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RECOVERY AND CHARACTERIZATION OF BIOMASS FROM FACULTATIVE STABILIZATION PONDS: ENVIRONMENTAL, MITIGATION AND ENERGY APPLICATION

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Abstract. *Is known that residual water effluent contains organic material and mineral such as nitrogen and phosphate that generates environmental problem. The volatilization of nitrogen causes air pollution due to NO# production, and phosphorus permeates the solids damaging the ground water. The present work deal the development of a new method for recovery these biomass from facultative stabilization ponds (FSP) and the characterization in terms of elemental and proximate analyses, calorific value, solids series, nutrients and biological composition. The recovery method involves coagulation and flocculation, and the characterization serves both to energetic way, i. e., via gasification, and to verify the hazardous level that this kind of material can cause in human health. The biomass production was close to 0,30 mg.L^{-1}. The biomass is rich in Carbon and Oxygen, about 35%wt, white Hydrogen and Nitrogen close to 5 and 3,5 wt.%, respectively. The proximate analysis shows, 90,2 wt.% of Volatile Solids to facultative stabilization pond treatment with 60% in high rates ponds.*

Keywords: *recovery of biomass, organic material of facultative stabilization ponds, characterization of the biomass, thermo energy.*

1. INTRODUCTION

The process of wastewater treatment by stabilization ponds is considered in many parts of the world as one of the first choices for treating wastewater due to the simplicity of design, construction and operation, good profitability, few maintenance requirements and energy, high operational efficiency and easily adaptable and widely. Stabilization ponds have been extensively used to treat waste water from cities of medium and small, (Felizatto, 2000) and (Lardon L., 2009). The ponds are particularly suitable in tropical and subtropical countries because the intensity of sunlight and temperature are key factors for the development of micro-organisms. Life in a pond is formed by microscopic plants and animals that coexist and depend on each other. Aerobic bacteria need oxygen to keep alive. This use of oxygen is measured as free dissolved oxygen, whose demand increases with increasing amount of bacteria and algaes. And this increases food supply with the biochemical oxygen demand.

The algaes contain chlorophyll that converts sunlight into energy for growth through photosynthesis and act as a cell factory using solar energy, (Chisti, 2007), making the conversion of CO2 into O2, reducing (sequestering) CO2 atmospheric, (Zhu, Hiltunen et al., 2014) and (Swahili and Sarbatly 2012), while capture nutrients from the environment, (Ramachandra, 2013). In stabilization ponds, the algaes can double their mass several times a day. The overgrowth causes of the phenomenon of flowering, bloom, in water bodies due to the eutrophication process (Thomann, 1997). Sewage treatment systems based on algaes can significantly reduce the organic matter and nutrients in the waste water effluents with lower energy cost, (Abou-Shanab, Ji et al., 2013). Cultures of algaes offer an effective solution to the tertiary and quaternary treatments of sewage due to the ability of algaes to use inorganic nitrogen and phosphorous for growth (Oswald, 1988) and (Rawat, Ranjith Kumar et al., 2011).

The element that determines the profitability of using biomass from facultative stabilization ponds (FSP) for energy production is the choice of their culture technologies (Agency, 2001). The algaes can be grown to various methods, technologically advanced from solutions in which the process is carefully monitored and controlled by less predictable techniques based on open tanks, (CPCB, 2000). Biomass can also be acquired for energy production purposes from eutrophicated natural water bodies and degraded, (Debowski, Zieliński et al., 2013). A promising way to make production more profitable algaes biofuel is to integrate the treatment of waste water with biomass from FSP, (Abou-Shanab, Ji et al., 2013). Biofuels are considered promising alternatives to conventional fossil fuels, because they have the potential to eliminate most environmental problems, such as emissions of greenhouse gases than fossil fuels would create (Show, Lee et al., 2013).

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2.1 Algaes from FSP

The process of wastewater treatment by stabilization ponds is considered in many parts of the world as one of the first choices for treating wastewater due to the simplicity of design, construction and operation, good profitability, few maintenance requirements and energy, high operational efficiency and easily adaptable and widely, used in most medium and small cities.

The algaes to perform important role in cleaning wastewater, causing problems later in the discharge of effluent into water bodies. They present as suspended solids, polluting visually and contributing negatively to the balance of oxygen in water bodies, (Kim, 2003). The removal of organic matter and nutrients of stabilization ponds is an essential step to decrease the concentrations of organic matter, suspended solids and nutrients from wastewater. Nutrients from wastewater, mainly nitrogen and phosphorus, generate a significant environmental problem. Nitrogen in the form of ammonia can be volatilized and cause air pollution. Phosphorus can permeate the soil and cause damage to groundwater. When in excess, cause eutrophication of water sources and damage this ecosystem (Silva, 2013)

The blooming or bloom occurs resulting in eutrophication of surface water bodies in an environment with temperatures above 25 ° C, pH at about 7.5, prolonged exposure to solar radiation and the presence in excess of nitrogenous compounds and phosphate. Second Amengual-Hill, Moyà Niell et al. (2012), the occurrence of cyanobacteria has been found in ponds of anaerobic and facultative type. The growth of algaes in ponds and water bodies, and the inevitable work of removal generate the opportunity for exploitation and enhancement of this amount of organic matter such as biomass.

