

Evaluation of Operating Conditions for *Chlorella emersonii* Harvesting Using Electrocoagulation–Flocculation

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Abstract

*Efficient harvesting remains a major challenge for large-scale microalgae utilization because conventional separation methods can be energy-intensive and economically burdensome. This study evaluated electrocoagulation–flocculation (ECF) for harvesting *Chlorella emersonii* by examining electrode material, electrolysis time, current density, and electrode spacing. Harvesting performance was quantified by the decrease in optical density at 680 nm (OD_{680}); therefore, the reported endpoint is an OD-based apparent harvesting efficiency rather than a direct measurement of intact dry biomass recovery. Zn performed better than Cu and was selected for the subsequent sequential evaluation of operating conditions. The selected conditions were a Zn electrode, 60 min electrolysis, 4.5 mA cm⁻² current density, and 1 cm electrode spacing. Under these conditions, OD-based harvesting efficiency reached $90.35 \pm 0.15\%$, compared with $36.88 \pm 0.19\%$ after 60 min of gravitational sedimentation (mean $\pm$ SD of three recorded OD-derived measurements). The final measured pH at 4.5 mA cm⁻² was approximately 9.8. The observed clarification may be associated with in situ metal hydrolysis products, cell aggregation, and hydrogen-bubble-assisted flotation; however, cell integrity and absolute biomass concentration were not determined. These results identify the best-performing conditions within the tested range and provide a basis for future validation through gravimetric biomass measurements, cell-integrity measurements, energy consumption, and scale-up analysis.*

Keywords: *Chlorella emersonii*; microalgae harvesting; electrocoagulation–flocculation; OD_{680} ; zinc electrode.

Introduction

Microalgae have attracted considerable attention as sustainable biological resources due to their rapid growth, high photosynthetic efficiency, and capacity to produce proteins, lipids, carbohydrates, pigments, vitamins, and other bioactive compounds. These characteristics support applications in functional foods, nutraceuticals, pharmaceuticals, cosmetics, biofuels, and other bio-based products. Despite advances in cultivation technology, downstream harvesting remains one of the most demanding stages

because microalgal cells are small, settle slowly, and often possess negatively charged surfaces that promote colloidal stability and hinder aggregation and settling. Centrifugation, filtration, gravitational sedimentation, and chemical flocculation can separate biomass, but their practical use may be constrained by energy demand, membrane fouling, chemical addition, or scale-up limitations^[1–3].

Electrocoagulation–flocculation (ECF) is an electrochemical harvesting approach that integrates coagulation, flocculation, and flotation into a single batch operation. During

electrolysis, metal ions released from an electrode can undergo hydrolysis to form metal hydroxide/hydroxo species that promote destabilization and aggregation of negatively charged cells. Hydrogen bubbles generated at the cathode can simultaneously assist in the flotation of the aggregates. ECF performance depends on electrode material, electrolysis time, current density, conductivity, solution chemistry, and electrode spacing because these variables influence electrode dissolution, gas evolution, electrical resistance, and transport processes^[3-6].

Most electrochemical microalgae-harvesting studies have focused on commercially common species such as *Chlorella vulgaris*, whereas information for *Chlorella emersonii* remains limited ^[4-6]. Cu and Zn were selected for comparison because both have been investigated as electrocoagulation electrode materials and can show substantially different dissolution and hydrolysis behavior depending on the applied electrochemical conditions ^[5]. The novelty of the present work lies in the system-specific sequential evaluation of Cu and Zn electrode performance, along with electrolysis time, current density, pH evolution, and electrode spacing, for *C. emersonii*, followed by a same-duration comparison with gravitational sedimentation. Because the variables were evaluated sequentially rather than through a statistically designed multivariable model, the study identifies selected or best-performing conditions within the tested ranges rather than a global optimum.

Experimental

Materials

Chlorella emersonii was obtained from a stock culture maintained at the Biochemistry Laboratory, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Andalas, Indonesia. Bold Basal Medium (BBM) was prepared from the

documented stock formulation containing NaNO₃, MgSO₄·7H₂O, NaCl, K₂HPO₄, KH₂PO₄, CaCl₂·2H₂O, ZnSO₄·7H₂O, MnCl₂·4H₂O, CuSO₄·5H₂O, Co(NO₃)₂·6H₂O, EDTA–KOH solution, FeSO₄·7H₂O, and H₃BO₃. The medium was prepared according to the documented BBM stock-solution formulation used in this study.

