Chapter 7
Investigation of Photobioreactor Design for Biomass Production by Green Microalgae

Amel Ounnar, Fayrouz Kaidi, Lamia Benhabyles, and Majda Amina Aziza

Abstract In order to improve biological processes involved in biofuel production from microalgae, photobioreactors (PBR) should be adapted to control the production in optimal conditions. It should be first to study and control adapted reactors to model the entire process and facilitate the decision on the choice of raw material and design means, and finally to demonstrate the experimental feasibility of the process and allow biomass conversion for energy.

In this chapter, an overview on the role of PBR design over the microalgae growth efficiency is presented. Also, the study of the growth of *Chlorella sp*. microalgae, locally isolated from freshwater from southern Algeria, is followed inside a lab-scale PBR under controlled conditions. Some process parameters such as dry weight, and optical density were followed during the process. The obtained results show clearly the effectiveness of the closed-controlled reactor for a better growth of the *Chlorella sp*. microalgae.

Keywords Biofuel • Microalgae growth • *Chlorella sp*. • Air-lift photobioreactor

7.1 Introduction

Microalgal species are recently in the spotlight for biofuel production [1, 2]. They are also used as a biofertilizer, and source or potential source of high-value products such as polyunsaturated fatty acids or lipids [3, 4], natural colorants [5], biopolymers, and therapeutics [6]. In addition, a significant quantity of microalgal biomass is produced as essential aquaculture feed for shellfish and fish juveniles.

In fact, photosynthesis plays a fundamental role in all biofuel production. It drives the first step in the conversion of light to chemical energy and is therefore ultimately responsible for the production of the feedstocks required for all biofuel synthesis: protons and electrons (for biohydrogen), sugars and starch (for bioethanol), oils (for biodiesel), and biomass (for BTL products and biomethane).

A. Ounnar (✉) • F. Kaidi • L. Benhabyles • M.A. Aziza
Centre de Développement des Energies Renouvelables (CDER), BP. 62, Route de l'Observatoire - Bouzaréah, 16340 Alger, Algerie
e-mail: a.ounnar@cder.dz

I. Dincer et al. (eds.), *Progress in Clean Energy, Volume 2*,
DOI 10.1007/978-3-319-17031-2_7

Consequently, any increase in photosynthetic efficiency will also enhance the competitiveness of biofuel production.

In this way, it is of interest to find the most appropriate system to cultivate microalgae with very high productivities. It is essential to provide water, light energy, nutrients, carbon dioxide, as well as specific environmental conditions.

So, cultivation of microalgae can be done in open systems (lakes, ponds) and in controlled closed systems called photobioreactors (PBR). In order to improve biological processes from microalgae growth, PBR should be adapted to control the production in optimal conditions. It should be first to study and control adapted reactors to model the entire process and facilitate the decision on the choice of raw material and design means, and finally to demonstrate the experimental feasibility of the process and allow biomass conversion for energy.

Some photosynthetic microorganisms such as unicellular green microalgae (*Chlamydomonas reinhardtii*, *Chlorella fusca*, and *Scenedesmus obliquus*) are able to produce biofuel from light (artificial or solar energy) using water as electron and proton donor. In Algeria, the availability of algal resources that can be used as energy source makes the process of biofuel production interesting. Therefore, improving biological process involved in this technique led us to study air-lift PBR adapted to biofuel production control in optimal conditions.

In this work, an overview on the role of PBR design over the microalgae growth efficiency is presented. Also, the study of the growth of *Chlorella sp*. microalgae, locally isolated from freshwater from southern Algeria, is followed inside a lab-scale air-lift PBR under controlled conditions. Some process parameters such as dry weight, and optical density were followed during the process.

7.2 Photobioreactor Design

A PBR can be described as an enclosed, illuminated culture vessel designed for controlled biomass production. PBR refers to closed systems that are closed to the environment having no direct exchange of gases and contaminants with the environment [7].

When designing a PBR, some points should be taken into consideration [8]. The reactor must provide a uniform illumination of the culture surface and a fast mass transfer of CO_2 and O_2; its design must prevent or minimize the fouling of the reactor, particularly of its light-transmitting surfaces. Also, high rates of mass transfer must be attained by means that neither damage cultured cells nor suppress their growth.

The PBR which are used for the purpose of growing microalgae are tubular, flat panel, horizontal tubular, helical type, stirred tank, etc. These PBR have their own advantages and disadvantages.