2.2 Use and appreciation of algaes

The factors that contribute most to the growth of algaes and cyanobacteria in lakes are solar radiation, temperature and nutrients, (Esteves, 2011). They may also be classified as abiotic (intensity and amount of light, temperature, O2, CO2, pH, salinity and nutrients N, P, K, etc.), biotic (bacteria, fungi, viruses and others) and operating (width and depth, degree of mixing and stirring, dilution rate, frequency of collection and adding bicarbonate, (Zhu, Hiltunen et al., 2014). The algaes represent diverse and specialized group of microorganisms adapted to different ecological habitats (Richmond, 2004), (Abou-Shanab, Matter et al., 2011) and (Abou-Shanab, Hwang et al., 2011). It is photosynthetic microorganisms with increasing demands that can produce liquids, proteins and carbohydrates in larger amounts, for short periods of time. These products can be transformed into biofuels and chemicals, (Demirbas, 2011).

Algae have been highlighted as a potential energy source for the production of biofuels due to the high productivity of biomass (175 $ton.ha^{-1}.year^{-1}$) and the ability to grow in poor quality water, (Jena, Vaidyanathan et al., 2011). Algae form aquatic biomass system with improved fuel production potential with lower demand of water compared to traditional energy crops, (Posten, 2009). Compared to other land plants, seaweed species have higher biomass production, (Dismukes, Carrieri et al., 2008), can produce from 10 to 100 times more oil per hectare, (Abou-Shanab, Ji et al. 2013), and have greater power carbon dioxide fixation (Wang, 2008). Due to its high growth rate requires less cultivation area and generates greater biomass than for other crops, (Chisti, 2007) and (Antunes, 2010). Comparing the farmland for the production of biomass from plants grown with the production of biomass from FSP, this has advantages for high photosynthetic efficiency, (Peng, 2001) and (Schenk, 2008), the ability to be grown in water media under different conditions and resulting high levels of lipids (Rodolfi, 2009).

Fuels obtained from these biomasses have higher production yield compared to that obtained by other cultures, (Wang, 2008), does not require cultivation of resources that could be used for food production, you do not need soil and earth thrive in salt, brackish or just dirty and not compete for scarce freshwater resources, (Khoo, Koh et al., 2013). The biofuels of biomass from FSP are known as third generation biofuels, biodegradable, does not contain sulfur, are non-toxic and can be recycled, (Debowski, Zieliński et al., 2013). They are obtained from a renewable resource that is carbon neutral and emissions from fuel burning are in balance with the absorption of CO2 during photosynthesis, (Coast and De Morais, 2011) and (Swahili and Sarbatly, 2012). These are alternatives for clean, sustainable and profitable energy and can be performed through small micro-organisms, such as oil algaes, (Chisti, 2007). The true mark of algaes is the fact that these microscopic organisms can provide the raw material for biomass for flexible production of several different types of renewable and sustainable biofuels, (Zhu, Hiltunen et al., 2014).

Additionally, hydrogen can be produced directly by a process of separation of water through the photosynthetic capacity of algae and cyanobacteria, (Show, Lee et al., 2011). In the process of separation of water, oxygen is produced which in turn eliminates the production of hydrogen, (Kapdan and Kargi, 2006). The bio-hydrogen production have focused on bio-photolysis of water using biomass from FSP that contain algae and cyanobacteria, photo-decomposition of organic compounds by photosynthetic bacteria and dark fermentation of organic compounds anaerobes (Show Lee et al., 2011) and (Show and Lee, 2013).

Another point to consider is that global phosphate reserves are decreasing in quantity and quality. It is assumed that the phosphate rock production will peak at approximately 50 and 100 years and then decrease as the reserves are depleted, (Cordell, Drangert et al., 2009). Therefore, the sustainable supply of nutrients for the production of biofuels of biomass from FSP, is of great importance in economic terms, due to the depletion of natural resources and environmental protection, (Lardon L., 2009). The use of wastewater can reduce the need for additional nitrogen sources and phosphorus approximately 55%, (Zhang, Yang et al., 2014).