Instrument

The ECF experiments used a laboratory-scale batch reactor equipped with a DC power supply (GPS-3030D), a magnetic stirrer, and two parallel rectangular metal plates. Cu and Zn plates measured 10 cm × 4 cm. One plate was connected to the positive DC terminal (anode), and the other to the negative terminal (cathode); the metal tested was Cu or Zn, depending on the experimental run. From the documented current/current-density pairs (0.05 A/1.5 mA cm⁻², 0.10 A/3.0 mA cm⁻², and 0.15 A/4.5 mA cm⁻²), the area used in the current-density calculation was approximately 33.3 cm². The exact immersed depth, electrode-cleaning procedure, solution conductivity, and experimental temperature were not documented in the archived records and are therefore not available for reconstruction. OD₆₈₀ was measured with a UV–Visible spectrophotometer (Genesys 20), and cell morphology was examined using a light microscope.

Method

Microalgae Cultivation

The prepared BBM was sterilized in an autoclave before inoculation; the archived records do not specify the autoclaving temperature, pressure, or duration. The documented culture preparation used 500 mL of BBM and a 50 mL inoculum of *C. emersonii*. Cultures were maintained autotrophically with continuous aeration for 24 days. Light intensity, photoperiod, and cultivation temperature were not recorded. Growth was followed every two days by OD₆₈₀. For these measurements, 3–4 mL

culture aliquots were transferred to a cuvette. No OD dilution factor, explicit blank-correction procedure, or calibration between OD₆₈₀ and dry biomass concentration was available in the archived documentation.

Electrocoagulation–Flocculation (ECF)

Harvesting tests were performed on day 24 using a laboratory-scale batch ECF system. Each ECF test used 500 mL of culture. The archived calculation sheets report an initial OD₆₈₀ of 1.033 (approximately 1.0) for the harvesting experiments. The ECF suspension was stirred at 100 rpm, and the DC power supply was set to 24 V. A separate 500 mL culture from the same experimental series was used as the gravitational sedimentation control and left to settle without electrical treatment or active ECF operation. For the initial electrode-material comparison, the interelectrode spacing was 1 cm.

Operating variables were evaluated sequentially. Electrode material was first screened using Cu and Zn, and a separate electrolysis time series was then evaluated at 20, 40, 60, and 80 min. Zn was carried forward to the current-density tests at 1.5, 3.0, and 4.5 mA cm⁻², corresponding to applied currents of 0.05, 0.10, and 0.15 A, respectively. OD-based harvesting efficiency was recorded at 20, 40, and 60 min for the current-density and electrode-spacing experiments. Solution pH was recorded at 20, 40, and 60 min. Electrode spacing was evaluated at 1, 3, and 5 cm using Zn, 60 min electrolysis, and 4.5 mA cm⁻². The initial pH was not reliably documented; the measured pH after 60 min at 4.5 mA cm⁻² was approximately 9.8. The main reactor configuration and operating conditions used in the ECF experiments are summarized in Table 1.

Determination of OD-Based Harvesting Efficiency

Harvesting performance was evaluated from the decrease in OD₆₈₀ of the suspension. The available experimental records define OD₀ as the initial optical density before treatment and OD_t as the optical density at treatment time *t*. Because no OD-to-dry-biomass calibration or quantitative post-treatment dry-mass measurement was documented, this metric is reported as OD-based apparent harvesting efficiency and should not be interpreted as direct proof of intact biomass recovery.

$$\text{HEOD (\%)} = [(\text{OD}_0 - \text{OD}_t) / \text{OD}_0] \times 100$$

HEOD is the OD-based apparent harvesting efficiency, OD₀ is the initial OD₆₈₀, and OD_t is the OD₆₈₀ measured at time *t*. The archived documentation does not specify the exact vertical position from which post-treatment aliquots were collected, nor does it document dilution or explicit blank correction; these limitations are reported rather than reconstructed. For the gravitational-sedimentation control, the same OD-based calculation was applied at 20, 40, and 60 min, and the 60-min result was used for direct comparison with the 60-min ECF treatment.

Data analysis

The operating variables were evaluated sequentially, with the best-performing tested condition carried forward to the next stage; no response-surface, factorial, or other multivariable optimization model was applied. The archived calculation sheets contain three OD-derived values for each harvesting condition. These are presented descriptively as mean ± standard deviation (SD), and error bars show the SD. Because the records do not establish whether the three values arose from independent experimental replicates or repeated

analytical measurements, no inferential statistical testing was performed. The pH series is presented as recorded. Missing historical metadata (including conductivity, exact

temperature, electrode cleaning, and exact sampling position) is explicitly identified as a limitation.