7.2.1 Vertical Tubular Photobioreactor

It is made up of vertical tubing that is transparent in nature to allow light penetration. Sparger is attached at the bottom of the reactor which converts the sparged gas into tiny bubbles. Sparging with gas mixture provides overall mixing and mass transfer of CO_2 and also removes O_2 produced during photosynthesis [9]. Vertical tubular PBR can be divided into bubble column [10], torus shape reactor, and air-lift reactor based on their mode of liquid flow (Fig. 7.1).

7.2.2 Flat-Panel Photobioreactor

The flat-panel reactor has cuboidal shape with minimal light path (Fig. 7.2). It can be made from transparent materials like glass, plexiglas, and polycarbonate [13]. It is characterized by high surface area-to-volume ratio and open gas disengagement systems. Agitation is provided either by bubbling air from its one side through perforated tube or by rotating it mechanically through motor. Some works applied especially to the study of air-lift bioreactors showed the benefits of this type of reactor compared to conventional ones (low energy dissipation, controlled fluid circulation, good distribution of light, effective heat and light dissipation, etc.). Limiting parameters in the culture of microalgae are light, nutrients, temperature, and pH. Agitation is also an important parameter because it strongly influences the efficiency of gas-liquid transfer in the reactor. It serves to increase the conversion efficiency of light. A good mixing in the air-lift bioreactor could be obtained without causing too much shear force in the liquid phase, which could inhibit the growth of the algae. In addition, it was mentioned that the well-defined circulation pattern resulted in a better light utilization particularly for the system with high density of cells [14].

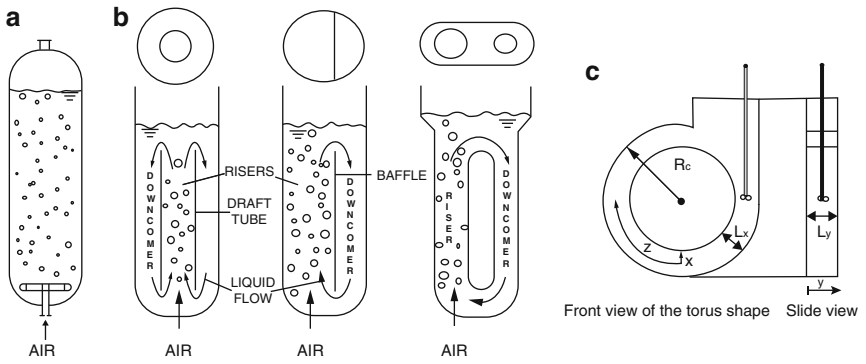

Fig. 7.1 Vertical tubular photobioreactor [11, 12]. (**a**) Bubble column, (**b**) air-lift reactor, (**c**) torus reactor

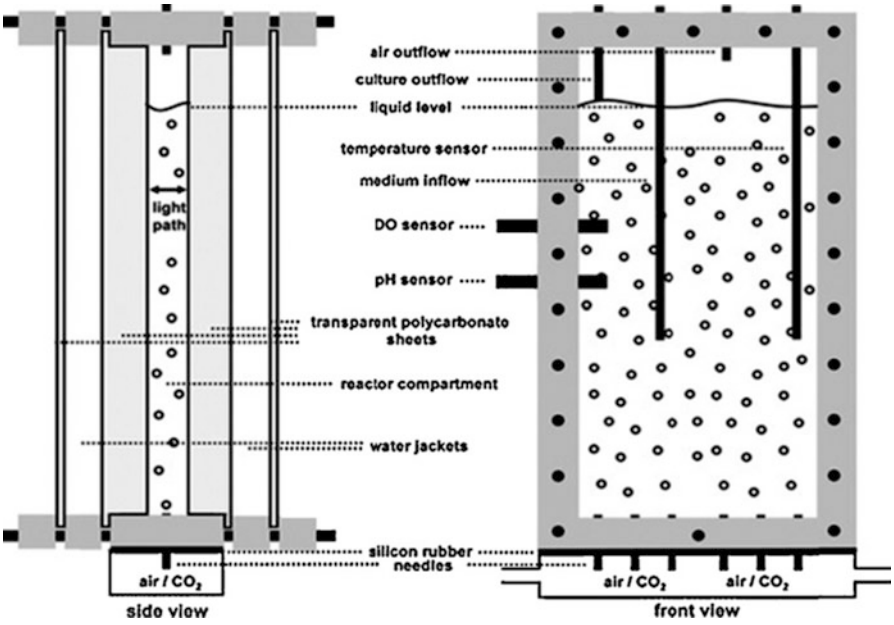

Fig. 7.2 Flat panel photobioreactor [7]

