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ENERGY ANALYSIS OF MICROALGAE BIOMASS RECOVERED FROM INDUSTRIAL PHOTOBIOREACTOR

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Abstract. *Potential friendly energy sources are being developed as result of the world's high energy demand and as alternative to fossil fuels. The microalgae stand out among them due to its elevated percent of lipids per dry weight, which indicates promising biodiesel applications. It also can be cultivated in several medium formulations and requires flexible parameters control. The microalgae use as biological treatment has achieved good results for swine wastewater in the NPDEAS (Center for Research of Self-Sustaining Energy Development) through industrial photobioreactor cultivation. In order to understand the energy utilization in the dry microalgae biomass production this study analyzes three different methodologies of biomass recovery. In the first (i), the microalgae from the industrial photobioreactor was subject to flocculation, centrifugation and drying in the oven. In the second (ii), to centrifugation and subsequent drying in the oven. Finally, in the third (iii), to flocculation and a two-steps sun-oven drying. The results were: i) 2,13x107J / g of biomass; ii) 2,23x107J / g of biomass; iii) 3,11x107J / g of biomass. Tests have shown that the less energy required process is the first, which consume 31.5% less energy than the third situation. Thus, it presents itself as the best alternative because it minimizes energy consumption, reduces recovery time per gram of biomass and maximizes the production.*

Keywords: *energy, photobioreactor, microalgae, biomass*

1. INTRODUCTION

Microalgae are described as photosynthetic microorganisms with high bioenergetic potential due mainly to its rapid growth, homogeneous composition and high oil content (Konur, 2011). Another important feature of the microalgae cultivation is the system versatility, in which different goals to be achieved in the same process, such as the wastewater treatment, the production of food supplements, animal feed, pharmaceuticals and chemicals (De La Noue and De Pauw, 1988).

The algal biomass production in open ponds has lower energy costs and financial investments, but in other hand has less yield volumetric productivities than in the closed photobioreactors such as piping systems, in which the volumetric productivities can be about 30 times higher than in open lakes (Chisti, 2007). The advantage of cultivating microalgae in closed photobioreactors is that they provide an excellent framework for measuring crop production in a controlled environment (Ugwu, Aoyagi, and Uchiyama, 2008). This avoids problems with contamination, and allows maintenance

of a stable physical and chemical environment, for example, evaporation, pH, nutrients (Kunjapur and Eldridge, 2010; Morweiser, Kruse and Posten, 2010.) The use of photobioreactors also has the advantage of occupying a much smaller area than that of open systems and hence no competition for the use of agricultural areas that could be used for food production. Photobioreactors also have high efficiency in biomass production when used CO_2 injection in the middle, increasing the growth of microalgae (Suali and Sarbatly, 2012).

Microalgae are an important alternative source to diversify the raw materials used to produce biofuels use of areas unsuitable for agriculture; higher binding capacity of carbon dioxide (CO_2), increased synthesis of lipids, use of water unfit for human consumption (effluents and wastewater), depending on the region and cultivated species it can produce the whole year, and when grown in photobioreactors compact, it reduces areas of crops (Chisti, 2007; Rodolfi et al., 2009).

The microalgae biomass is currently produced in the NPDEAS (Núcleo de Pesquisa e Desenvolvimento de Energia Auto-Sustentável) through industrial photobioreactors. Therefore, the energy spend in the recovery biomass process must be analyzed for a better understanding of the global system.

The aim of this study is to investigate the energetic costs of the main three forms to obtain dry biomass cultivated in the industrial photobioreactors of the NPDEAS. In the first, the microalgae from the industrial photobioreactor was subject to flocculation, centrifugation and drying in the oven (experiment one). In the second, to centrifugation and subsequent drying in the oven (experiment two). Finally, in the third, to flocculation and a two-steps sun-oven drying (experiment three).