Table 1. ECF reactor configuration and operating conditions

Parameter	Recorded/derived condition
Reactor / operating mode	Laboratory-scale batch ECF; 500 mL culture; magnetic stirring at 100 rpm; DC power supply set to 24 V
Electrodes	Cu or Zn parallel plates, 10 × 4 cm; one anode (+) and one cathode (-)
Area for current-density calculation	≈33.3 cm ² , derived from the recorded current/current-density pairs
Electrode spacing	1 cm for initial screening; 1, 3, and 5 cm for spacing evaluation
Applied current / current density	0.05, 0.10, and 0.15 A / 1.5, 3.0, and 4.5 mA cm ⁻²
Electrolysis time	20–80 min in the time study; 60 min selected for subsequent tests
Undocumented variables	Conductivity, exact temperature, electrode-cleaning procedure, exact immersed depth, and initial pH were not reliably recorded

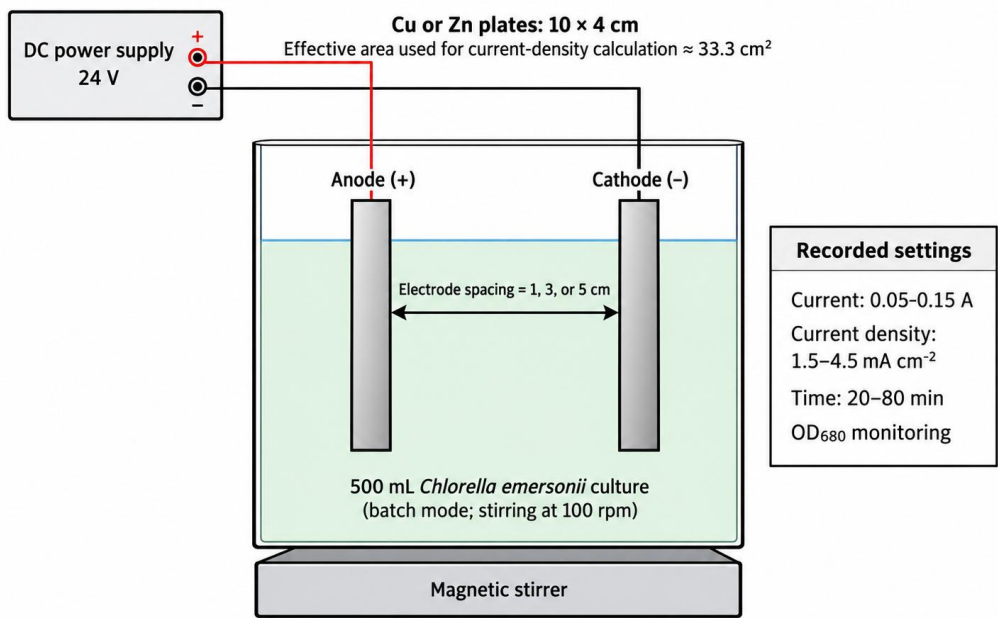


Figure 1. Schematic representation of the laboratory-scale batch ECF configuration

Result and Discussions

Morphological Characterization and Growth Profile of *Chlorella emersonii*

The morphology of *Chlorella emersonii* was examined prior to the electrocoagulation-flocculation (ECF) experiments to confirm that the cultivated cells exhibited the expected microscopic appearance. As shown in Figure 2, the cells were predominantly oval to nearly spherical, green in appearance, and relatively uniform in shape. These features are consistent with previous descriptions of *C. emersonii*. Perdana et al.^[7] reported coccoid cells measuring approximately 5–7 μm , whereas Yani et al.^[8] observed green, spherical cells of approximately 6 μm under light microscopy at 400 $\times$ magnification. A recent characterization of *Graesiella emersonii* (syn. *Chlorella emersonii*) similarly described green unicellular cells with spheroidal to ellipsoidal morphology^[9].

No obvious morphological abnormalities or large contaminating cells or particles were apparent at the resolution used in this study. This observation supports the morphological consistency of the culture used for the subsequent harvesting experiments. However, light microscopy alone cannot establish axenic purity or exclude low-abundance microbial

contaminants. Accordingly, microscopic observation is interpreted only as evidence that the culture showed the expected cellular morphology before ECF treatment rather than as proof of microbiological purity.

