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Biomass from microalgae separation by electroflotation with iron and aluminum spiral electrodes

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HIGHLIGHTS

- Electroflotation for separation of microalgal biomass was applicate.
- Spiral-shaped electrode using aluminum and iron tubes was tested.
- The impact of metal electrodes on the effluent contamination was measurement.
- The best condition achieved was of 3 A/20 min, for aluminum electrode.
- Concentration of iron and aluminum ions in the treated wastewater was significant.

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ABSTRACT

The aim of this study was to evaluate the biomass separation of the microalgae *Desmodesmus subspicatus* by electroflotation with a spiral-shaped electrode using aluminum or iron tubes and to identify the metal contamination present in the effluent and biomass. Both time and electric current were controlled in the experiments. The most effective conditions for this experiment involved the use of an iron electrode for 30 min with a current of 3 A, whereas the aluminum electrode has been used effectively for 20 min with a current of 3 A. The contribution of the electroflotation system to the concentration of iron or aluminum ions in the treated wastewater is significant, and the use of the iron electrode may be less detrimental to human and animal health due to the lower toxicity remaining concentration in the effluent.

1. Introduction

Microalgae are essential components of the global ecosystem because they are the major oxygen producers. These microorganisms have great potential for use in biotechnological and commercial areas because of the importance of their biomass compounds. The biodiversity inherent to this class of organisms allows the development of new research, resulting in technologies that may provide benefits that are currently unknown [1].

Microalgae play a large role in the task of mitigating the effects of pollution caused by humans. They perform CO_2 capture to reduce atmospheric waste and the effects caused by greenhouse gases [2–4].

These microorganisms generate products and by-products of great relevance to the food, pharmaceutical, and especially the biofuel industries [5–7]. Their ability to adapt to different environments confers upon them an important role in bioremediation, for example in water reuse and the cleanup of industrial effluents or otherwise contaminated areas. They also have the ability to capture heavy metals dissolved in their surroundings [8].

Several authors reported that 1 kg of dry microalgae biomass requires approximately 1.8 kg of CO_2 to survive [2–4]. The efficiency CO_2 fixation for these organisms can be 10–50 times higher than for terrestrial plants [4].

The study of the microalgae production chain also involves an assessment of the environmental impact from each step in produc-

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tion. It is important to control for the negative effects caused by water and air pollution; the production of microalgae should be performed cleanly to ensure an ecologically sustainable system. Thus, one of the steps of microalgal biomass production that requires more care is the separation of the cells from the culture medium. Many methods can be used for this purpose, for example, the addition of flocculating agents [9,10].

The formation of flocs during gas evolution in the electrochemical treatment of water and wastewater is called electroflotation. The floating layer can be easily removed from the system's surface [11].

Flocculating agents are reagents that may have environmental impacts associated with them. In particular, NaOH is inexpensive and reacts quickly; however, its solutions must be neutralized before disposal. Something that should be considered is the possibility of changing the profile of fatty acids from the biomass depending on the type of flocculating agent used [12–14].

In the electroflotation step, the metal composition resulting from the separation of the biomass and effluent (the liquid phase after biomass separation) is still unknown. This technique may have environmental consequences due to the electrolytic methods used for biomass removal, because metal ions are generated from the electrodes and remain in the culture medium [15].

It has been established that the material used in the electrodes plays an important role in the electrolytic processes. Aluminum and iron have been widely employed by researchers [16,17] as materials for electrodes in the electrocoagulation–flotation process.

The electroflotation method was performed to cause electrolytic oxidation and significant microalgal biomass recovery. The electrodes of iron and aluminum suffer during water electrolysis, and the suspended microalgae are destabilized by both Fe^{2+} and Al^{3+}. These ions originate from the dissolution of their respective electrode anodes and are removed by the evolution of micro bubbles of hydrogen (H_2). The micro bubbles are generated at the cathodes and capture the floating or suspended particles.

Recent researchers have demonstrated that the technology of electro coagulation–flotation offers an attractive alternative to traditional methods of water treatment for algae biomass, with a relatively low energy consumption (0.3 kWh m^{-3}) [18–20].

Moreover, aluminum electrodes achieve better algae separation as compared to iron electrodes, increasing the efficiency of removal from 78.9% to 100% in 45 min. This could be explained by the higher current generated at aluminum electrodes [15].

