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# Energy potential of algal biomass cultivated in a photobioreactor using effluent from a meat processing plant

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ABSTRACT

The objective of this study was to assess the energy potential, in terms of lipids and biogas, of the algal biomass cultivated in a photobioreactor using effluent from a meat processing plant (primary effluent = after the flotation unit and secondary effluent = after the activated sludge unit) as culture medium. Among the tested routes, the objective was to define the best one for energy use of the biomass and, in order to incorporate the concept of biorefinery, the biogas production was assessed with and without the previous lipid extraction. After 6 days of operation, the biomass cultivated in both effluents presented similar lipid content (7.0 and 6.1%), accounting for mean lipid productivities of 10.0 mg/L·d for the primary effluent and 3.4 mg/L·d for the secondary effluent. The methane production potential (MPP) of the post-flotation biomass was 0.44 $m^3$ biogas/kg of total volatile solids (TVS) and of the post-activated sludge 0.28 $m^3$ biogas/kg TVS. For the biomass after lipid extraction, the MPP was 2.38 $m^3$ biogas/kg TVS for cultivation in the post-flotation effluent and 2.26 $m^3$ biogas/kg TVS in the post-activated sludge effluent. None of the energy routes presented a net energy ratio (NER) higher than one. The energy gain with production of biogas after the lipid extraction was small, although higher NER values were obtained for this pathway. The biogas production from raw biomass, regardless of the culture medium, was the most favorable energy route.



## 1. Introduction

Microalgae are currently considered promising feedstock for the production of biofuels. Different types of renewable fuel can be obtained from microalgae biomass, such as methane produced through anaerobic digestion, biodiesel derived from oil extraction and photobiological hydrogen production. In addition to versatility, the algal substrate presents other advantages such as rapid and continuous growth of the biomass throughout the year, exceeding the yield of the most productive oil cultures [1].

However, despite the undeniable advantages, there are still challenges to the development of technologies for the production of bioenergy from microalgae. We have not yet reached a scenario of economic viability. Energy consumption and environmental impacts are the main weakness. Also, the still immature technologies for algal biomass dewatering, the high installation and operation costs of photobioreactors (PBRs) and the low productivity of high-rate ponds should be overcome.

Efforts have focused on the search for alternatives for a sustainable process, both environmentally and economically. Among these alternatives are the cultivation in effluent, in consortium with other microorganisms, and the maximum exploitation of the biorefinery concept.

Biodiesel is one of the most studied options of bioenergy production, due to the high lipid accumulation capacity of microalgae. Biogas production through anaerobic digestion is another interesting route that saves energy in the biomass dewatering process. However, when cultivating microalgae in wastewater, low lipid content is expected due to the stressful environment and to the production of a heterogeneous biomass, which contains not only algae but also bacteria with lower lipid content. Moreover, energy consumption of the biomass dewatering process required for lipid extraction accounts for significant costs. Regarding biogas production of algal biomass, the main challenge is the improvement of pre-treatment methods, which is essential to a better efficiency of algal biomass anaerobic digestion due to high resistance of the algal cell wall. Some studies reported that the viability and sustainability of the process would only be achieved if the biogas production was combined with a prior biodiesel recuperation [2,3]. However, the integration of the biodiesel production systems with the methane production from microalgae has scarcely been reported in the literature [3].

With respect to wastewater, most systems for microalgae cultivation are open ponds where biomass concentration is usually below 1 kg/$m^3$, with mean values of 0.2 and 0.6 kg/$m^3$ [4,5]. Although PBRs are usually

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considered as having higher installation and operation costs than high-rate ponds, they are more stable and capable of producing greater photosynthetic efficiency, biomass density, $CO_2$ use efficiency and volumetric productivity [6]. For the viable large-scale production of biofuels, the energy used for the process, regardless of the system, must be minimized in order to maximize the energy yield.

There are still uncertainties about how to determine the energy balance in microalgae biofuel production [7]. The net energy analysis, which uses concepts of the lifecycle analysis, is one of the most widely accepted methods for assessing the energy potential of a system in general [8]. Another coefficient for assessing the efficiency of the cultivation system is biomass specific productivity, defined as the ratio between biomass productivity and the energy input, as proposed by Pegallapati et al. [9]. In addition, several other coefficients are extensively used in the literature to measure the energy efficiency of the production system and the use of the biomass produced (see [7,10]).

The aim of the study was to apply energy analysis in an integrated context of biorefinery, with the main objective of defining, among the tested routes, the best use of biomass, in addition to determining the energy efficiency of the production system. Therefore, we assessed the energy potential, in terms of lipids and biogas, of the biomass cultivated in a photobioreactor (PBR) using effluent from the meat processing industry as culture medium.