2.3 Recovery of biomass from FSP

The removal of the biomass from FSP is a detected problem (Kothandaraman, 2006). It is essential to decrease the concentrations of organic matter, suspended solids and nutrients from effluents from stabilization ponds to minimize the harmful effects of eutrophication. There is no definitive consensus on the best method for performing this removal, by centrifugation, microfiltration, coagulation, biofluculação, among others. Pittman, Dean et al. (2011) report that, tertiary treatment of effluent with the recovery of biomass from FSP and subsequent removal of nutrients and organic matter and use in biofuel production, is a technically feasible solution. The important factors that justify this study is that the algaes are made from renewable resource whose emissions from fuel burning are in balance with the absorption of CO2 by growing bodies and when they are used for the production of oil per hectare shows superior results when compared to other crops, (Grobbelaar, 1981) and (Antunes, 2010).

Compared with the biomass from agricultural plants, biomass from the FSP has the following advantages: (i) high photosynthetic efficiency, (Lin, Lai et al, 2013) and (Xu, 2006), (ii) capable of being grown in media with different water conditions and with high lipid content, (Chiaramonti, Prussi et al., 2013) and, even more important (iii) does not compete with crops of land and food, (Soratana, 2011). Also, if the production of biofuels were introduced on a large scale or national levels, social concerns, such as global supply safeguard food security and must be accounted for. Microalgae offer the benefit of resource use non-edible biomass, (Ahmad Yasin et al., 2011). On the other hand, Pittman, Dean et al., (2011), reported that in spite of wastewater from urban, agricultural and industrial activities provide efficient and sustainable ways of growing algaes to biofuels, their studies that consider that with current technologies algaes of cultivation for biofuel production is unlikely to be economically viable.

With the biomass from the FSP may be similar to the oil producing petroleum products available on the market, which can be converted into gasoline and diesel using existing refineries, (Mostert and Grobbelaar, 1987) and (Oswald, 1988). Challenges related to the use of biomass from FSP involve technologies for the collection in ponds, (Rawat, Ranjith Kumar et al., 2011), and its use as fuel for burning or direct gasification, (Pittman, Dean et al., 2011), (Swahili and Sarbatly, 2012), (Khoo, Koh et al., 2013) and (Silva, 2013).

2.4 Algaes harvesting technologies

Selection of harvesting technologies depends principally on the characteristics of algae and the state of stability in which they thrive, (Cooney et al., 2009 and (Chen, Yeh *et al.*, 2011). Current work on algae for the production of biofuel was mainly focused on microalgae. For microalgae grown in aqueous medium, concentrating loose algae suspension until a thick algae slurry or cake is a vital stage of harvesting. The water content of algae suspension must be reduced as far as possible to enable practical harvesting and downstream processes. The process steps for recovering and collecting biomass from FSP are: algae in suspension, screening (micro straining and vibrating screen), thickening (coagulation-flocculation, flotation, gravity sedimentation, flotation and other harvesting techniques such as electrophoresis, electro flotation and ultrasound, (Chen, Yeh *et al.*, 2011)), dewatering (filtration and centrifugation) e drying (rotary dryers, spray drying, solar heat drying, cross-flow and vacuum shelf drying, (Show, Lee et al., 2013).

2.5 Productivity of biomass from FSP

The first indicator on the productivity of biomass from FSP dry basis, was 200 mg .L^{-1} and with counts in the range 10-103 organismos.L^{-1}, (Hackenberger, 1981). Ji, Abou Shanab, et al., (2013) developed biomass productivity research from FSP in urban sewage for different types of algaes and with addition of carbon dioxide, the same lighting condition, cultivation period and pre-treatment and compared their results with those obtained with researchers with different conditions of carbon dioxide addition, lighting and pretreatment. The biomass containing the seaweed O. Multisporus, originated from residual sewage water showed higher productivity 0.203 g.L^{-1}, on a dry basis.

3. METHODOLOGY AND RESULTS

3.1 Characterization of wastewater from FSP Barcelona

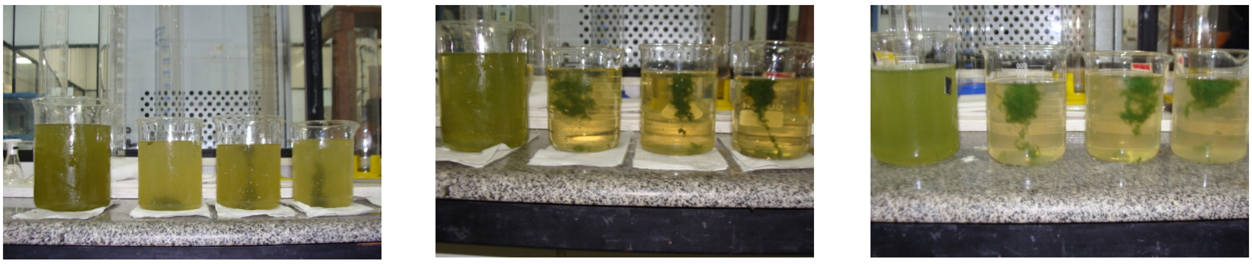
Table 1 shows the values of parameters that characterize the wastewater from FSP Barcelona. These are average values over environmental monitoring from October, 2014 to march, 2015. Referring to the operational control contacts the efficacy of treatment with the reduction of turbidity, electrical conductivity and the effluent and increasing the dissolved oxygen in the pond and subsequent reduction in the effluent. Concerning the quality of the water there is an increase of chlorophyll in photosynthesis due pond and the consequent reduction in the effluent and reduce the organic matter (BOD5 DQOT, COD) and nutrients (nitrate e phosphorus) in the lagoon and in the effluent, and also the reduction of the total dissolved solids in the pond.

