Contemporary Engineering Sciences, Vol. 10, 2017, no. 22, 1067 - 1074
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2017.7884

Design of a Microalgae Bio-Reactive Facade Reactor for Cultivation of *Chlorella vulgaris*

Crisóstomo Barajas Ferreira[1], Lucero Castro Padilla[1], Ginna Vanegas Sánchez[1], Ángel González-Delgado[2] and Andrés Barajas-Solano[3]

[1] Industrial University of Santander, Chemical Engineering Department
Cra 27 Calle 9 Ciudad Universitaria, Bucaramanga, Colombia

[2] University of Cartagena, Chemical Engineering Department
Avenida del Consulado Calle 30 No. 48 – 152, Cartagena, Colombia

[3] University of Santander UDES, Program of Environmental Engineering
Calle 70 No. 55 – 210, Bucaramanga, Colombia

Abstract

The increasing global demand for energy that has existed during many decades has affected the environment due to the greenhouse gas emissions, which are the result of the inadequate use of fossil fuels. This situation has contributed to the development of researchers regarding the microalgae production to capture the CO_2 present in the atmosphere. Therefore, this paper presents the influence of the design variables (width and depth) of a flat-plate photobioreactor on the biomass productivity of *Chlorella vulgaris* UTEX 1803 and the evaporated volume for a period of 74 days, under the environmental conditions of Bucaramanga, Colombia. In addition, the effect of evaporated volume and temperature on biomass productivity was analyzed. It was verified that the average temperature of 29.72 °C is not an influential variable on biomass productivity. According to the results, the design of a photobioreactor with width dimensions greater than 15 cm and depth 3 cm is required to obtain a productivity of 0.35 g/L d.

Keywords: Facade photobioreactor, *Chlorella vulgaris*, Biomass Productivity

1. Introduction

In a world where the requirements for economic and social expansion change quickly, the efficient use of energy plays an important role. Sustainable urban development must be considered as an integral process of global rural development, aimed at improving the living conditions and productivity of large population groups [1], however, it requires feasible and low-cost energy sources that allow their rational use and a low environmental footprint [2]. Recently, the use of bioreactors has been proposed as a biofacade building, which has microalgae cultures in glass plates that allow to produce energy from the biomass methanogenesis[3,4], reduce the environmental impact of the city by the CO_2 sequestration and provide the building with a bio-climatic system. Binding carbon dioxide by microalgae is ecologically sustainable when it is combined with other environmental protection processes such as wastewater treatment [5,6] or heavy metals removal. However, these types of flat photobioreactors depend on several environmental factors that can substantially reduce photosynthetic efficiency; therefore, there is no a "better" photobioreactor than other, but adjusted to the environmental needs of the workplace. Even so, the conditions that allow optimizing biomass production will always be the same regardless of their geographical position. Nowadays, the development and research on microalgae in Colombia have been strongly focused on obtaining strains for biofuels production (mainly biodiesel) [7,8], so that the design, construction, and testing of different photobioreactors have been relegated to this field [9,10]. There are no experiments to solar scale with this type of photobioreactors or information on the biomass productivity, energy capacity or other architectural and mechanical considerations that could negatively affect the stability of building's facade. Therefore, this paper presents the design of a facade photobioreactor as a cornerstone for the evaluation of sustainable constructions. The effects of the photobioreactor dimensions (width and length) were evaluated; in addition, aspects such as material selection, assembly, analysis of variables influencing the strain behavior (pH, temperature, and conductivity) and nutrients supply to increase the productivity of biomass were considered.

2. Materials and Methods

Microalgae

Chlorella vulgaris UTEX 1803 was acquired from the University of Texas, USA and grown in Bold Basal modified media. Cylindrical reactors with internal diameter 14 cm and 35 cm in height with a culture volume of 8 L were used. The reactors were coupled to a bubbling aeration system for the air injection at a flow rate of 1.5 L/min. Each liter of culture media employed had the composition of macronutrients and micronutrients listed in Table 1.

Table 1. Composition of Modified Basal Bold culture media

Nutrient	Name	Amount	Unit
Macronutrients	$NaNO_3$	$2.94x10^{-3}$	moles
	$MgSO_4.7H_2O$	$3.04x10^{-4}$	
	NaCl	$4.28x10^{-4}$	
	K_2HPO_4	$4.31x10^{-4}$	
	KH_2PO_4	$1.29x10^{-3}$	
	$CaCl_2.2H_2O$	$1.70x10^{-4}$	
Micronutrients	$ZnSO_4.7H_2O$	$3.07x10^{-5}$	g/L
	$MnCl_2.4H_2O$	$7.28x10^{-6}$	
	MoO_3	$4.93x10^{-6}$	
	$CuSO_4.5H_2O$	$6.29x10^{-6}$	
	$Co(NO_3)_2.6H_2O$	$1.68x10^{-6}$	
	H_3BO_3	$1.85x10^{-4}$	
	EDTA	$1.71x10^{-4}$	
	KOH	$5.53x10^{-4}$	
	$FeSO_4.7H_2O$	$1.79x10^{5}$	