2. MATERIALS AND METHODS

The cultures of Scenedesmus sp. were performed on a compact tubular photobioreactor (FBR) which occupies an area of 10 m² and operates with approximately 12 m³ of volume. The FBR has 3.5 kilometers of transparent PVC tubes modularly and alternately arranged in order to maximize the space. In addition to the structure itself, the photobioreactor is composed of a 1 HP pump, responsible for the circulation of the fluid within the system. Compressed atmospheric is also provided to the photobioreactor in a degasser column. Figure 1 shows the appearance of the photobioreactor used in the experiments.

Figure 1 – Photobioreactor

The microalgae culture for the experiment was developed with swine wastewater as substratum and carried for 20 days with daily homogenization. In order to evaluate the level of biomass presented in the system, pH, number of cells per volume, dry biomass and optical density (540nm, 670nm and 750nm) were previous analyzed in triplicate.

All tests were realized simultaneously aiming to reduce the number of variables. The experiments that contain the flocculation step were conducted with 210g of Tanfloc for 1000L of cultivation rate, homogenized during 10 minutes and left for sedimentation over night. The experiments that contain the centrifugation step required the running time of

30 minutes for the flocculated samples and 60 minutes for the raw cultivation. The one step drying experiments went to the oven in the same tray, occupying half of the tray's area each. The test that required dying under sun went to a second oven in consequence of the longer time planned for the sample out of the oven. Each oven was equipped with 3000W of resistance. The thickness of all trays was 3,5cm.

The drying was conducted during 28 hours, period that the samples were considered dried since no drastically humidity variation were seen in the subsequent analyzes. The humidity tests were conducted periodically, in periods of a few hours.

3. RESULTS AND DISCUSSION

The presented cultivation characteristics presented in the table 1 matches the data of previous experiments developed in the NPDEAS with the same type of photobioreactor, using the same substract source. The high pH was expected since microalgae are photosynthetic organisms. They consume the CO_2 conteined in the medium, which is an acid molecule, resulting in a higher pH than the cultivation start. A dilution for the optical density was need because of the machine limiting absorbance value of two. Therefore, the dilution was made and an extrapolation can be performed to find the original information. The high optical density, number of cells and dry biomass also were expected because of the natural increase of volume and number that the microalgae perform when they are growing.

Table 1 – Cultivation characteristics

pH	10,64
Optical density (540 nm)	1:10 dilution = 0,3388
Optical density (650 nm)	1:10 dilution = 0,2847
Optical density (750 nm)	1:10 dilution = 0,2688
Number of cells per L	2,52x10^7
Dry biomass (g/L)	0,6353

The energetic analysis is an important factor to validate the overall production of microalgae biomass. Its calculation depend of some crucial energy information of the equipments utilized during the experiments: the flocculator motor operates at 0,92 kW, the centrifuge motor at 2,24kW and the oven at 3kW.

In the first experiment, which includes flocculation, centrifugation and oven drying, the flocculator motor operated during 10 minutes, the centrifuge during 30 minutes and the oven during 28 hours. Therefore, the energy consumption was $2{,}13 \times 10^7$ J/g of biomass. The correlation between the humidity and the time for drying is shown in the table 2 and the curve formed by it is presented in the figure 2. They indicate that in the initial moments the drying was not as effective, however, after 10 hours the humidity drops faster and the overall time is not affected. The total of biomass recovered in this mode was 97,4g.

Table 2 – Drying data of experiment one

Floculation/Centrifugation/Oven	
Time (h)	Humidity (%)
0	94,12
3,5	85,66
7	84,36
10	81,99
19	23,14
22	17,69
25	9,67
28	6,51