Table 1. Parameter values that characterize of wastewater from FSP Barcelona.

Aspect	Parameter	Symbol	Unity	Affluent 1	Affluent 2	Pond	Effluent
Operational control	Turbidity	TU	NTU	347 ± 91	254 ± 65.1	299 ±163	192 ± 99.3
	Electrical conductivity	EC	mS	995 ± 143	1,034 ± 279	636 ± 81.2	655 ± 123
	Temperature	T	°C	28.9 ± 1.7	28.0 ± 2.0	29.9 ± 1.54	28.2 ± 1.26
	Hydrogen potential	HP		7.26 ± 1.92	7.26 ± 0.29	7,73 ± 0.57	7,24 ± 0.25
	Dissolved oxygen	DO	$mg.L^{-1}$	3.96 ± 1.30	4.17 ± 1.34	5.17 ± 3.20	2.82 ± 1.75
	(-) Redox potential	ORP	mV	223 ± 129	155 ± 85.7	186 ± 90.2	198 ± 79.3
Water quality	Phosphorus	PT	$mg.L^{-1}$	13.29 ± 4.55	11.16 ± 4.57	7.96 ± 1.68	3.98 ± 2.35
	Nitrate	NTK	$mg.L^{-1}$	1.91 ± 0.59	1.86 ± 0.50	0.62 ± 0.17	0.52 ± 0,17
	Chlorophyll α	CLA	$mg.L^{-1}$	3.42 ± 0.65	2.90 ± 0.59	75,3 ± 24.0	28.5 ± 17.2
	Organic matter	DBO5	$mg.L^{-1}$	553 ± 50.3	516 ± 68.0	148 ± 48.4	107 ± 27.9
		DQOT	$mg.L^{-1}$	1314 ± 218	910.2 ± 258	320 ± 203	254 ± 206
		DQO	$mg.L^{-1}$	442 ± 108	418 ± 64.3	125 ± 31.3	101 ± 48.5
	Total dissolved solids	TDS	$mg.L^{-1}$	487 ± 93.2	556 ± 210	310 ± 63.0	343 ± 28,8

3.2 New method for recovery the biomass from FSP

The developed method aims to serve those communities and was based on he recommendation of Ferrari, (2004). It consists of clotting followed by flocculation and sedimentation of biomass from FSP to be reliable and economical. Cationic synthetic polymer was used. The method was composed of the following steps: separating certain volume of wastewater pond water sample under study in a backer; add the cationic synthetic polymer; mix the wastewater and polymer with manual movement; await the formation of the "cake" of biomass; remove the supernatant; collect biomass produced wet and dry biomass produced Fig. 1 and Fig. 2.

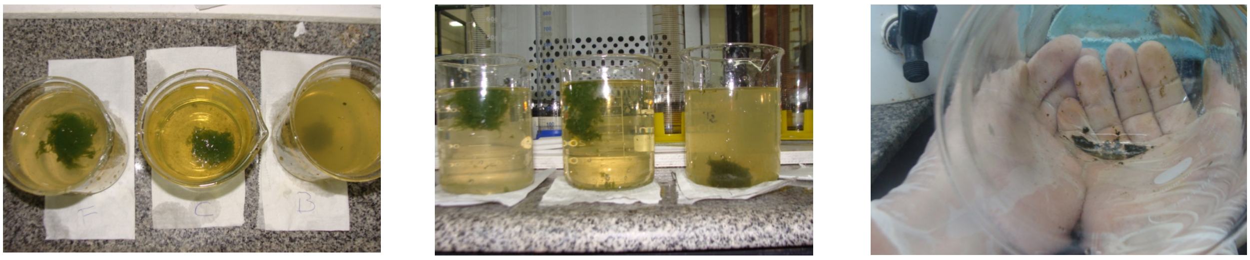


(a) (b) (c)

Figure1. Sample crude rejoinder and sample removal of biomass from FSP: (a) Barcelona, (b) Civit and (c) Feu Rosa.