Experimental design

In order to determine the effect of the reactor dimensions on biomass production, the width (10, 15 and 20 cm) and the depth (5, 7 and 11 cm) of each photobioreactor were evaluated without modifying the height (40 cm), based on a non-factorial central experiment design 2^3 carried out using the software STATISTICA 7.0. Each of the reactors was built in 8-line glass reinforced with structural aluminum foils, which were washed with 0.03% NaClO during 3 days of contact time to prevent any kind of microorganism or dirt that could affect the microalgae growth. Then, they were filled with 10 L of culture media and placed in the engineering building placed at the University of Santander, then were coupled to a stirring system by the addition of air by bubbling at 0.6 L/L.

Measurement of operating variables: Temperature, pH, and conductivity

The temperature, pH, and conductivity of the cultures were measured using a multiparameter portable meter (IQ 160, HACH) using a sensor which was calibrated with buffer solutions at standard pH of 4, 7, and 10 to adjust the signal during measurements.

Measurement of evaporated volume and biomass quantification

Evaporation rate was calculated every 3 days based on known dimensions and height changes recorded in all photobioreactors. On the other hand, the biomass concentration C_B (g/L) was calculated using the Equation 1. Culture samples of 1 ml were taken from each photobioreactor and diluted in 9 ml of distilled water every three days; then, its optical density (OD) was measured at 550 nm using a spectrophotometer (DR 1900, Hach).

$$C_B = (OD_{550} - 0.1734)/1.3161 \tag{1}$$

3. Results and Discussion

Biomass concentration

Chlorella vulgaris remained in growth for 74 days, exposed to solar radiation. Figure 1 shows that the first growth cycle is between day zero and day 24, where the maximum biomass concentrations reached correspond to the photobioreactors 1 and 2 with values of 6.61 and 6.33 g/L, respectively. For the second cycle, between days 25 and 49, the maximum value of biomass concentration was 10.68 g/L corresponding to the photobioreactor 6; in addition, it was observed that photobioreactor 1 decreased from day 40 until the end of the cycle, possibly due to different factors to which the crops are exposed such as cell stress and climatic changes (heavy rains or high radiation values). Finally, during the cycle 3, the photobioreactor 6 had a maximum value of 8.96 g/L of biomass. For this cycle, the concentrations were smaller respect to the first one due to the decrease of nutrients and the possible tamponade of diffusers, which impeded a constant air flow that affected the productivity and the biomass concentration.

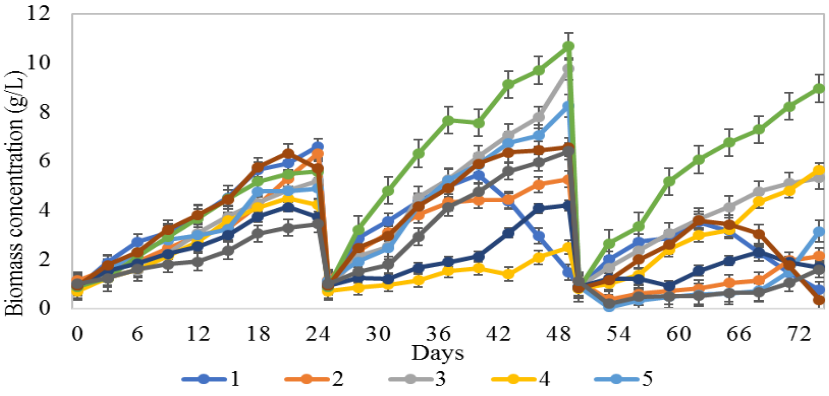


Figure 1. Biomass concentration for each photobioreactor

Biomass productivity

According to the concentration data in the cycles, the productivity was calculated by means of a difference between the maximum and the minimum value of biomass concentrations in a 24-day cycle, as it is shown in Equation 2.

$$Productivity = \frac{x_{máx} - x_{min}}{days} \tag{2}$$

Table 2 shows that the highest productivity was obtained for photobioreactors 6 and 3 with average values of 0.314 and 0.246 g/L d, respectively. These results were higher than those reported in literature for *Nannochloris atomus* (0.18 g/L d in a flat-plate artificial light bioreactor for 165 days) Dogaris *et al*., (2015) [11] and *Nannochloropsis gaditana* (0.19 g/L d in outdoor flat-plate photobioreactors for 2 years) San Pedro *et al*., (2016) [12]. In addition, it was found that the productivities of photobioreactors 1 and 8 in the final cycle were negative, indicating that the initial biomass concentration was higher than the one obtained at the end. The productivity of any microalgae system is a direct function of the total intercepted solar radiation and the type of photobioreactor.