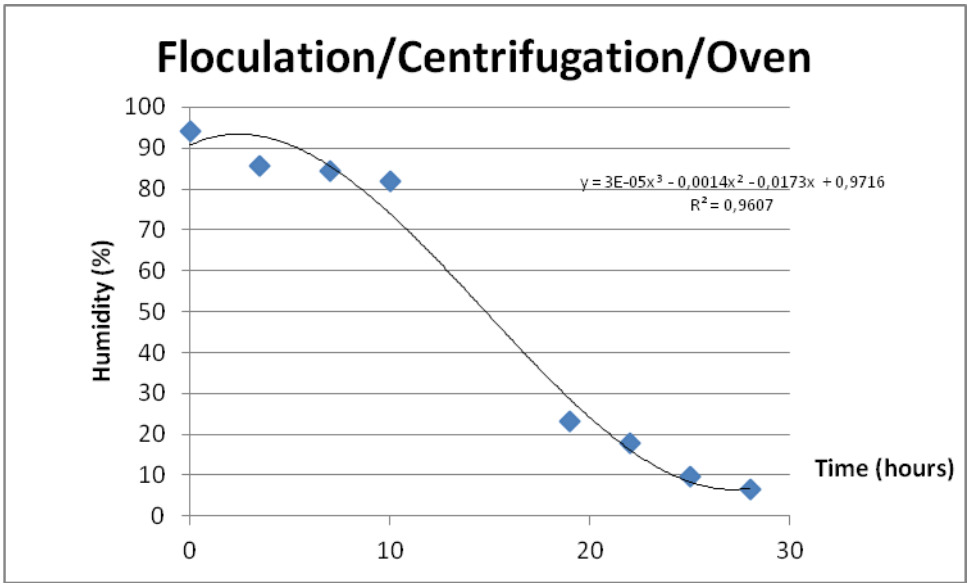

Figure 2 – Drying data of experiment one

In the second experiment, which includes centrifugation and oven drying, the centrifuge operated during 60 minutes and the oven during 28 hours. Therefore, the energy consumption was $2{,}23 \times 10^7$ J/g of biomass. The correlation between the humidity and the time for drying is shown in the table 3 and the curve formed by it is presented in the figure 3. They indicate a rapid decrease of the humidity already in the first moments of the drying, which carries on till the end. The total of biomass recovered in this drying mode was 137,5g.

Table 3 – Drying data of experiment two

Centrifugation/Oven	
Time (h)	Humidity (%)
0	89,21
3,5	79,91
7	59,32
10	23,58
19	12,87
25	32,69
28	3,31

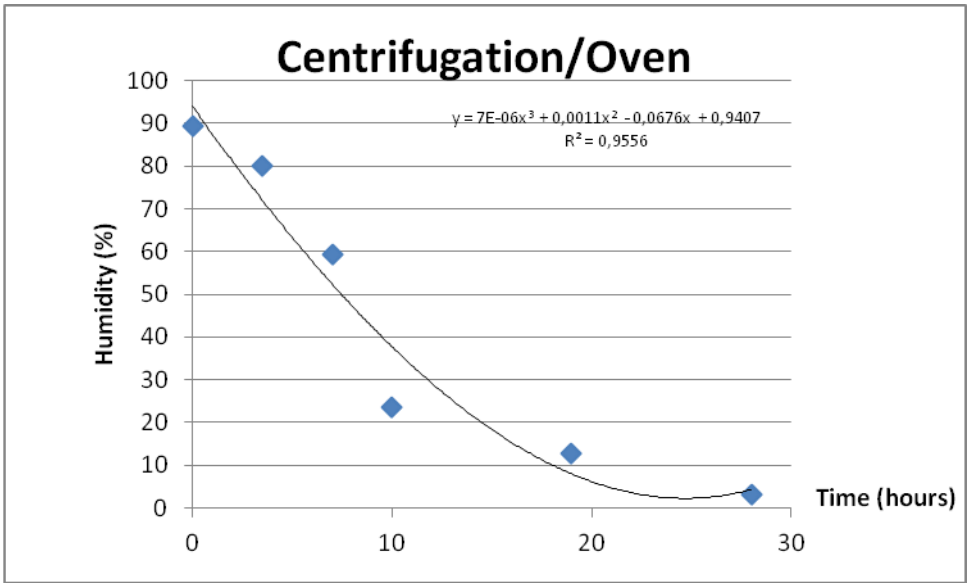

Figure 3 – Drying data of experiment two

In the third experiment, in which includes flocculation and a two step sun-oven drying, the flocculator motor operated during 10 minutes and the oven during 28 hours. Therefore, the energy consumption was $3{,}11 \times 10^{7}$ J/g of biomass. The correlation between the humidity and the time for drying is shown in the table 4 and the curve formed by it is presented in the figure 4. They also indicate that in the initial moments the drying was not as effective and a few hours the humidity drops faster and the overall time matches the other experiments. The total of biomass recovered in this drying mode was 144,2g.