3.3 Characterization of biomass from FSP

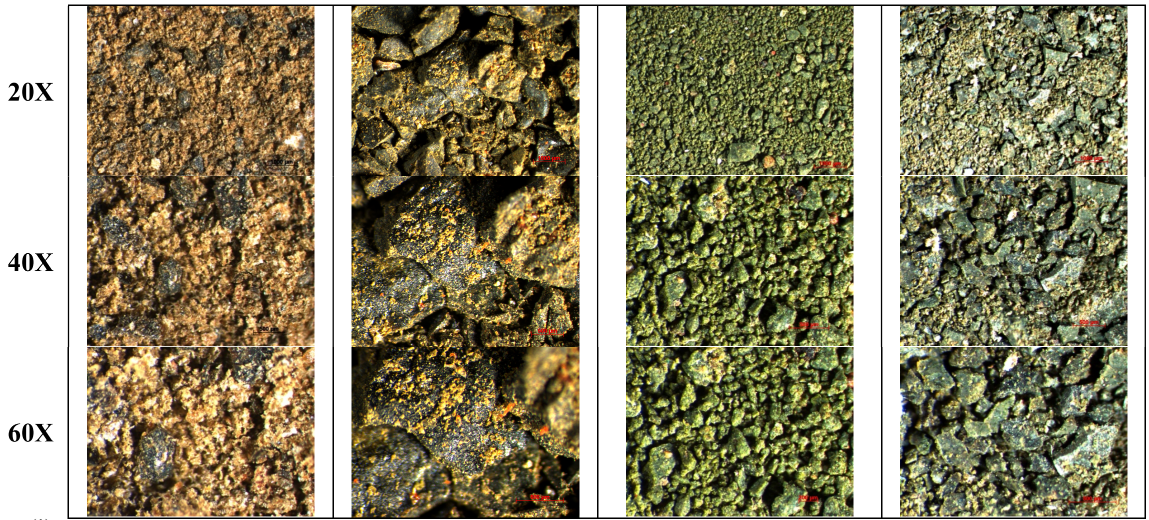
For this study were chosen the facultative stabilization ponds, FSP, Barcelona (classical system, known as Australian), located in the city of Serra, ES, the Company Espirito Santo Sanitation, Cesan, (Cesan, 2013), and chosen the from FSP Gama (composed reactor anaerobic up-flow, bioreactor and clarifier) and FSP Alagado (composed of reactor anaerobic up-flow, high-rate pond, pond, run off and final polishing) both in the city of Brasilia, DF, Company Environmental Sanitation of the Federal District, Caesb, (caesb, 2013).



(a) (b) (c)

Figura 2. Recovery of biomass from FSP Feu Rosa, FSP Civit and FSP Barcelona: (a) upper view, (b) front view and (c) separation of the supernatant and collecting biomass from FSP.

Visual characterization of the biomass from FSP's (Barcelona, Alagado e Gama) was performed by their shapes, colors and empty by optical microscopy. The images were magnified and reduced by approximately 5 times for text. Figure 3 shows that biomass derived from FSP that operate regularly have coloring in shades of green while the irregularly features reddish brown color. Regarding the form of the grains, FSP Gama is characterized by angular corners, while STP's Barcelona and Alagado with rounded corners. FSP Barcelona characterized by having more voids than the other two FSP's studied due to irregularity of the grain size, which facilitates the transfer of heat and mass, (Hobbs ML 1993), facilitating the spread the combustion front, (Shin and Choi, 2000).



(1) FSP Barcelona operates improperly, has reddish brown color having overload indicating the possible presence of organic matter and photosynthetic bacteria oxidizing sulphide, (Arceivala, 1983), (Uehara, 1989) apud (Von Speling, Ano Edição 2006)

Figure 3. Enlarged images of biomass from FSP by optical microscopy.

To characterize the biomass from FSP's, parameters were selected as the elemental and proximate analysis, calorific value, solids series, nutrients, biological composition, thermo energetic and its classification as a solid residue. The parameters to characterize the biomass studied, their technical standards and values are presented in Tab 2. The study of influence of the drying and storage conditions is presented in Tab. 3.

Study was conducted regarding the loss of calorific value due to drying and storage conditions. With the biomass from FSP Gama, it was found a loss of 20% of the calorific value when compared to biomass tested after drying and the biomass stored and subsequently assayed. The biomass from FSP Alagado when used drying bed, exposed to sun, rain and wind, has reduced calorific value by 17% compared with the test of biomass after drying in environment with sun protection and rain. The loss of biomass from FSP Alagado increases to 48% when besides being dried in drying bed and exposed to sunlight, wind and rain and is stored in a closed container. In FSP Barcelona found that the loss of calorific value may be 60% when the pond operates improperly.