Table 2. Productivity (g/L d) of each growth cycle of *Chlorella vulgaris*

Reactor	Cycle 1	Cycle 2	Cycle 3	Average
1	0.239	0.026	-0.003	0.012 ± 0.02
2	0.216	0.171	0.043	0.143 ± 0.09
3	0.182	0.373	0.184	0.246 ± 0.11
4	0.146	0.074	0.201	0.141 ± 0.06
5	0.163	0.297	0.094	0.185 ± 0.10
6	0.195	0.408	0.339	0.314 ± 0.11
7	0.117	0.136	0.033	0.095 ± 0.05
8	0.199	0.235	-0.020	0.138 ± 0.14
9	0.102	0.225	0.020	0.115 ± 0.10

Figure 2 presents the Pareto statistical diagram to evaluate the photobioreactor dimensions significance on the biomass production. So, it can be concluded that no sizing is statistically relevant so that other important factors such as solar radiation, temperature, pH and evaporated volume should be taken into account.

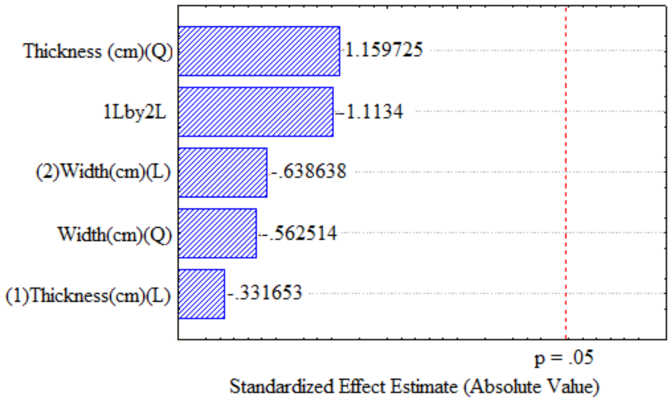
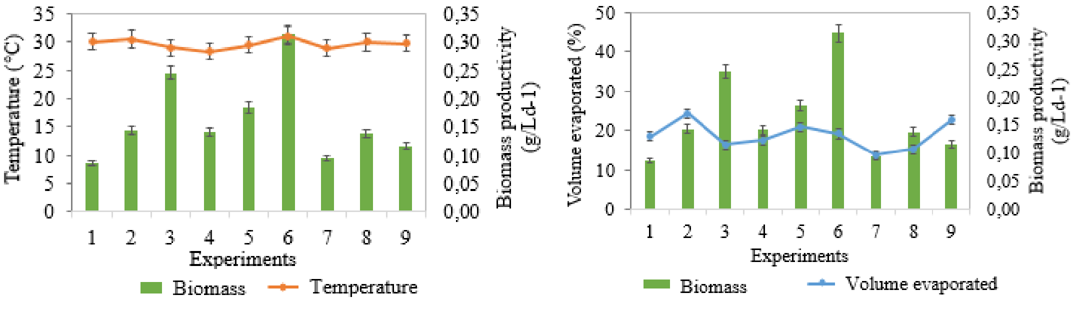


Figure 2. Pareto of photobioreactor dimensions effect on biomass production

Influence of temperature and evaporated volume on biomass productivity

Figure 3 (a) shows that the average temperature in all photobioreactors (29.72 ± 0.86 °C) does not affect biomass productivity, having maximum and minimum points of 0.314 and 0.087 g/L d. On the other hand, in Figure 3(b) it is observed that photobioreactors 2, 5 and 6 generated the most water consumption. It was determined that the orientation (E/W and N/S) did not affect significantly the biomass productivity. Due to Colombia does not have seasons, the photobioreactors can be located in lateral or frontal position. This is consistent with San Pedro *et al*., (2016) [12], who reported that biomass production (0.16 g/L d) was not highly influenced by the E/W and N/S orientation.



(a) **(b)**

Figure 3. Variation of a) average temperature and b) evaporated volume respect to biomass productivity

Design of the flat-plate photobioreactor

According to the results obtained in the experiments, Table 3 shows the design of the photobioreactor with the optimum dimensions to obtain a higher biomass productivity in the *Chlorella vulgaris* UTEX 1803 culture.