Table 4 – Drying data of experiment three

Floculation/Sun/Oven	
Time (h)	Humidity (%)
0	83,91
3	95,00
6,5	88,54
10	90,32
13	78,43
22	17,76
25	19,38
28	2,61

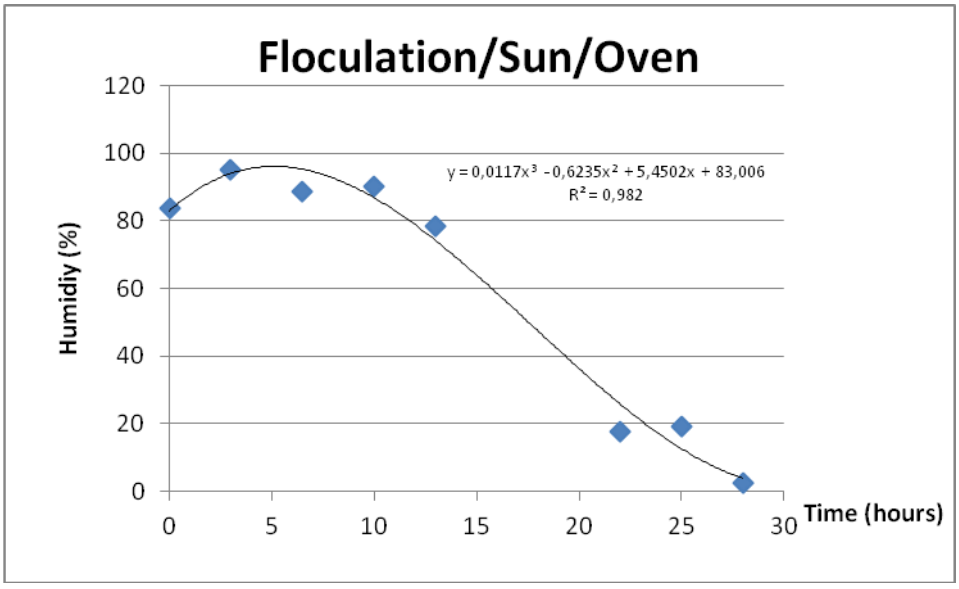

Figure 4 – Drying data of experiment three

It is important to highlight that the energy analysis is correlated with the amount of dry biomass produced and the lowest overall energy consumption, for example, does not necessarily reflect the best energy option because, at this point, the biomass production is not taken in account. The goal of the global process is to produce the maximum amount of biomass as possible so future researches can be developed. Therefore, dividing the overall energy consumption by the weight of dry biomass generated was considered the best approach to analyze the results.

Although the scale of the equipments was not designed for the amount of biomass recovered, a comparative result can be done. The energy consumption results per biomass weight are summarized in table 5 to highlight the data resulting from the tests. The experiment number one consumed 68% of the energy used by the last and 95% of the experiment number two. Those numbers indicate that the process of flocculation, centrifugation and oven drying has the best energetic balance.

Table 5 – Experiments results

Experiment	Floculation	Centrifugation	Sun Drying	Oven Drying	Energy per biomass (J/g of biomass)
1	x	x		x	$2{,}13 \times 10^7$
2		x		x	$2{,}23 \times 10^7$
3	x		x	x	$3{,}11 \times 10^7$

4. CONCLUSION

The primary purpose of this study consisted in the energy process analysis of a semicontinuous cultivation mode of microalgae in photobioreactor developed with swine wastewater. Of the three forms chosen to perform this recovery, the best energy cost balance between the overall energy spending and the dry biomass production was the one containing flocculation, centrifugation and oven drying. It was also notable that the drying step is, in all experiments, the major energy cost of the processes. Therefore, an effort to develop a more efficient form to dry the samples is indicated. Another option is to find use for humid biomass as well, which would eliminate the drying part and give a boost to the energy balance of the global process developed in the NPDEAS.

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