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Table 2. Parameter values that characterize the biomass studied from FSP's.

Parameter			Technical standard	Facultative stabilization pond (FSP)		
Description		Unit		Gama	Alagado	Barcelona
Elemental analysis	Carbon	%	4500 CO_2 (1)	36.15 ± 0.41	32.01 ± 0.29	48.06 ± 0.77
	Hydrogen	%	5560 D (1)	4.74 ± 1.14	4.82 ± 0.66	4.18 ± 0.30
	Total nitrogen	%	4500 N_{ORG} (1)	3.87 ± 0.02	2.72 ± 0.06	6.03 ± 0.11
	Oxigen	%	4500 O (1)	34.88 ± 0.27	37.45 ± 0.76	22.14 ± 1.42
Total phosphorus		$mg.L^{-1}$		2.748 ± 0.076	3.155 ± 0,028	2.775 ± 0.153
Volatile suspended solids		(%)	2540 F (1)	62.02 ± 0.85	60.61 ± 0.43	91.15 ± 3.48
Value calorific		$kJ.kg^{-1}$	(Abnt, 1983c)	11.435 ± 1.649	10.120 ± 318	10.700 ± 1.543
Biological	Colimetric assays	NMP/100mL		10.000	75	150
	Coliforms and *E. Coli*	NMP/100mL		0	40	40
Eco toxicological				No acute toxicity of dilution samples 1:10 for *Vibrio fischer*		
Solids waste		Classification	(Abnt, 2004)	Class II A: non-hazardous and non-inert		

(1): (Apha, 2012).

Table 3. The calorific values of biomass from FSP studied, drying and storage conditions.

Trial date	Biomass from FSP	Calorific value (kJ/kg)	Production date	Collection	Drying	Storage
10/14 to 01/15	Gama	11,435.2 ± 1,649.4	25/07/14	25/07/14	Protected from sun and rain	Open plastic bag
11/14 to 12/14	Alagado	10,122.1 ± 318.2	27/11/14	27/11/14	Air bed Protected from sun and rain	Open plastic bag
10/14 to 01/15		8,404.5 ± 1,758.6	09/13	01/08/14	Drying bed exposed to the weather: sun, rain and wind	Open plastic bag
01/15		5,181.8 ± 1,238.8				Closed glass
11/14 to 01/15	Barcelona	10,700.6 ± 1,543.1	Collected and dried	nov/14 to jan/15	In oven at 60 °C	Immediate test
01/15	Barcelona	4,230.2 ± 393.8		dez/14		Open container

3.4 Sobrenadante

Para validar a eficácia da remoção e coleta da biomassa LEF, foi comparada a qualidade das águas residuárias do efluente com as do sobrenadante, utilizando como parâmetros a clorofila α, o fósforo e o nitrogênio. O efluente reduz o valor da clorofila a em 44.9 %, enquanto que o sobrenadante reduz para 73.2%. O efluente reduz o valor do fósforo em 53.2 %, enquanto que o sobrenadante reduz para 75.8 %.

4. CONCLUSÃO

The effluent from facultative stabilization ponds contains organic and mineral material and this creates an environmental problem due to be composed of phosphorus and nitrogen. In the FSP Barcelona total suspended solids value is greater than 300 mg L^{-1}. Applying the proposed method (coagulation, flocculation and sedimentation) for removing biomass from FSP was contacted reducing the increase of the parameter values of the wastewater, as compared with the effluent supernatant: chlorophyll (44.9 to 73.2%) and phosphorus (53.2% to 75.8%). Biomass production was close to 0.30 mg L-1. The biomass is characterized by being a non-hazardous waste and not inert, non-toxic, rich in carbon and oxygen, about 35wt%, hydrogen and nitrogen around 5 and 3.5 wt.%, respectively. The thermal energy application indicates the route via gasification, due to the high percentage of volatile solids, about 90% in the optional stabilization pond 60% with high rates of treatment lagoons.

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6. REFERENCES

Abou-Shanab, R. a. I., J.-H. Hwang, *et al.*, 2011. Characterization of microalgal species isolated from fresh water bodies as a potential source for biodiesel production. Applied Energy, v.88, n.10, 10//, p.3300-3306.

Abou-Shanab, R. a. I., M.-K. Ji, *et al.,2013.* Microalgal species growing on piggery wastewater as a valuable candidate for nutrient removal and biodiesel production. Journal of Environmental Management, v.115, n.0, 1/30/, p.257-264.

Abou-Shanab, R. a. I., I. A. Matter, *et al.*, 2011. Characterization and identification of lipid-producing microalgae species isolated from a freshwater lake. Biomass and Bioenergy, v.35, n.7, 7//, p.3079-3085.