The growth profile of *Chlorella emersonii* was monitored by measuring OD₆₈₀ throughout the cultivation period (Figure 3). Optical density increased progressively during cultivation and reached the highest observed value on day 24, followed by a decline at the subsequent measurement. The gradual change in culture color from light green to darker green was also consistent with increasing optical density and cell accumulation during cultivation.

Growth of *C. emersonii* under cultivation conditions has previously been evaluated using optical density and cell density measurements^[7,8]. The post-maximum decline observed in the present series may reflect nutrient limitation, self-shading, or other physiological constraints, but these causes were not directly measured. Nevertheless, the day-24 OD maximum should not be interpreted as definitive evidence that the culture had reached a physiologically stable stationary phase. Optical density records light attenuation by the suspension and does not independently establish growth phase, cell viability, or dry biomass concentration.

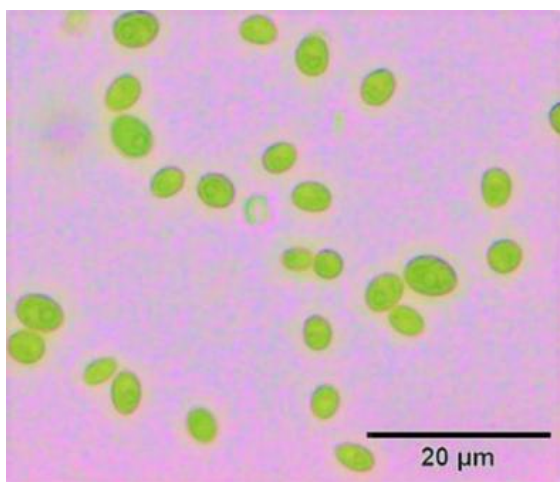


Figure 2. Light microscopic image of *Chlorella emersonii* cells cultivated in Bold Basal Medium (BBM) at 400 $\times$ magnification

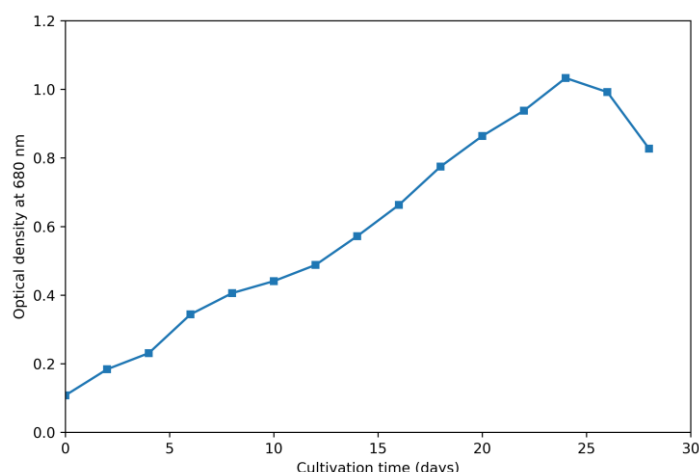


Figure 3. Growth profile of *Chlorella emersonii* cultivated in Bold Basal Medium (BBM), monitored as optical density at 680 nm (OD₆₈₀)

Day 24 was therefore selected as the harvesting point because it corresponded to the highest measured OD₆₈₀ across the available cultivation series and provided a sufficiently dense culture for evaluating the ECF process. This wording is deliberately restricted to the observed OD profile because no complementary cell count, chlorophyll, or dry weight measurements were available to verify the physiological growth phase.

Effects of Electrode Material and Electrolysis Time on OD-Based Harvesting

In a separate preliminary electrode-material screening conducted at 60 min, Zn produced a higher OD-based harvesting efficiency (68.47%) than Cu (41.66%), supporting the selection of Zn for subsequent experiments. The separate electrolysis-time series is presented in Figure 4. As shown in Figure 4, OD-based harvesting efficiency increased with electrolysis time for both Cu and Zn electrodes, while Zn consistently produced the higher response throughout the treatment period. For Zn, efficiency increased from 20.75% at 20 min to 47.76% at 40 min and 68.22% at 60 min, then increased only slightly to 68.34% at 80 min. For Cu, the corresponding efficiencies were 13.20%, 25.81%, 41.59%, and 41.69%, respectively. These results show that electrolysis time strongly

influenced OD clarification during the early and intermediate stages of treatment, whereas the additional benefit became minimal after 60 min.

