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Optimisation of high rate algal ponds performance for post-treatment of upflow anaerobic sludge blanket reactor effluents

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Highlights:

- High Rate Algal Ponds offers a promising solution for sewage treatment in tropical areas.
- Calibrated model suggests 6-day HRT as an optimal trade-off for quality effluent.
- Practical guidelines emerge for implementing UASB+HRAP in tropical regions.

Keywords: Anaerobic digestion; Decision-making support; HRAP biokinetic modelling.

INTRODUCTION

Sanitation remains a critical health and environmental challenge in developing countries. In Brazil, only 45% of the population receives wastewater treatment before discharge. Anaerobic treatments like UASB reactors are popular in tropical regions due to their low capital and operational costs. UASB reactors efficiently remove organic matter and suspended solids, producing biogas for heating or electricity. However, the effluent from UASB reactors requires further treatment to meet discharge standards, necessitating a post-treatment step.

High Rate Algal Ponds (HRAPs) have been studied as a post-treatment for UASB reactor effluents in tropical climates (Vassalle et al 2020). HRAPs utilize the symbiotic relationship between microalgae and bacteria, where microalgae absorb nutrients and produce oxygen, facilitating the degradation of organic matter by bacteria. Environmental factors like light intensity and temperature significantly influence HRAP performance. Despite promising initial results, there is limited research on combining UASB reactors with HRAPs, especially under tropical conditions, and no full-scale implementations exist.

Combining UASB reactors with HRAPs offers several advantages, including enhanced organic matter removal, nutrient assimilation by microalgae, and increased biogas production through co-digestion. Mathematical biokinetic models, such as BIO_ALGAE (Solimeno et al 2017;2019), help optimize these processes. This study aims to provide guidelines and tools for designing and optimizing HRAPs for UASB effluent treatment in tropical regions, using experimental data and simulations to assess system performance and scaling up.

METHODOLOGY

The experimental setup involved a UASB reactor followed by two HRAPs operating in parallel and a settling tank for biomass harvesting, fed with real wastewater from a full-scale WWTP in Brazil. Wastewater underwent pre-treatment for coarse solids and grit removal before being pumped into the UASB reactor. The UASB reactor had a working volume of 343 L and operated at a flow rate of 50 L/h with a hydraulic retention time (HRT) of 7 hours. The HRAPs, each with a useful volume of 205 L and a surface area of 0.41 m², operated at a flow rate of 25.5 L/d and an HRT of 8 days. The system operated continuously for over a year, with microalgal biomass harvested daily and recirculated back into the UASB reactor.

To assess the efficiency of wastewater treatment, samples were collected twice weekly from various points: raw wastewater, UASB reactor effluent, HRAPs, and settler effluent. Parameters such as pH, temperature, dissolved oxygen, COD, total and volatile suspended solids, total nitrogen, ammonium, nitrite, nitrate, and orthophosphate were analyzed. The harvested microalgal biomass was also characterized. Biogas production and composition were monitored from the UASB reactor. Analytical methods included in-situ measurements, ion chromatography, and standard methods for water and wastewater examination.

The BIO_ALGAE model was calibrated using experimental data to simulate the performance of HRAPs treating UASB reactor effluent under tropical conditions. Key parameters were adjusted to achieve an accurate match between simulated and experimental data. Various HRT scenarios (4, 6, and 8 days) were simulated to evaluate the impact on treatment efficiency, land requirements, and energy production. A multi-criteria decision-making method (TOPSIS) was used to determine the best operational strategy based on different priorities such as CAPEX, OPEX, land availability, and effluent quality. Statistical analysis was performed using the Wilcoxon test to compare the results of different scenarios, with significance evaluated at a 5% level.

RESULTS AND CONCLUSIONS

The study monitored the performance of a UASB reactor followed by HRAPs over 12 months, assessing the removal of pollutants such as organic matter, nutrients, and pathogens. The results indicated that the UASB-HRAP system achieved a total COD removal of 72%, with the UASB reactor contributing 55%. TSS and VSS removal efficiencies in the UASB reactor were 77% and 84%, respectively. HRAPs removed 57% of ammonium and 30% of orthophosphate.

The BIO_ALGAE model was calibrated using experimental data to simulate HRAP performance under various hydraulic retention times (HRTs) of 4, 6, and 8 days. The model accurately predicted the removal of COD, TSS, and nutrients, providing insights into the optimal operational conditions. Results showed that while a 4-day HRT led to the lowest ammonium removal, extending the HRT to 6 or 8 days significantly improved effluent quality without much difference between the two. Additionally, microalgal biomass production was higher at longer HRTs, but required more surface area.

A decision-making guide was developed to recommend the most appropriate HRT for HRAPs based on various scenarios, considering factors such as CAPEX, OPEX, land availability, and treatment priorities (Table 1). The guide indicated that while a 4-day HRT was sufficient for standard effluent quality and bioenergy production, a 6-day HRT was optimal for nutrient removal and microalgae agriculture, especially when space and investment were not constraints.

Table 1. Different HRT recommendations for system priorities.

Priority \ Area	Low CAPEX* and OPEX* capacity		High CAPEX* and OPEX* capacity	
	Medium availability	**High availability**	**Medium availability**	**High availability**
Standardized Effluent	4	4	4	4
Nutrients Removal	6	6	6	6/8
Fertilizer	4	4	4/6	6/8
Bioenergy production	4	4	4	4

Note: Numbers indicate the most appropriate HRT in each situation. *OPEX – Operational Expenditure; CAPEX – Capital Expenditure

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