Ahmad, A. L., N. H. M. Yasin, *et al*, 2011. Microalgae as a sustainable energy source for biodiesel production: A review. Renewable and Sustainable Energy Reviews, v.15, n.1, 1//, p.584-593.

Amengual-Morro, C., G. Moyà Niell, *et al.*, 2012. Phytoplankton as bioindicator for waste stabilization ponds. Journal of Environmental Management, v.95, Supplement, n.0, 3//, p.S71-S76.

Antunes, R., Silva, I., 2010. Utilização de algas para produção de biocombustível. INPI. Rio de Janeiro: INPI Instituto Nacional de Propriedade Industrial. Rio de Janeiro, Brazil.

Apha. Standard Methods for the examination of water and wastewater. A. W. W. a. A. American Public Health Association (Apha), American Water Environment Federation (Awef), 2012. Washington DC, USA.

Arceivala, S. J., 1983. Wastewater Treatment and Disposal. New York and Basel: Marcel Dekker Inc., v.86 Internationale Revue der gesamten Hydrobiologie und Hydrographie.

Chen, C. Y., K.-L. Yeh, *et al.,* 2011. Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review. Bioresource Technology, v.102, n.1, 1//, p.71-81.

Chiaramonti, D., M. Prussi, *et al.,* 2013. Review of energy balance in raceway ponds for microalgae cultivation: Re-thinking a traditional system is possible. Applied Energy, v.102, n.0, 2//, p.101-111.

Chisti, Y., 2007. Biodiesel from microalgae. Biotechnology Advances, v.25, n.3, 5//, p.294-306.

Cooney, M., Young, G., Nagle, N., 2009. Extraction of bio-oils from microalgae. Journal of Separation and Purification Reviews. Rev. 38, 219–325.

Cordell, D., J.-O. Drangert, *et al.,* 2009. The story of phosphorus: Global food security and food for thought. Global Environmental Change, v.19, n.2, 5//, p.292-305.

Costa, J. a. V. e M. G. De Morais., 2011. The role of biochemical engineering in the production of biofuels from microalgae. Bioresource Technology, v.102, n.1, 1//, p.2-9.

Dębowski, M., M. Zieliński, *et al.,* 2013. Algae biomass as an alternative substrate in biogas production technologies—Review. Renewable and Sustainable Energy Reviews, v.27, n.0, 11//, p.596-604.

Demirbas, M. F., 2011. Biofuels from algae for sustainable development. Applied Energy, v.88, n.10, 10//, p.3473-3480.

Dismukes, G. C., D. Carrieri, *et al.,* 2008. Aquatic phototrophs: efficient alternatives to land-based crops for biofuels. Current Opinion in Biotechnology, v.19, n.3, 6//, p.235-240.

Esteves, F. A., 2011. Fundamentos de limnologia. Rio de Janeiro: Interciência. Rio de Janeiro, Brazil

Felizatto, M. R. , 2000. Reuso de água em´piscicultura no Distrito Federal: potencial para pós-tratamento de águas residuárias associao à produção de pescado. Departamento de Engenharia Civil e Ambiental UNB, Brasília, DF.

Grobbelaar, J. U., 1981. Open semi-defined systems for outdoor mass culture of algae. Wastewater for aquaculture. Bloemfontein, South Africa.

Hackenberger, J. S., Arceivala, J., 1981. Wastewater treatment and disposal. Internationale Revue der gesamten Hydrobiologie und Hydrographie, 895–896 p.

Jena, U., N. Vaidyanathan, *et al.,* 2011. Evaluation of microalgae cultivation using recovered aqueous co-product from thermochemical liquefaction of algal biomass. Bioresource Technology, v.102, n.3, 2//, p.3380-3387.

Ji, M.-K., R. a. I. Abou-Shanab, *et al.,* 2013. Cultivation of microalgae species in tertiary municipal wastewater supplemented with CO2 for nutrient removal and biomass production. Ecological Engineering, v.58, n.0, 9//, p.142-148.

Kapdan, I. K. e F. Kargi., 2006. Bio-hydrogen production from waste materials. Enzyme and Microbial Technology, v.38, n.5, 3/2/, p.569-582.

Khoo, H. H., C. Y. Koh*, et al.,* 2013. Bioenergy co-products derived from microalgae biomass via thermochemical conversion – Life cycle energy balances and CO2 emissions. Bioresource Technology, v.143, n.0, 9//, p.298-307.

Kim, Y., Giokas, D. L., 2003. Separation of algal particles from waste stabilization ponds by floating aquatic plant. E. E. Research. 8**:** 152-161 p.

Kothandaraman, V., Evans, R., 2006. Removal algal from waste stabilization ponds effluents - a state of the art.

Lardon L., H. A., Sialve B., Bernard Steyer J., 2009. Life-cycle assessment of biodiesel production from microalgae. Environmental Science & Technology, v.43, p.6475–81.