The consistently higher response obtained with Zn in the time-course experiment was consistent with the preliminary screening result. However, the difference between Zn and Cu should be interpreted as system-specific rather than as evidence that Zn is universally superior. Previous electrochemical microalgae-harvesting studies have reported varying relative performance of Cu and Zn across species, medium composition, applied electrical conditions, and electrode configuration [5,10]. Thus, electrode chemistry interacts with the broader electrochemical environment rather than acting as an isolated determinant of harvesting performance.

The higher Zn response may be associated with differences in anodic dissolution, passivation, solution chemistry, mass transfer, and pH-dependent metal hydrolysis under the applied conditions. Although standard electrode potential can influence the tendency for anodic oxidation, the actual amount and form of dissolved metal also depend on current density, electrode surface condition, electrolyte composition, and passivation. Released Zn²⁺ can undergo hydrolysis to form zinc

hydroxide/hydroxo species that may promote cell destabilization and aggregation, while hydrogen bubbles generated at the cathode can assist flotation of the resulting aggregates [3,4,6]. Because the zinc-containing species were not directly characterized, the discussion does not specifically identify the coagulant as $\text{Zn}(\text{OH})_2$.

The increase from 60 to 80 min was only 0.13 percentage points for Zn and 0.10 percentage points for Cu. This very small increment indicates that the OD-based harvesting response approached a practical plateau within the tested time range. Extending electrolysis beyond the point of diminishing returns is expected to increase treatment duration and electrical input without providing a meaningful additional benefit in clarification. Consequently, 60 min was selected for subsequent experiments as the practical treatment time within the investigated range [4,6,11].

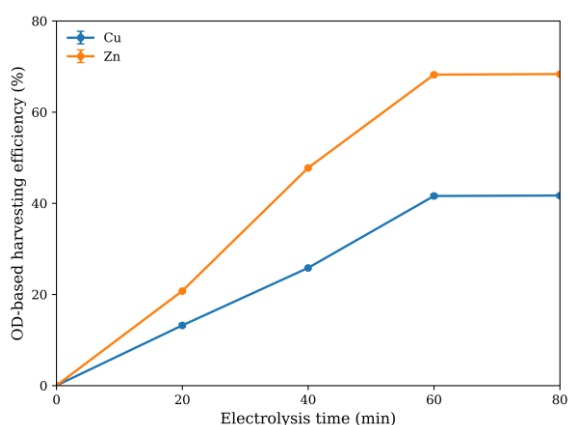


Figure 4. Effect of electrolysis time on the OD-based harvesting efficiency of *Chlorella emersonii* using Cu and Zn electrodes

Effect of Current Density on OD-Based Harvesting

Current density had a pronounced effect on the OD-based harvesting response (Figure 5). At 20 min, increasing current density from 1.5 to 3.0

and 4.5 mA cm^{-2} increased harvesting efficiency from approximately 20.75% to 30.53% and 35.85%, respectively. The same ordering was maintained at 40 and 60 min. After 60 min, harvesting efficiencies of 68.22%, 75.57%, and 90.35% were obtained at 1.5, 3.0, and 4.5 mA cm^{-2} , respectively. Thus, both treatment time and current density contributed to the progressive increase in OD clarification.

This trend is consistent with greater electrochemical activity at higher current density. According to Faraday's law, the amount of electrode material electrochemically transformed is proportional to the applied charge; consequently, increasing current can enhance anodic metal release and the formation of hydrolyzed metal species that contribute to cell destabilization and aggregation. Higher current density can also intensify cathodic hydrogen evolution, increasing the availability of gas bubbles that can assist the flotation of cell-containing flocs [3,4,6]. These simultaneous coagulation and flotation effects provide a mechanistically plausible explanation for the higher OD-based harvesting response at greater current density.

Nevertheless, 4.5 mA cm^{-2} was the highest current density examined in the present study. It should therefore be described as the best-performing current density within the tested range rather than as a true or global optimum. A higher current density may further improve harvesting performance, but it may also increase electrical energy demand, electrode consumption, residual metal loading, and process costs. Because the experiment did not extend above 4.5 mA cm^{-2} and did not use a statistically designed multivariable optimization, the location of a formal optimum cannot be established from the present dataset.

