Harvesting microalgae biomass from wastewater via electrocoagulation: Operational parameters and efficiency

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Highlights:

- Operating conditions (pH 6, 7, 8), time (3, 5, 7 min), and electric current (1, 3, 5 A) were assessed;
- The process performance was evaluated based on harvest efficiency and aluminum content;
- Highest harvesting efficiency (92.61%) achieved at pH 8, 5A electric current, and 7-minute operation time.

Keywords: Microalgae; Wastewater; Electrocoagulation.

INTRODUCTION

Microalgae biotechnology, a promising alternative that integrates nutrient recovery with wastewater treatment, faces a significant challenge in biomass harvesting. This challenge is due to the operational complexity, high energy consumption, and elevated costs associated with conventional methods (Pereira et al., 2024). However, these alternatives are slower processes, requiring chemical inputs that affect nutrient concentrations and increase salinity (Morais et al., 2023). In this context electrocoagulation (EC) technology emerges as a promising method for efficient, rapid, and low-energy consumption harvesting. The EC process, which occurs through the electrolytic oxidation of an anode, releases ions that neutralize the negative electrostatic charges on the microalgae surface, thus facilitating the harvesting (Lucakova et al., 2022). The efficiency of this method can be influenced by various factors, from operational parameters to the characteristics of the wastewater used. Therefore, the study aims to evaluate the performance of an EC reactor as a harvesting technology for microalgae cultivated in wastewater, investigating the impact of current intensity, reaction time, and pH on the process.

METHODOLOGY

The microalgal biomass (MB) was cultivated using domestic wastewater as the culture medium. This effluent was collected after passing through a septic tank at a wastewater treatment plant. MB production was carried out in batch mode in pilot-scale high-rate algae ponds (HRAPs). At the end of the batch, the treated domestic wastewater presented the following characteristics: 10.15 mg/L of dissolved oxygen; 679.62 µS/cm of electrical conductivity; pH of 8.66; 569.22 mg/L of chemical oxygen demand; 12.57 mg/L of ammoniacal nitrogen; and 6.34 mg/L of total phosphorus.

The EC system consisted of a set of parallel aluminum (Al 99.9%) plates, connected in series, along with a 32 V power supply (Hikari brand). The EC tests were performed to investigate the effect of operational parameters such as pH (6, 7, and 8), electric current (1, 3, and 5A), and reaction time (3, 5, and 7 minutes), totaling 27 experimental units. The sample pH was adjusted with 0.1 mol/L NaOH or 0.1 mol/L H_2SO_4. The performance of the electrocoagulation (EC) reactor was evaluated based on the aluminum content, following the methodology described in the Standard Methods for the Examination of Water and Wastewater (APHA, 2012) method 3500-Al B. The harvesting efficiency was assessed by measuring the optical density (OD) of the liquid phase at 750 nm using a spectrophotometer (Hach DR3800) before and after each experiment, following the procedure described by Parmentier et al. (2020).

The statistical analysis was conducted using Minitab® 17 software (trial version). A multivariate regression analysis was performed to determine the significance of the effects and their interactions, with a significance level of $\alpha = 0.05$. Contour plots were generated to visualize the effects of pH, electrolysis time, and current on the response variables: harvesting efficiency (HE) and aluminum content (AC).

RESULTS AND CONCLUSIONS

The results of the multivariate regression analysis are presented in Equations 01 and 02.

$$HE = 14.90 - 4.60\ pH + 33.26\ \text{Electric current} + 4.99\ \text{Time} - 3.63\ \text{Electric current}^2 \quad \text{Equation 01}$$

$$AC = 8.43 + 1.37\ pH - 0.38\ \text{Electric current} - 2.83\ \text{Time} + 0{,}24\ \text{Time}^2 \quad \text{Equation 02}$$

For the response variable HE ($R^2 = 94.49$ %, p-valor < 0.001), the analysis revealed that Electric Current was the main contributor to the model, explaining 79.03% of the variability, followed by Time with 17.73 %, and pH with 3.69 %. For the response variable AC ($R^2 = 64.26$ %, p-valor < 0.001), pH had the highest contribution, with 36.65 %, followed by Time (25.55 %) and Electric Current (14.99 %).

The statistical analysis results show significant variations in harvest efficiency and Al content as a function of time, current, and pH (Figure 1). It was found that shorter periods and lower currents result in less dissolution of Al electrodes. Consequently, this reduces effluent contamination and promotes energy savings, which are essential for the environmental and economic sustainability of the process. The highest harvesting efficiency (92.61%) was observed at pH 8, an electric current of 5A, and an operation time of 7 minutes. The harvesting efficiency of traditional methods can reach 85% for chemical flocculation and exceed 95% for centrifugation (Morais et al., 2023).