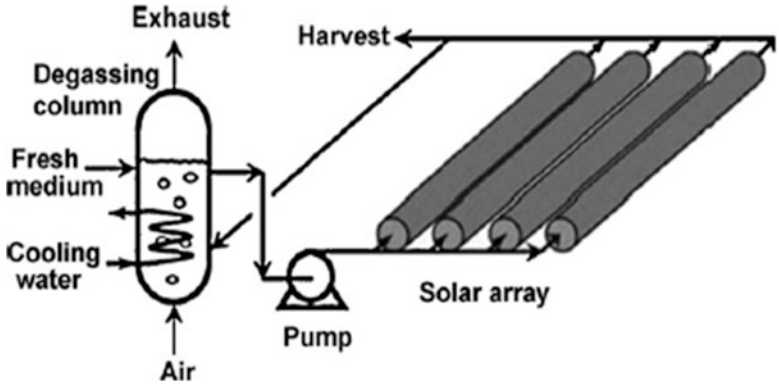

Fig. 7.3 Horizontal tubular photobioreactor [7]

7.2.3 Horizontal Tubular Photobioreactor

Horizontal tubular reactors are placed horizontally giving the design of parallel set of tubes, loop shape, inclined tubular shape, or horizontal tubular reactor (Fig. 7.3). Their shape gives advantage in outdoor culture for their orientation towards sunlight resulting in high light conversion efficiency.

7.2.4 Helical Type Photobioreactor

Helical type PBR consists of coiled transparent and flexible tube of small diameter with separate or attached degassing unit. A centrifugal pump is used to drive the culture through long tube to the degassing unit (Fig. 7.4). Travieso et al. experimented different algal strains with this system [15]. CO_2 gas mixture and culture medium can be circulated from either direction but injection from bottom gives better photosynthetic efficiency [16].

7.2.5 Stirred-Tank Photobioreactor

Stirred-tank reactor is most conventional where agitation is provided mechanically with the help of impeller of different sizes and shapes. Baffles are used in order to reduce vortex (Fig. 7.5). CO_2-enriched air is bubbled at the bottom to provide carbon source for the growth of algae. This type of bioreactor has been turned into PBR by illuminating it externally by fluorescent lamps or optical fibers but the main disadvantage of this system is low surface area-to-volume ratio which in turn decreases light-harvesting efficiency.

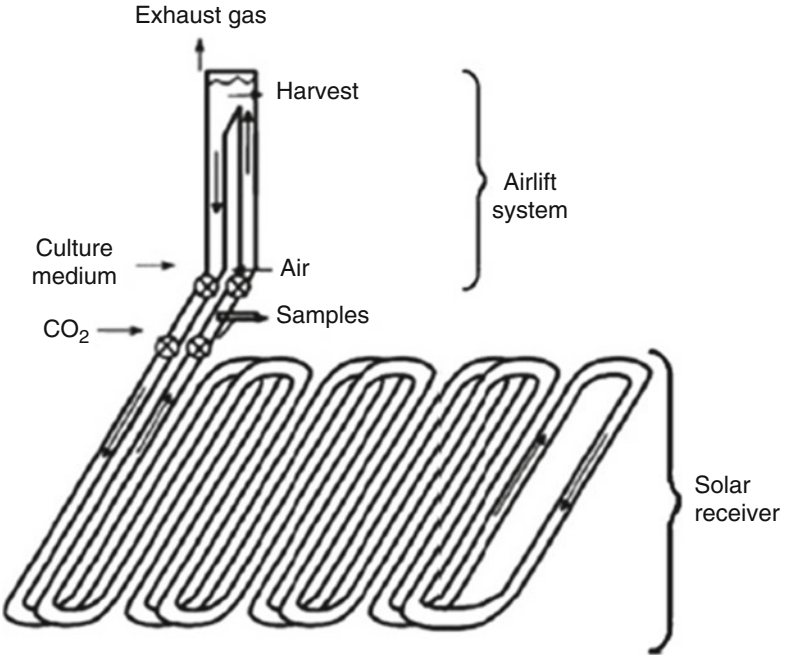

Fig. 7.4 Helical type photobioreactor [7]