Table 3. Design of the flat-plate photobioreactor for *Chlorella vulgaris* culture

Dimensions	(mm)
Width	200
High	600
Depth	30
Construction material	4-line glass, reinforced with aluminum foils
Accessories	Ball-type discharge valve and air injection diffuser (152 mm in length
Agitation	0.6 L air/L media
Efficient use of light	High
Advantages	High productivity of biomass, economical, easy to clean, low accumulation of oxygen
Disadvantages	Difficulty of temperature control and some degree of growth on the wall

4. Conclusions

The design of a facade photobioreactor was proposed based on experimental results, where the influence of width and depth of a flat-plate photobioreactor on biomass productivity of *Chlorella vulgaris* UTEX 1803 and evaporated volume under solar radiation Colombian conditions was studied. In addition, the effect of evaporated volume and temperature on biomass productivity was analyzed. Results showed that temperature measurements in each photobioreactor did not significantly affect biomass productivity, which is proved by the value of standard deviation obtained (0.86 °C < 1 °C). In addition, it was evidenced that the E/W - N/S orientation and the position of the photobioreactor (frontal and lateral) did not affect the biomass productivity since Colombia does not present changes on climatic seasons that might generate significant variations on temperature and incidence of the sunlight. Finally, it was demonstrated that it is required a photobioreactor with dimensions of 20 cm width and 3 cm depth to obtain a productivity of 0.35 g/L d.

Acknowledgements. Authors thank to University of Santander UDES, University of Cartagena and Industrial University of Santander for the supply of software and materials necessary to successfully conclude this research.

References

[1] Y. Sun, Z. Chen, G. Wu, Q. Wu, F. Zhang, Z. Niu and H.-Y. Hu, Characteristics of water quality of municipal wastewater treatment plants in China: implications for resources utilization and management, *Journal of Cleaner Production*, **131** (2016), 1–9. https://doi.org/10.1016/j.jclepro.2016.05.068

[2] I. Zambon, D. Monarca, M. Cecchini, R. Bedini, L. Longo, R. Romagnoli and A. Marucci, Alternative Energy and the Development of Local Rural Contexts: An Approach to Improve the Degree of Smart Cities in the Central-Southern Italy, *Contemporary Engineering Sciences*, **9** (2016), 1371–1386. https://doi.org/10.12988/ces.2016.68143

[3] Á. D. González-Delgado and Y. Peralta-Ruiz, Thermodynamic Modeling of Microalgae Oil Extraction Using Supercritical Fluids, *Contemporary Engineering Sciences*, **10** (2017), 503–511. https://doi.org/10.12988/ces.2017.7334

[4] L. Janke, A. F. Leite, K. Batista, W. Silva, M. Nikolausz, M. Nelles, and W. Stinner, Enhancing biogas production from vinasse in sugarcane biorefineries: Effects of urea and trace elements supplementation on process performance and stability, *Bioresource Technology*, **217** (2016), 10–20.

https://doi.org/10.1016/j.biortech.2016.01.110

[5] M. Husaini, K. Rosyadi, N. Pujianti, R. Setyaningrum and F. Rahman, Evaluation of wastewater treatment toward physical, chemical and biology parameters in WWTP Lambung Mangkurat Banjarmasin, *Journal of Engineering and Applied Science*, **12** (2017), 226–231.

[6] X. Chen and K. Fukushi, Development of an innovative decentralized treatment system for the reclamation and reuse of strong wastewater from rural community: Effects of elevated CO_2 concentrations, *Journal of Environmental Management*, **180** (2016), 401–408. https://doi.org/10.1016/j.jenvman.2016.05.071

[7] Y. Christi, Biodiesel from microalgae, *Biotechnology Advances*, **25** (2007), 294–306. https://doi.org/10.1016/j.biotechadv.2007.02.001

[8] D. C. Kligerman and E. J. Bouwer, Prospects for biodiesel production from algae-based wastewater treatment in Brazil: A review, *Renewable & Sustainable Energy Reviews*, **52** (2015), 1834–1846. https://doi.org/10.1016/j.rser.2015.08.030

[9] I. Rawat, R. Ranjith Kumar, T. Mutanda and F. Bux, Biodiesel from microalgae: A critical evaluation from laboratory to large scale production, *Applied Energy*, **103** (2013), 444–467. https://doi.org/10.1016/j.apenergy.2012.10.004

[10] M. P. Caporgno, A. Taleb, M. Olkiewicz, J. Font, J. Pruvost, J. Legrand and C. Bengoa, Microalgae cultivation in urban wastewater: Nutrient removal and biomass production for biodiesel and methane, *Algal Research*, **10** (2015), 232–239. https://doi.org/10.1016/j.algal.2015.05.011

[11] I. Dogaris, M. Welch, A. Meiser, L. Walmsley and G. Philippidis, A novel horizontal photobioreactor for high-density cultivation of microalgae, *Bioresource Technology*, **198** (2015), 316–324. https://doi.org/10.1016/j.biortech.2015.09.030

[12] A. San Pedro, C. V. González-López, F. G. Acién and E. Molina-Grima, Outdoor pilot production of *Nannochloropsis gaditana* : Influence of culture parameters and lipid production rates in flat-panel photobioreactors, *Algal Research*, **18** (2016), 156–165. https://doi.org/10.1016/j.algal.2016.06.011

Received: September 4, 2017; Published: November 14, 2017