Apart from the electrode material, another important parameter influencing the efficiency of electroflotation is the size of the electrodes, i.e., the medium contact surface. Evidence has shown that the amount of micro-bubble production is proportional to the size of the electrode surface. In the same way, a higher current density in the electrolysis of water results in the generation of more micro-bubbles, providing better separation and easier removal of the suspended particles [21].

The aim of this study was to evaluate the process of electroflotation with a spiral-shaped electrode in biomass separation of the microalgae *Desmodesmus subspicatus*, using either aluminum or iron tubes. An additional objective was to identify the metal contamination present in the effluent and biomass resulting from this process.

2. Materials and methods

2.1. Microalgal biomass production

The microalgae *D. subspicatus* was obtained from the Ecotoxicology Laboratory of the Santa Cruz do Sul University. The strain was initially acclimatized in a medium containing nitrogen, phosphorus and potassium (N:P:K, 18:6:18 m/m) at 3 g L^{-1}, proceeding with the maintenance of cultures. For the cultivation of the microalgae, a 500 mL Erlenmeyer flask was sterilized with a solution of sodium hypochlorite 4 mL L^{-1}, followed by the addition of 0.5 mL of sodium thiosulfate (250 g L^{-1}) as a hypochlorite chelating agent.

Subcultures of *D. subspicatus* were then acclimated in the 500 mL Erlenmeyer flask. Homogenization was performed by an aeration system using a diaphragm pump.

This subculture, while in the exponential phase, was employed as inoculum for the biomass production in a bubble column tubular photobioreactor. An N:P:K culture medium was used to grow microalgae in the photobioreactor. The culture was incubated for 7 days while maintaining homogeneity and aerating the medium via diaphragm pumps. During this period, the culture was kept under artificial lighting using fluorescent bulbs for 24 h day^{-1}.

2.2. Monitoring the growth of microalgae

The growth of the microalgae *D. subspicatus* was monitored by evaluating the cell density and growth rate. To quantify the cell density, samples were collected daily. The cell density (cell mL^{-1}) was obtained by an adapted method [22]. In this procedure, the sample was diluted into 10 mL volumetric flasks to obtain absorbance measurements in the range of 0.1–10. The quantification of the number of cells per mL was performed by cell counting in a Neubauer chamber. The same samples were analyzed by a Spectrophotometer UV/Visible FEMTO Model 600 Plus with a wavelength of 682 nm and standard curves were generated. All the measurements were performed in triplicate. The cell density of samples was calculated through linear regression of data obtained from the absorption results and the separated solid biomass.

The growth curve was then formulated by repeated daily quantification of cell density during the growth period.

The specific growth rate (k) was obtained using the (Eq. (1)) [23]:

$$k = 3.322/T2 - T1 \log N2/N1 \quad (1)$$

where k = growth rate; 3.322 = conversion factor of log base 2 to base 10; $T2 - T1$ = time interval in days; $N1$ = initial cell density; $N2$ = final cell density; log = logarithm to base 10.

The rate of growth was obtained as the number of cell divisions by unit of time (days) specific to each experiment.

2.3. Electroflotation

For this experiment, a continuous source of power (Instrutherm model FA-3003) and two electrodes of different compositions (iron and aluminum) were used. The use of electrodes in spiral shape is unconventional for biomass flotation, and plate-type electrodes are more usually employed. In this study, we designed electrodes in spiral shape understanding that this arrangement could bring a number of benefits to the process, such as: (I) significant increase of the surface area promoting a more effective flotation process; (II) the arrangement of the anode and the cathode in the same plane to form small bubbles of oxygen fast-dispersing, improving the formation of flocs and homogenization of the solution, and (III) reducing the distance between the columns of the cathode and anode (about 2 mm), reduces the power consumption of the process and an increase in the electrode lifetime [24]. Both the iron and aluminum electrodes were built using two metal bars, each bar measuring 1700 mm in length. These were then made into a spiral shape with an 80 mm diameter. The contact surfaces were approximately 534.19 cm^2 (Fig. 1).

To optimize this process, the time variation and current density were tested. To create the data matrix, two independent parameters were considered: time (10, 15 and 20 min) and current (1.0, 2.0 and 3.0 A). The current densities obtained were 1.9, 3.7 and