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Research paper

Development of heat-aided flocculation for flotation harvesting of microalgae

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ABSTRACT

Biofuel from microalgae has significant potential, but the economics of production are still not on par with fossil fuels. One stage of production commonly cited as requiring improvement is harvesting the microalgae from dilute culture solutions. Flotation has emerged as a promising harvesting method that avoids the high energy costs of methods such as centrifugation, but requires the addition of chemical flocculating agents that add to the cost and can contaminate the biomass. To address this, a novel derivative, heat-aided flocculation, is examined. By potentially using waste heat from industry, flotation can be achieved without addition of chemicals.

1. Introduction

Microalgae are a promising biological feedstock for both biofuels and other bioproducts. Microalgae's high lipid content can be converted into fuels that can be utilized as drop-in replacements in traditional diesel engines [1,2]. Compared to terrestrial plant sourced biofuels, microalgae biofuel has several advantages including that its production does not require agricultural land, has higher areal productivities, and can be produced year-round. Furthermore, microalgae production can be coupled to industrial carbon dioxide (CO_2) off-gas emissions for carbon capture and mitigation [3,4]. This in turn can provide increased growth rates through utilizing the CO_2 as a carbon source [5–10].

The possible industrial CO_2 sources for algae cultivation are significant worldwide, but utilization is currently limited due to ambient temperature considerations. This has lead to large-scale microalgae cultivation being mainly in tropic and sub-tropic areas. To expand the potential of these technologies, the use of industrial waste heat in off-gas emissions to allow for year-round cultivation in cold climates has been also advocated [11,12].

A common premise with proposed industrially coupled operations is that the utilization of waste industrial heat, such as in in off-gas emissions, is considered only in the cultivation stage. However, it has been demonstrated that the use of heat can be also used to promote flotation harvesting [13]. Elevating the culture temperature to at least 65 °C prior to gas flotation allows for efficient microalgae harvesting without the addition of chemicals. This approach could allow for bulk harvesting of algae while avoiding contamination from the addition of traditional flotation flocculants, such as aluminum sulfate or ferric chloride [13,14]. Many published papers make the point that this contamination can significantly limit the usage of the residual biomass after lipid extraction, especially as animal feed or fertilizer [14–16]. Other studies have also mentioned the importance of the ability to recycle uncontaminated microalgae in the cultivation process [17,18]. There is however, the potential that some additives can have a positive effect, such as CTAB, which is a surfactant that has been shown to increase lipid recovery [19].

In this study, a heat-aided flotation process that avoids use of added chemical flocculants, which was originally used for bacteria recovery [20], is further developed for harvesting of microalgae. The method is presented as a process-coupled system that could utilize otherwise waste heat from industrial operations. The parameters examined include the algae concentration prior to harvesting, pH modification and effects on the growth media in terms of its value for recycling back into the cultivation stage.

2. Materials and methods

2.1. Algae cultivation

Scenedesmus dimorphus #1237 (UTEX culture collection, University of Texas at Austin, TX, USA) samples were grown in Bold Basal medium [21]. The cultures were incubated in a flask, in an Infors HT Multitron Standard (Montreal, QC, Canada) at 25 °C, continuously agitated at 125 rpm, under photosynthetic light conditions of ~70–80 μmol photon $m^{-2}s^{-1}$ (Sylvania Gro-Lux F15W/Gro T8, Infors) using a 12:12 h light:dark cycle.