Although centrifugation is a fast and efficient method, its main limitation is the high energy consumption, along with operational and investment costs. Therefore, centrifugation is not employed, especially when the final product does not have a high market value. Therefore, sedimentation, flotation, and chemical coagulation are more economical alternatives, especially in the context of microalgae cultivated in wastewater. The search for emerging microalgae harvesting methods is the focus of numerous studies. Assis et al. (2020) proposed a hybrid reactor, composed of HRAP and a biofilm reactor, achieving a harvesting efficiency of 61%. Bioflocculation with fungi, evaluated by Shitanaka et al. (2023), reached a harvesting efficiency of 80–85% within 24 hours.

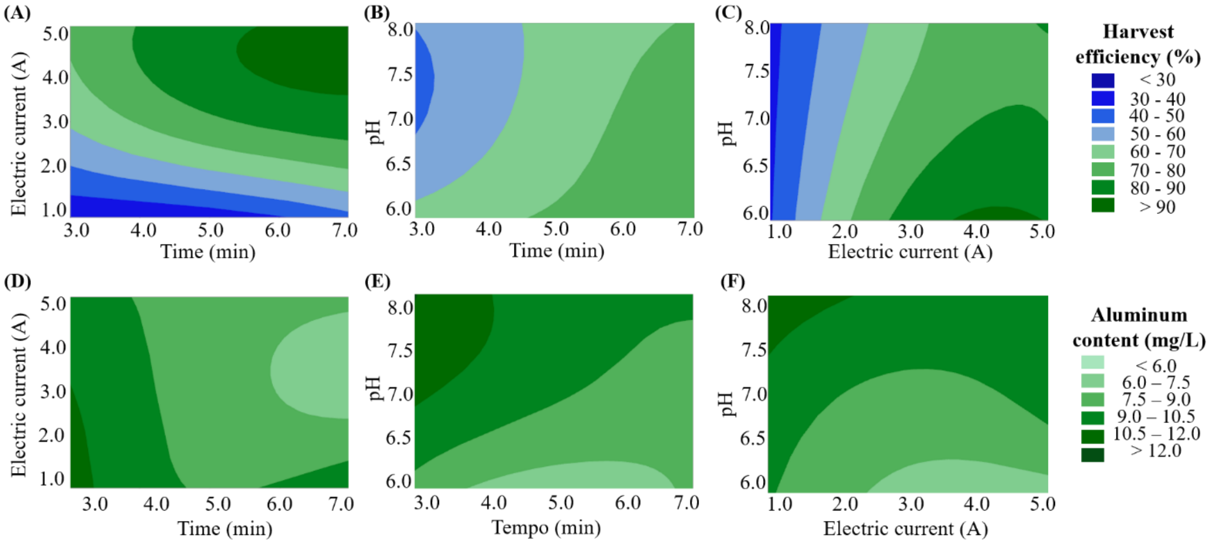

Figure 1. Electrocoagulation performance in terms of harvesting efficiency (A, B, and C) and aluminum content (D, E, and F) with respect to the parameters observed in the study (electric current, pH, and time).

Several studies have been conducted to evaluate the performance of EC in harvesting microalgae. Khatib et al. (2021) implemented a cylindrical arrangement of interconnected electrodes, which significantly intensified the reactor's electric field, minimized the Al electrode's passivation, and achieved a harvest efficiency of 96.18%. Lucakova et al. (2022) investigated the performance of a pilot-scale continuous EC reactor (with a working volume of 111 L and a flow rate of 240 L h^{-1}) for harvesting microalgae cultivated in synthetic medium. The authors observed high harvesting efficiency (> 85%), low contamination of the collected biomass, and significant energy savings.

The results of this research can drive the large-scale application of microalgae biotechnology and enhance the value of wastewater resources. The biomass generated from wastewater and harvested via EC is rich in valuable compounds like lipids, carbohydrates, proteins, making it suitable as raw material for biofertilizers and biofuels (Assis et al., 2020; Pereira et al., 2024). These by-products have the potential to make wastewater treatment more sustainable, both economically and environmentally.

Therefore, for the EC process, the analysis indicates that significant variations in harvest efficiency are directly related to time, current, and pH. Considering Al contamination, evidenced by the chemical reactions involved and the need to minimize the content of this metal, is crucial for operating strategies in reduced times and elevated pH. Thus, it is important to further the understanding of the interactions between the studied variables to enhance the efficacy of microalgae biomass harvesting and production.

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