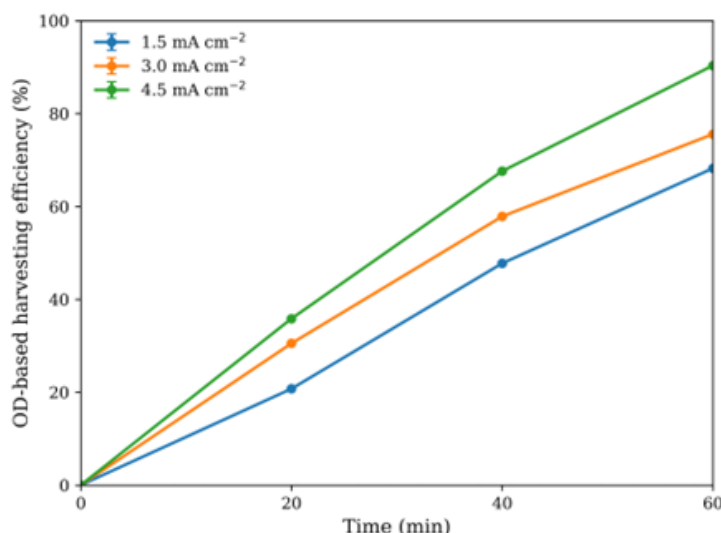


Figure 5. Effect of current density on the OD-based harvesting efficiency of *Chlorella emersonii* during electrocoagulation–flocculation

Effect of Current Density on Solution pH

Solution pH increased during electrolysis, and the increase was greater at higher current density (Figure 6). At 20 min, the recorded pH values were 7.1, 8.3, and 9.2 at 1.5, 3.0, and 4.5 mA cm⁻², respectively. After 40 min, the values increased to 7.3, 8.4, and 9.6; after 60 min, they reached 7.5, 8.5, and 9.8. The highest final pH was therefore observed under the same current-density condition that produced the highest OD-based harvesting response.

The rise in pH is consistent with cathodic water reduction, in which water is reduced to form hydrogen gas and OH⁻. Increasing current density increases the rate of electrochemical reactions and can therefore increase OH⁻ generation, leading to stronger alkalization of the suspension. At the same time, the evolving pH influences the hydrolysis and speciation of dissolved Zn, which can alter the abundance and behavior of zinc hydroxide/hydroxo species involved in cell aggregation [5,10,12]. Thus, pH is an important part of the electrochemical environment rather than an independent response that can be considered separately from current density.

Importantly, the association between higher pH and higher harvesting efficiency does not prove that pH alone caused the improvement in separation. In this experiment, pH was not independently adjusted or varied as a controlled factor; instead, it evolved during electrolysis as a consequence of electrochemical activity. In addition, the initial pH was not reliably documented in the archived experimental records. The pH data are therefore interpreted as evidence of electrochemically induced alkalization that may influence Zn speciation and floc formation, rather than as proof of a direct causal effect of pH on harvesting efficiency.

Effect of Electrode Spacing on OD-Based Harvesting

Electrode spacing also influenced the OD-based harvesting response (Figure 7). At 20 min, efficiencies of 35.85%, 27.17%, and 16.72% were obtained at electrode spacings of 1, 3, and 5 cm, respectively. The same trend persisted throughout the treatment period. After 60 min, harvesting efficiencies were 90.35% at 1 cm, 77.86% at 3 cm, and 67.15% at 5 cm. Increasing the electrode spacing from 1 to 5 cm was therefore associated with a substantial reduction in OD clarification under the investigated conditions.

The observed trend is consistent with the electrochemical consequences of increasing the

ionic transport distance between the electrodes. A shorter interelectrode distance can reduce the path length for charge transport and lower ohmic losses, thereby facilitating electrochemical reactions and interactions among dissolved metal species, gas bubbles, and suspended microalgal cells. In contrast, a greater distance can increase resistance-related losses and reduce the effectiveness of the applied electrical input for a given operating condition [3,4,6,13]. The shorter distance may also favor more frequent contact between generated coagulant species and suspended cells within the batch reactor.

However, solution resistance and cell voltage at each spacing were not measured independently, so the explanation based on ohmic loss remains mechanistically consistent with the experimental trend rather than being directly demonstrated by the available measurements. Based on the observed performance, 1 cm was selected as the working spacing for the final comparison with gravitational sedimentation. This distance should be regarded as the best-performing spacing among the tested values of 1, 3, and 5 cm, not as a universally optimized interelectrode distance.