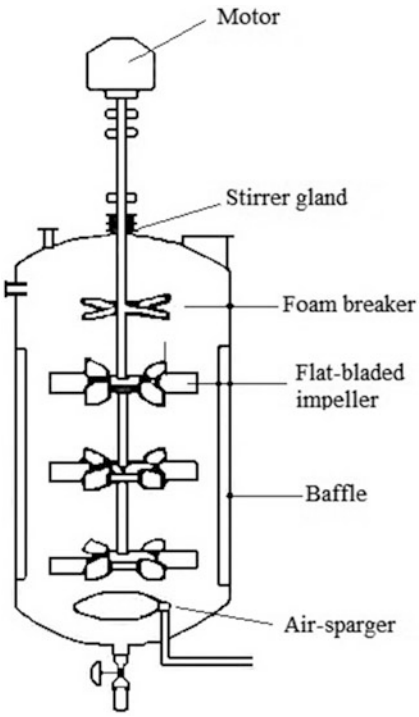

Fig. 7.5 Stirred-tank photobioreactor [7]

Despite their costs, PBR have several major advantages over open systems. They minimize contamination and allow axenic algal cultivation of monocultures; they offer better control over conditions such as pH, temperature, light, and CO_2 concentration. They also lead to less CO_2 loss, prevent water evaporation, and permit higher cell concentrations. In this work, the air-lift PBR is used to study the microalgae growth. It has characteristic advantage of creating circular mixing pattern where liquid culture passes continuously through dark and light phase giving flashing light effect to algal cells [13].

The microalgae cultivation in different types of PBR from locally identified microalgae was the subject of several research works in the Research Center of Renewable Energy Development (CDER) in Algeria [10, 17].

7.3 Experimental

7.3.1 Microalgae Strain

Microalgae specie used in this work is *Chlorella sp*. locally isolated from freshwater samples collected from southern Algeria (Fig. 7.1). The *chlorella* is a green microalga which has, most often, spherical or ellipsoidal shape. It is a solitary cell

of maximum 20 μm and has a distinctive membrane and one or rarely two plasts [18]. It has a very fast reproduction. *Chlorella* is widespread in different locations such as freshwater, air, and soil [19]. For the purpose of determining favorable growth conditions for this microalga, it was cultured in a triacetate phosphate (TAP) medium containing (quantities in g L^{-1}) NH_4Cl, 0.4; $MgSO_4$, $7H_2O$, 0.1; $CaCl_2$, $2H_2O$, 0.05; K_2HPO_4, 0.108; KH_2PO_4, 0.056; Tris, 2.42; glacial acetic acid, 1 mL; and trace of metal. The pH of the medium was adjusted to 7.2.

Chlorella sp. was maintained as pure culture in 250 mL Erlenmeyer flasks containing 50 mL of the medium. The culture was kept at 25 °C under light intensity of 11.718 μmol m^{-2} s^{-1}. Every 3 weeks 0.5 mL of a culture was transferred to a new flask containing fresh medium.

7.3.2 Air-Lift Photobioreactor

The batch cultivation of the microalgae was performed by inoculating 100 mL starter culture into 700 mL of TAP medium. The culture was grown in a 1 L air-lift PBR made of borosilicate glass with an internal diameter of 12 cm (Fig. 7.6). It was equipped with an external loop in the bottom which allows introduction of air through a central sparger diffusing from riser (where gas is sparged) to downcomer.

In the external loop, riser and downcomer are separated physically by two different tubes. Mixing is done by gas bubbling through sparger in the riser tube without any physical agitation. Riser is similar to bubble column where sparged gas moves upward randomly and haphazardly. This decreases the density of the riser making the liquid to move upward. This upward movement is assisted by the gas hold up of riser.

