Intermittent Mixing in High Rate Algal Ponds: Implications for Surfactant and Pathogen Removal

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Highlights:

- The removal efficiency of surfactants and *E. coli* was statically equal under conditions with continuous and intermittent agitation;
- HRAPs effectively removed the pollutants under study, achieving removal rates above 90% for surfactants and over 98% for pathogens;
- Intermittent mixing also did not negatively impact biomass growth, obtaining concentrations of 0.9 ± 0.5 gTSS L^{-1};

Keywords: Microalgae-bacteria system; Wastewater treatment; Circular bioeconomy.

INTRODUCTION

High rate algal pond (HRAP) characterized by a shallow and open design is a prominent technology of microalgae-bacteria systems for wastewater treatment. Key features of HRAPs are their exceptional efficiency, operational simplicity, scalability, and the advantage of recovering wastewater nutrients as harvestable algal and bacterial biomass for valuable products such as biofertilizers (Craggs, Sutherland, et al., 2012).

Additionally, one of the advantages is the low operating cost. Compared to conventional systems like Activated sludge, HRAPs consume significantly less electricity and there are patented models with even lower power requirements at less than 2 W/m³ (Acién Fernández, Gómez-Serrano, et al., 2018). The use of paddlewheels that ensure the mixing of the culture, preventing sedimentation of microalgae/bacteria flakes and facilitating enhanced nutrient diffusion across the cellular boundary layer, is the process with the second highest demand for energy consumption in HRAPs (Sutherland and Ralph, 2020; Kohlheb, van Afferden, et al., 2020).

Given the importance of the HRAP system, it is crucial to explore configurations that enhance performance and address existing gaps to confirm its viability for large-scale application. A potential area for exploration involves different mixing strategies, with the challenge of maintaining a homogeneous exposure of algae to light, thereby ensuring efficient nutrient removal and the elimination of other pollutants, such as pathogens and surfactants.

In this context, this study aimed to evaluate the effect of intermittent mixing on the removal of surfactants and pathogens from domestic sewage, potentially reducing costs without compromising performance.

METHODOLOGY

The experimental set-up consisted of two High Rate Algal Pond type reactors (R1 and R2) of 40 L with an illuminated surface area of 0.35 m^2 and hydraulic retention time (HRT) of 5 days. The HRAPs were agitated by a submersible pump (Sarlo Better B650, Brazil) with a nominal flow rate of 650 $L·h^{-1}$, ensuring a recirculation velocity of 20 ± 2 $cm·s^{-1}$. The operating configuration of the reactors was: R1 with constant agitation and R2 with agitation turned on in the period from 06:00 am to 06:00 pm. Secondary domestic wastewater was obtained from the septic tank of a sewage plant. A microalgae culture with 0.95 g L^{-1} of total suspended solids (TSS), coming from an HRAP and nitrifying-denitrifying activated sludge from a sewage treatment plant (WWTP), with 0.9 gTSS L^{-1} were used as inocula.

The anionic surfactant concentration was determined according to the simplified methodology developed by Jurado, Fernández-Serrano, et al (Jurado, Fernández-Serrano, et al., 2006). *E. coli* was detected using Colilert® kits (IDEXX Laboratories, Westbrook, ME, USA). Statistical analysis of the data was carried out using the software/programming language R. ANOVA analysis of variance was applied, followed by Tuckey's hypothesis test, using a confidence level of 95%.

RESULTS AND CONCLUSIONS

The experiment was conducted outdoors for 26 days, with average temperatures of 24.1 ±5ºC. In both reactors, the environmental conditions were quite similar, with pH levels greater than 9.0 and dissolved oxygen (DO) concentrations around 5.0 mg L^{-1}, as shown in Table 1. Intermittent agitation provided equivalent conditions for microalgae growth, achieving total suspend solids (TSS) concentrations of 0.9 ± 0.5 gTSS L^{-1}. This indicates that the reactor maintained homogeneous conditions for microalgae cultivation, mainly due to the active agitation maintained during periods of sun exposure.

