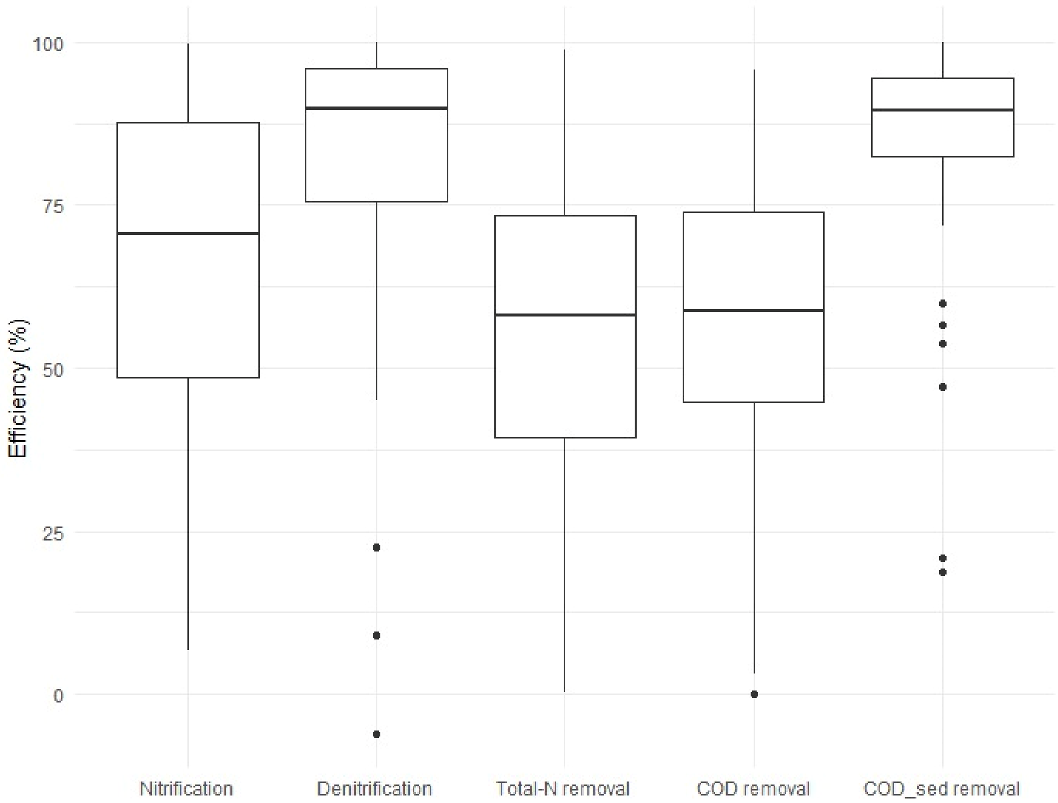

Figure 1 – Mean efficiencies of Total-N removal, nitrification, denitrification, COD removal and COD_sed removal

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