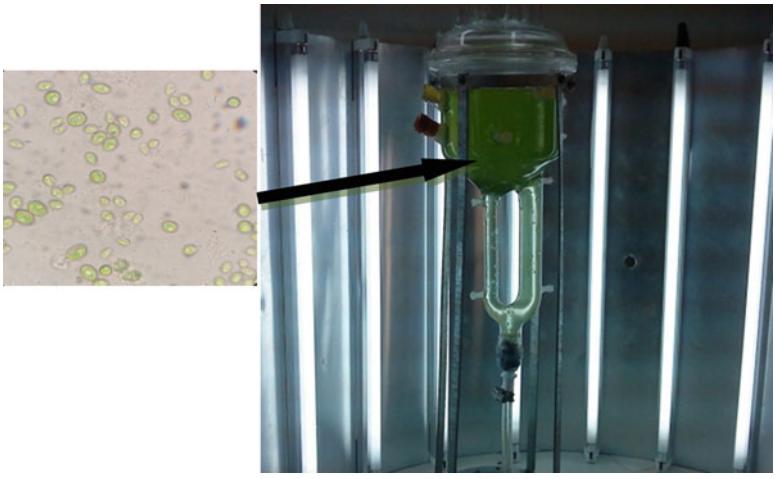

Fig. 7.6 Experimental setup

Supply of air was provided from a compressor to the loop in order to allow liquid circulation. The aeration rate was controlled by the calibrated flow meter and was fixed along the experiment to a value of 286.4 mL min^{-1}. Light was supplied through ten fluorescent white lamps connected in parallel and equidistant at the side around the length of the reactor, which yielded approximately 113.67 μmol m^{-1} s^{-1} of light intensity for a continuous photoautotrophic cultivation (24-h/24-h light photoperiod). The temperature was kept at system condition and was measured in the range of 30 °C. The top of the reactor has holes for sampling and measuring pH through appropriate probes.

In order to study the growth kinetic of microalgae, samples of the culture were taken over the time of experiment and analyzed in a spectrophotometer UV-Visible Biomat 3 for absorbance determination.

7.4 Results and Discussion

7.4.1 *Growth of* Chlorella sp. *Microalgae Under Photoautotrophic Conditions*

As shown in Fig. 7.7, cultivation of microalgae in controlled conditions of light and air aeration inside the air-lift PBR is very efficient. It is clear that microalga concentration increases considerably in this type of reactor under continuous irradiation of 113.67 μmol m^{-1} s^{-1} of light intensity.

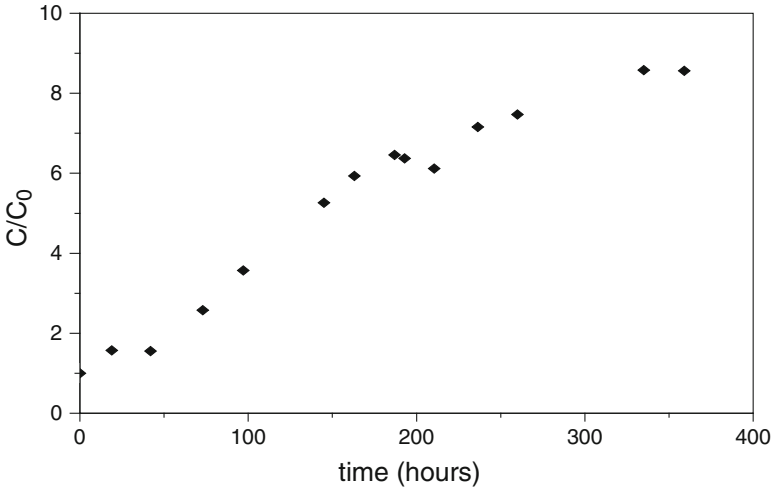

Fig. 7.7 Growth kinetic of *Chlorella sp.*

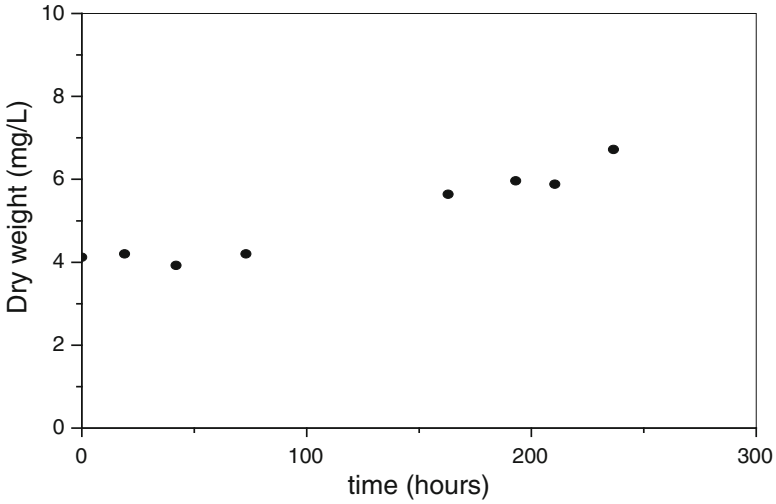

Fig. 7.8 Evolution of microalga dry-weight versus time

The growth of *Chlorella sp*. microalgae is characterized by a latency phase of about 48 h, and an acceleration phase of 100 h above the exponential phase. Thus, we observe a phase of slower growth after 300–350 h of culture.