Table 1- Results of pH, Dissolved oxygen (DO) concentration, cultivation broth temperature, biomass concentration and percentage of chemical oxygen demand (COD) removal in HRAPs with continuous mixing (R1) and with intermittent mixing (R2).

Reactors	pH	OD mg L^{-1}	Temperature ºC	TSS g L^{-1}	COD removal %
R1	9.7 ± 0.7	5.2 ± 1.0	23.7 ± 6	0.9 ± 0.5	59 ± 6
R2	9.9 ± 0.9	5.4 ± 0.9	23.3 ± 6	0.8 ±0.6	50 ± 5

The obtained removals of anionic surfactants were statically similar ($p > 0.05$) in the two mixing conditions with 89 ± 7 and 90 ± 6% for R1 and R2, respectively (Figure 1a). The final effluent concentrations were below 2 mg L^{-1} in both conditions tested. A similar result was obtained by Serejo, Farias, et al., (2020), whose removals varied between 90 and 97% when testing continuous and semi-continuous feeding regimes in Hraps of 20 L.

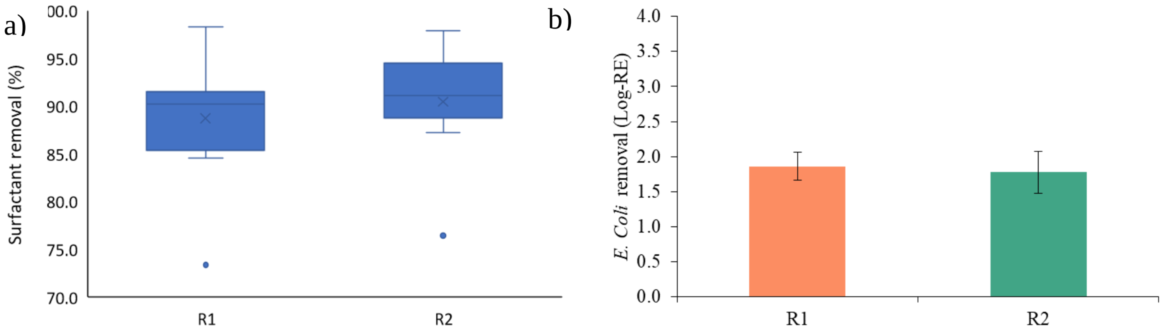

Figure 1- Removal efficiencies (average values and standard deviations): a) in percentages for surfactants (n=10); b) In logarithmic removal values (LRV) of Escherichia coli (n=5) in HRAPs R1- continuously mixed and R2- discontinuously mixed.

For pathogens, likewise, *E. coli* removals were significantly equal for both conditions, as show in Figure 1b. Under intermittent agitation (R2), the mean LRV (Log Removal Value) was1.9 ± 0.2, corresponding to a removal rate of 98.5 ± 0.5%. A similar result was found by Butterworth and Fallowfield, (2024), in an experiment evaluating the effect of cessation of mixing for 10 days, in which there was no significant difference in the *E. coli* LRVs between HRAP mixed continuously and discontinuously.

Lower performance was obtained in the removal of organic matter with average COD-Res percentages of 59 ± 6% for condition R1 and 50 ± 5% for the reactor with discontinuous mixture –R2, without a significant difference between them (Table 1). The final COD concentrations obtained are within the typical outflow values for HRAPs and below the limits established by discharge guidelines (Kohlheb, van Afferden, et al., 2020).

This study highlights the advantages of the HRAP system over conventional systems in terms of efficiency and operating costs (energy consumption). The results achieved in removing surfactants and pathogens, along with biomass growth in the discontinuously mixed condition, suggest that intermittent mixing could be a viable, energy-saving alternative without compromising the overall performance of the system.

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