## 2. Material and methods

### 2.1. Cultivation

#### 2.1.1. Experimental setup

The experimental plot consisted of a bubble column PBR. The experiment was carried out in the area outside the Laboratory of Environmental and Sanitation Engineering at the Federal University of Viçosa, Minas Gerais (20°45′14″S, 42°52′54″W), and altitude 686 m from the sea level. The predominating climate in the municipality is characterized with rainy and hot summers and cold and dry winters. It has an annual average precipitation of 1221 mm and an average annual temperature between 19 and 20 °C.

The PBR consisted of three independent acrylic tubes with an external diameter of 15 cm, internal diameter of 14.4 cm, 3 mm of wall thickness and a useful volume of 15 L each. The mixing of the cultivation medium was performed continuously through the bubbling of air (10 L/min) enriched with $CO_2$ (6.5%, *v*/*v*). The air for mixture was given by a diaphragmatic air compressor (Schulz, 0.25 kW of power) and conducted for each tube by a pneumatic hose followed by a PVC tube connected to a disperser made from a cylindrical oxygenating porous stone (22 mm of length and 12 mm of diameter). Flowmeters of 0–15 L/min were installed. The $CO_2$ supply was automatically controlled by the variation of pH. Values of pH were kept between 6 and 8, through pH online measurements (HACH, sc200 controller) connected to a solenoid valve (Jefferson, 2016BV221). Measurements were made in one tube of the PBR, considering that the other two units have the same behavior as they were in the same operational conditions. The main components of the systems are presented in Fig. 1A, and the dimensions of the acrylic tubes are shown in Fig. 1B.

The PBR was characterized in terms of its hydrodynamic characteristics. For the same conditions used in batch operations (airflow = 10 L/min and liquid volume = 15 L) the following characteristics were observed: i) mixing time ($t_m$95%) of 180 ± 54 s, corresponding to the time necessary to reach ±5% of $H^+$ concentration in the total mixing state; and ii) volumetric oxygen mass transfer coefficient ($k_La$) of 0.00257 $s^{-1}$.

#### 2.1.2. Operation

The PBR was operated with primary and secondary effluents from a meat processing industry located in Viçosa, Minas Gerais, Brazil. The primary effluent was collected at the exit of the flotation unit, and the secondary at the exit of the activated sludge unit, both at the wastewater treatment plant of the industry. Each culture medium was assessed during two outdoor batch operations of the PBR (during September 2014 for the primary effluent operation and October 2014 for the secondary effluent operation), until it reached the algal decay growth phase, monitored daily by the variable chlorophyll-*a*. For each operation was added an inoculum of 10% of the PBR volume. The inoculum was collected from high-rate ponds applied to domestic sewage treatment after the anaerobic reactor process.

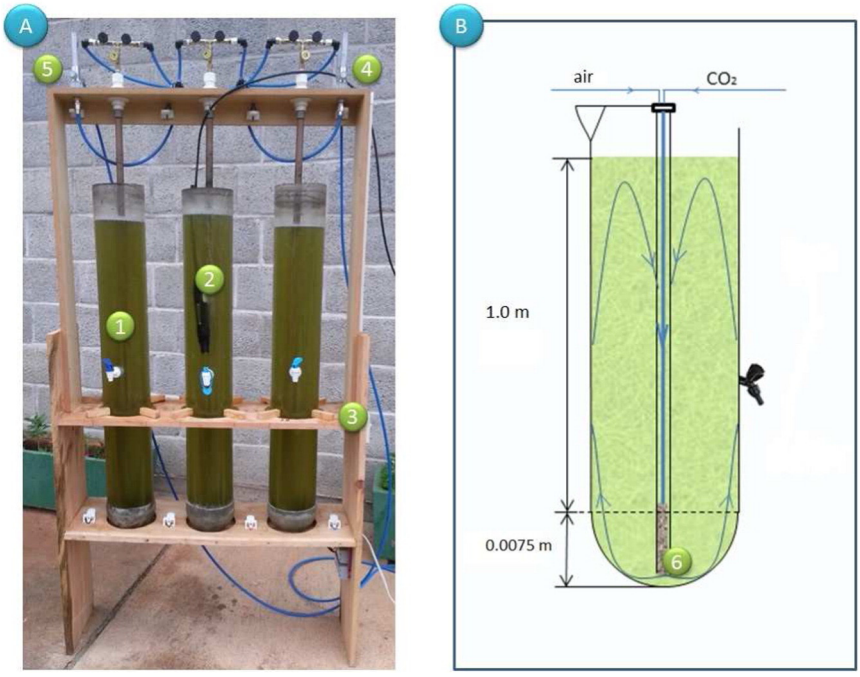


**Fig. 1.** (A) Bubble column PBR. The numbers indicate its parts: (1) acrylic tube; (2) pH sensor; (3) wooden supporting structure; (4 and 5) flowmeters; (B) (6) disperser and dimensions of each tube.