7.4.2 Dry Weight Evolution

Figure 7.8 shows the evolution of the dry weight of microalga samples collected during the growing period. It is clear that the trend of this parameter reflects the growth of microalgae in the air-lift reactor. The high density of cells observed at the end of the experiment reflects the good mixing in the air-lift bioreactor obtained without causing too much shear force in the liquid phase.

7.5 Conclusion

The air-lift PBR are the most suitable for microalga growth because of the performance of mass transfer and present mixing phases. The operating parameters must be optimized for better system performance. In this work, the obtained results show clearly the effectiveness of this type of reactor for a better growth of the *Chlorella sp*. microalgae. This way of microalga cultivation for producing biofuels is promising in the field of renewable energy and the environment. It is necessary to increase research and development studies to promote the production technology of biofuels.

References

1. Chisti Y (2007) Biodiesel from microalgae. Biotechnol Adv 25(3):294–306
2. Brennan L, Owende P (2010) Biofuels from microalgae-A review of technologies for production, processing, and extractions of biofuels and co-products. Renew Sustain Energy Rev 14 (2):557–577
3. Belarbi EH, Molina E, Chisti Y (2000) RETRACTED: A process for high yield and scaleable recovery of high purity eicosapentaenoic acid esters from microalgae and fish oil. Process Biochem 35(9):951–969
4. Kanda H, Li P, Ikehara T, Yasumoto-Hirose M (2012) Lipids extracted from several species of natural blue–green microalgae by dimethyl ether: Extraction yield and properties. Fuel 95:88–92
5. Lorenz RT, Cysewski GR (2000) Commercial potential for Haematococcus microalgae as a natural source of astaxanthin. Trends Biotechnol 18(4):160–167
6. Borowitzka M (1999) Pharmaceuticals and agrochemicals from microalgae. Chemicals from microalgae. Taylor & Francis, London, pp 313–352
7. Singh RN, Sharma S (2012) Development of suitable photobioreactor for algae production-A review. Renew Sustain Energy Rev 16:2347–2353
8. Tsoglin LN, Gabel BV, Falkovich TN, Semenenko VE (1996) Closed photobioreactors for microalgal production. Russian J Plant Physiol 43(1):131–136
9. Kumar K, Dasgupta CN, Nayak B, Lindblad P, Das D (2011) Development of suitable photobioreactors for CO_2 sequestration addressing global warming using green algae and cyanobacteria. Bioresour Technol 102:4945–4953
10. Kaidi F, Rihani R, Ounnar A, Benhabyles L, Naceur MW (2012) Photobioreactor design for hydrogen production. Procedia Eng 33:492–498
11. Chisti Y, Moo-Young M (2001) Bioreactors encyclopedia of physical science and technology. Meyers RA (ed.) Academic Press: New York 247–271
12. Pruvost J, Pottier L, Legrand J (2006) Numerical investigation of hydrodynamic and mixing conditions in a torus photobioreactor. Chem Eng Sci 61(14):4476–4489
13. Barbosa MJ, Janssen M, Ham N, Tramper J, Wijffels RH (2003) Microalgae cultivation in air-lift reactors: modeling biomass yield and growth rate as a function of mixing frequency. Biotechnol Bioeng 82(2):170–179
14. Merchuk JC, Ronen M, Geris S, Arad S (1998) Light/dark cycles in the growth of the red microalga *Porphylidium sp*. Biotechnol Bioeng 59:705–713
15. Travieso L, Hall DO, Rao KK, Benitez F, Sanchez E, Borja R (2001) A helical tubular photobioreactor producing Spirulina in a semi continuous mode. Int Biodeterior Biodegradation 47:151–155
16. Morita M, Watanabe Y, Okawa T, Saiki H (2001) Photosynthetic productivity of conical helical tubular photobioreactors incorporating *Chlorella sp*. Under various culture medium flow conditions. Biotechnol Bioeng 74(2):137–144
17. Rihani R, Bensmaili A, Kaidi F, Belhamel M (2006) Etude de la distribution des pertes de charge des systèmes diphasiques dans un réacteur torique en pyrex. Revue des Energies Renouvelables 9(3):355–361
18. Barthet L (2003) Contribution à l'évaluation de l'impact sur les écosystèmes de la valorisation de résidus de procédés thermiques en BTP. Thesis, 217 p. Institut National des Sciences Appliquées de Lyon
19. Wu HL (2001) Identification of *Chlorella sp*. isolated using ribosomal DNA sequences. Bot Bull Acad Sinica 42:115–121