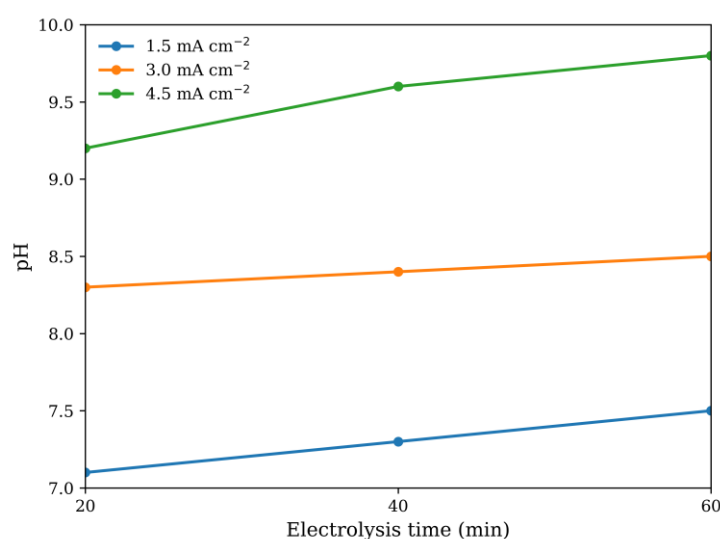


Figure 6. Effect of current density on solution pH during electrocoagulation–flocculation of *Chlorella emersonii*

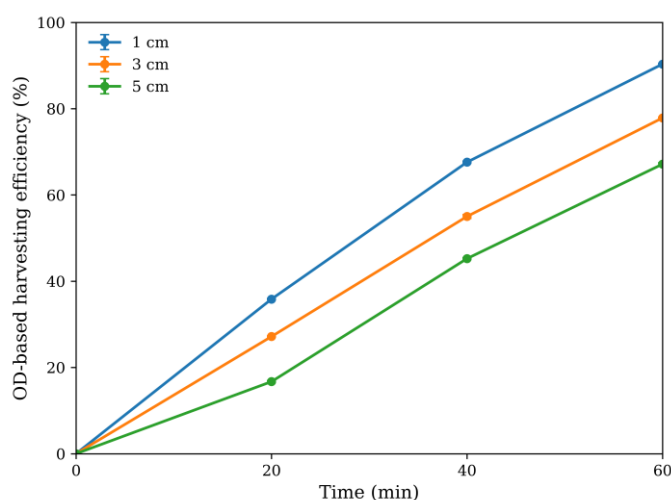


Figure 7. Effect of electrode spacing on the OD-based harvesting efficiency of *Chlorella emersonii* during electrocoagulation–flocculation

Selected Operating Conditions and Comparison with Gravitational Sedimentation

The final comparison was performed using the selected ECF conditions of a Zn electrode, 60 min electrolysis, 4.5 mA cm⁻² current density, and 1 cm electrode spacing. Figure 8 shows that ECF provided substantially greater OD-based harvesting efficiency than gravitational sedimentation throughout the observation period. At 20, 40, and 60 min, ECF achieved efficiencies of 35.85%, 67.60%, and 90.35%, respectively, whereas gravitational sedimentation achieved efficiencies of 12.42%, 24.91%, and 36.88%, respectively. Thus, the difference between the two approaches became progressively larger with treatment time.

The comparison used the same documented culture volume of 500 mL, the same initial OD₆₈₀ of 1.033, the same 20, 40, and 60-min observation schedule, and the same OD-based calculation. The sedimentation control was left untreated, whereas the ECF suspension was subjected to the selected electrochemical conditions. These matched documented variables improve the validity of the comparison. However, the archived records do not specify the exact vertical position from which aliquots were collected after treatment, so identical spatial sampling between the ECF and sedimentation conditions cannot be confirmed and is acknowledged as a methodological limitation.

The stronger OD clarification achieved by ECF is consistent with electrochemically induced cell aggregation and gas-bubble-assisted flotation, whereas gravitational sedimentation depends mainly on the natural settling behavior of small *Chlorella* cells [1–3,5]. Nevertheless, a decrease in

OD₆₈₀ should not be equated directly with quantitative recovery of intact biomass. Cells may aggregate, become entrained in metal-containing precipitates, undergo partial lysis, or experience changes in light-scattering behavior. Because no OD-to-dry-weight calibration, post-treatment dry biomass concentration, cell-viability assay, or biochemical composition measurement was available, the endpoint is appropriately reported as the OD-based apparent harvesting efficiency.

From a practical perspective, ECF should also be considered relative to other realistic microalgae-harvesting technologies. Centrifugation can provide rapid and efficient separation but is typically energy intensive; dissolved-air flotation can be effective but requires gas pressurization; chemical flocculation can reduce electrical demand but introduces external flocculants that may complicate downstream biomass use; and membrane-based recovery can provide strong separation but is susceptible to fouling and pressure-related operating costs [1–3]. ECF offers the advantages of in situ coagulant generation and simultaneous flotation, but its practical feasibility depends on electricity and electrode consumption, the presence of residual electrode-derived metal in the harvested biomass, and the preservation of cell integrity and biochemical quality.