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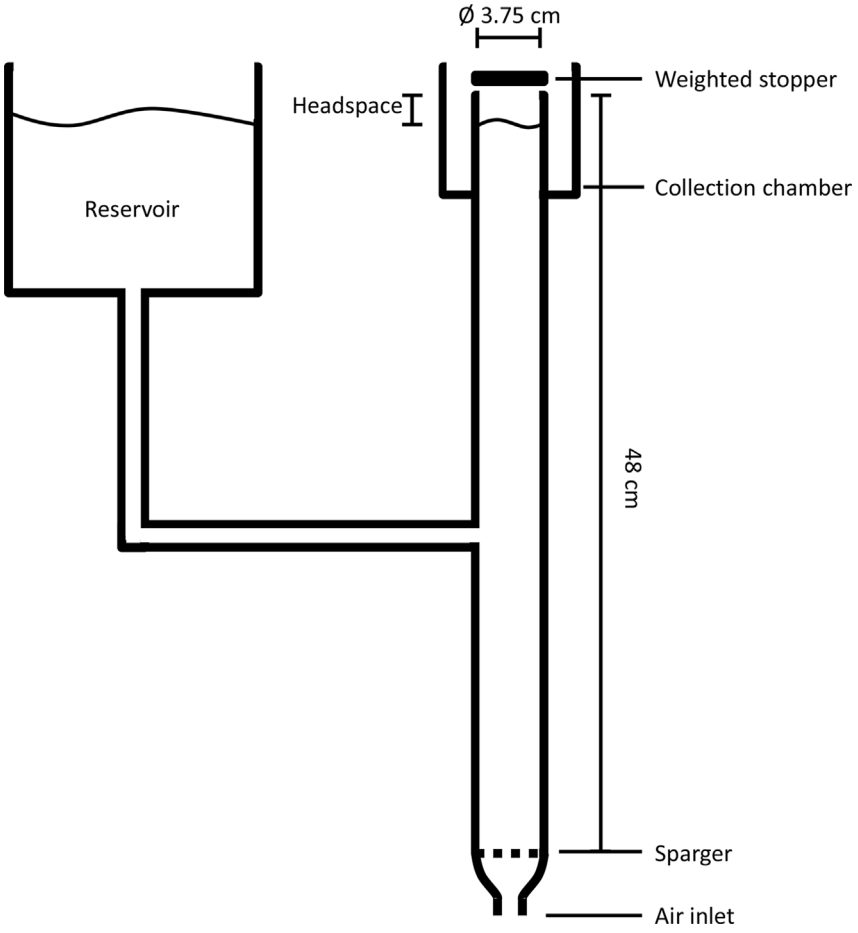

Fig. 1. Laboratory flotation column design.

2.2. Temperature and pH modification

Prior to separation, the temperature of each sample was raised in a water bath over for 30 ± 2 min to reach 65 °C and for 66 ± 2 min to reach 95 °C. After attaining the experimental run temperature, the samples were immediately transferred to an ice bath and rapidly brought back to room temperature (21 ± 2 °C). Heating the culture to these temperatures for a relatively short amount of time has been previously shown to have no adverse effects on the quality of the biodiesel produced [13].

In experiments where pH levels were modified from the existing culture pH, the adjustments were performed using concentrated sulfuric acid or sodium hydroxide.

2.3. Flotation column design

A laboratory scale dispersed air flotation column (Fig. 1) was made using a clear acrylic tube with a porous stone sparger at the bottom (mean pore size of 15 μm, Refractron Technologies Corp., NY, USA). A collection chamber was located at the top with a weighted deflection plate to force the bubbles to concentrate. A side port was connected to an external water reservoir to maintain a constant level in the tube. Individual flotation tests were carried out with 500 ml of culture and a headspace of 1.5 cm.

2.4. Separation experiments

After treatment, whether by temperature and/or pH alteration, 500 ml of sample was loaded into the flotation column. Microalgae separations were conducted over a run time of 5 min, after which, the recovered biomass was collected along with a sample of the remaining liquid in the column. Each experiment was carried out in triplicate.

2.5. Separation analysis

Biomass concentration was measured using a vacuum filter with an Ahlstrom 151 glass microfiber filter according to Equation (1):

$$C_{algae} = \frac{m_{final} - m_{filter}}{V_{filter}} \quad (1)$$

where C_{algae} (g/L) is the biomass of the measured algae. m_{final} (g) and m_{filter} (g) are the weights of dried sample and filter paper, respectively, and V_{filter} (L) the volume of sample filtered.

The volume and the biomass concentration of concentrate was measured, along with the initial biomass of the culture, in order to calculate the concentration factor and recovery efficiency, as shown in Equations (2) and (3):

$$Concentration\ factor = \frac{C_{concentrate}}{C_{initial}} \quad (2)$$

$$Collected\,(\%) = \frac{C_{concentrate} \cdot V_{concentrate}}{C_{initial} \cdot V_{initial}} \cdot 100\% \quad (3)$$

The concentration factor is the ratio of concentrate biomass concentration (g/L) to initial medium biomass concentration (g/L). The recovery (%) is the comparison of mass in the concentrate (g) to the mass initially in the column (g). These masses are calculated as concentration (g/L) multiplied by their respective volumes (L).

2.6. Media analysis

The media composition of major nutrients and other elements of