Lin, T., Q. Lai*, et al.,* 2013. Combined effects of carbonate alkalinity and pH on survival, growth and haemocyte parameters of the Venus clam Cyclina sinensis. Fish & Shellfish Immunology, v.35, n.2, 8//, p.525-531.

Mostert, E. S. e J. U. Grobbelaar., 1987. The influence of nitrogen and phosphorus on algal growth and quality in outdoor mass algal cultures. Biomass, v.13, n.4, //, p.219-233.

Oswald, W. J., 1988. Microalgae and wastewater treatment. Microalgal biotechnology. Cambridge: Cambridge University press.

Peng, W. M., Wu, Q.Y., Tu, P.G., 2001. Pyrolytic characteristics of heterotrophic Chlorella protothecoides for renewable bio-fuel production. Journal Application Phycology, v.13, p.5-12.

Pittman, J. K., A. P. Dean*, et al.,* 2011 The potential of sustainable algal biofuel production using wastewater resources. Bioresource Technology, v.10.2, n.1, 1//, p.17-25.

Posten, C., Schaub, G., 2009. Microalgae and terrestrial biomass as source for fuels e a process view. Journal of Biotechnology, v.142, p.64-69.

Rawat, I., R. Ranjith Kumar*, et al.,* 2011. Dual role of microalgae: Phycoremediation of domestic wastewater and biomass production for sustainable biofuels production. Applied Energy, v.88, n.10, 10//, p.3411-3424.

Richmond, A., 2004. Handbook of Microalgal Culture: Biotechnology and Applied Phycology: Blackwell Science Ltd.

Rodolfi, L., Zittelli, G.C., Bassi, N., Padovani, G., Biondi, N., Bonini, G., Tredici, M.R., 2009. Microalgae for oil: strain selection, induction of lipid synthesis and outdoor mass cultivation in a low-cost photobioreactor. Biotechnology Bioengergy, v.102, p.100-112.

Schenk, P. M., Thomas-Hall, S.R., Stephens, E., Marx, U.C., Mussgnug, J.H., Posten, C., Kruse, O., Hankamer, B., 2008. Second generation biofuels: high efficiency microalgae for biodiesel production. Bioenergy Research, v.1, p.20–43.

Show, K.-Y. e D.-J. Lee., , 2013. Chapter 13 - Bioreactor and Bioprocess Design for Biohydrogen Production. In: A. P.-S. C. C. H. Larroche (Ed.). Biohydrogen. Amsterdam: Elsevier. Chapter 13 - Bioreactor and Bioprocess Design for Biohydrogen Production, p.317-337

Show, K.-Y., D.-J. Lee*, et al.,* 2011. Bioreactor and process design for biohydrogen production. Bioresource Technology, v.102, n.18, 9//, p.8524-8533.

Silva, F. V. M., L. O., 2013. Pirólise de biomassa algal proveniente de lagoas de alta taxa aplicada ao tratamento de esgoto sanitário. XV Congresso Brasileiro de Energia. Rio de Janeiro, Brazil.

Soratana, K. L., A. E., 2011. Sulfate deficiency stimulates release of dissolved organic matter in synchronous cultures of scenedesmus obliquus. Bioresource Technology. 102**:** 6892–6901 p.

Suali, E. e R. Sarbatly., 2012. Conversion of microalgae to biofuel. Renewable and Sustainable Energy Reviews, v.16, n.6, 8//, p.4316-4342.

Uehara, M. Y. E. V., W.L., 1989. Operação e Manutenção de lagoas anaeróbias e facultativas - Série Manuais. CETESB Companhia de Tecnologia do Saneamento Ambiental - Secretaria do Meio Ambiente.São Paulo, Brasil.

Von Speling, M., 2003. Lagoas de estabilização: princípios de tratamento biológico de águas residuárias. Ano Edição 2006. 196 p. Belo Horizonte, MG.

Wang, B., Li, Y., Wu, N., Lan, C.Q., 2008. CO2 bio-mitigation using microalgae. Applied Microbiology Biotechnology, v.79, p.707–718.

Xu, H., ; Miao, X.; Wu., 2006. High quality biodiesel production from a microalgachlorella protothecoides by heterotrophic growth in fermenters. Journal of Biotechnology, v.126, n.(4), p.499 – 507.

Zhang, H., J. Yang*, et al.,* 2014. Mechanism of red mud combined with Fenton's reagent in sewage sludge conditioning. Water Research, v.59, n.0, 8/1/, p.239-247.

Zhu, L. D., E., 2014. Hiltunen*, et al.* Microalgal biofuels: Flexible bioenergies for sustainable development. Renewable and Sustainable Energy Reviews, v.30, n.0, 2//, p.1035-1046.

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