Accordingly, the present study is best interpreted as a laboratory-scale evaluation of operating conditions based on OD clarification. Future work should establish an OD₆₈₀–dry biomass calibration, quantify the biomass mass balance before and after ECF, assess cell integrity and biochemical preservation, measure conductivity and electrical-energy consumption, determine electrode consumption and residual metal, and apply a statistically designed multivariable experiment if formal optimization is intended.

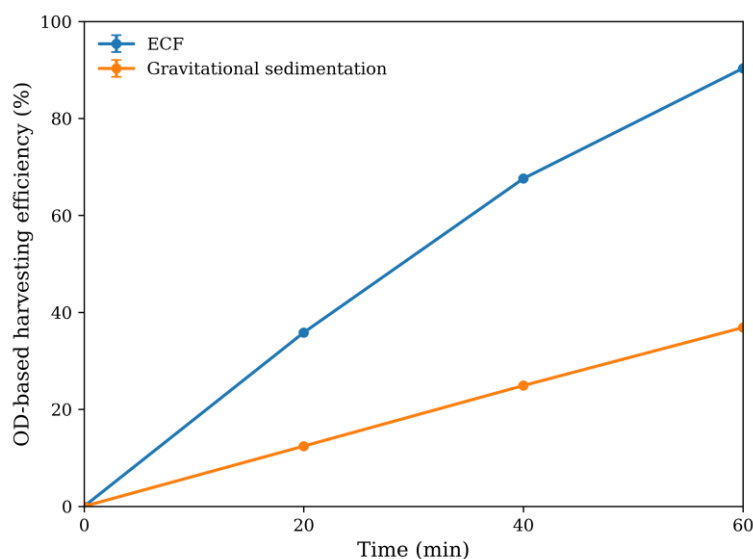


Figure 8. Comparison of OD-based harvesting efficiency between electrocoagulation–flocculation (ECF) and gravitational sedimentation for *Chlorella emersonii*

Conclusions

The electrocoagulation–flocculation (ECF) process was successfully evaluated for harvesting *Chlorella emersonii* under a series of tested operating conditions. Zn showed better harvesting performance than Cu and was therefore selected for subsequent experiments. Within the investigated ranges, the best-performing conditions were a Zn electrode, 60 min electrolysis, a current density of 4.5 mA cm⁻², and an electrode spacing of 1 cm. Under these conditions, the OD-based harvesting efficiency reached 90.35%, compared with 36.88% after 60 min of gravitational sedimentation. The solution pH increased during electrolysis, reaching approximately 9.8 at 4.5 mA cm⁻², consistent with increased electrochemical activity and cathodic OH⁻ generation. The improved OD clarification observed during ECF is consistent with the combined effects of electrode dissolution, formation of zinc hydroxide/hydroxo species, cell aggregation, and hydrogen-bubble-assisted flotation. However, because harvesting performance was evaluated from changes in OD₆₈₀, the reported efficiencies should be

interpreted as OD-based apparent harvesting efficiencies rather than direct measurements of intact dry-biomass recovery. The present study therefore identifies the best-performing conditions within the tested ranges rather than a statistically optimized process. Further studies should include OD₆₈₀–dry biomass calibration, biomass mass balance, cell integrity and biochemical quality assessment, conductivity and energy consumption measurements, electrode consumption and residual metal analysis, and statistically designed multivariable optimization for process scale-up.

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Declaration of Generative AI and AI-assisted Technologies

ChatGPT and Grammarly were used solely as editorial tools to improve language clarity, grammar, readability, and manuscript

organization. All scientific content, data interpretation, references, and final decisions were independently reviewed and approved by the authors, who take full responsibility for the final manuscript.

Author Contributions

Conceptualization, R.F. and R; methodology, I.B. M.S., and R; validation, R.; formal analysis, I.B. and R.F.; investigation, I.B. and R.F.; data curation, R.F.; writing—original draft, I.B.; writing—review and editing, I.B.; visualization, R.F.; supervision, R.

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Declaration of Conflicts of Interest

The authors declare no conflict of interest.

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possibility and advantages to operate at micro-distances with low-conductivity effluents? *Chemosphere*. 2024; 368:143794. doi: 10.1016/j.chemosphere.2024.143794.