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Development of operational strategies to remove carbon dioxide in photobioreactors

Eduardo Jacob-Lopes [a], Sergio Revah [b], Sergio Hernández [c], Keiko Shirai [d], Telma Teixeira Franco [e,*]

[a] Departamento de Engenharia Agrícola, Universidade Federal de Pelotas, UFPel, Pelotas, RS, Brazil
[b] Departamento de Procesos y Tecnología, Universidad Autónoma Metropolitana-Cuajimalpa, UAM-C, México DF, Mexico
[c] Departamento de Ingeniería de Procesos e Hidráulica, Universidad Autónoma Metropolitana-Iztapalapa, UAM-I, Mexico DF, Mexico
[d] Departamento de Biotecnología, Universidad Autónoma Metropolitana-Iztapalapa, UAM-I, México DF, Mexico
[e] Departamento de Processos Químicos, Universidade Estadual de Campinas, UNICAMP, P.O. Box 6066, 13083-970, Campinas, SP, Brazil

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ABSTRACT

The objective of this work was to evaluate different operational strategies for photobioreactors to remove carbon dioxide using the cyanobacteria, *Aphanothece microscopica Nägeli*. Two types of reactor configuration, bubble column and airlift were evaluated under three different operational conditions to treat air containing 15% carbon dioxide: simple operation, air recirculation and two sequential reactors. The results obtained showed that the reactor configuration and the operational mode were both determinant criteria for the performance of photobioreactors in the biological conversion of carbon dioxide. Operations with air recirculation showed possibilities for use in small-scale operations, but two-stage sequential photobioreactors (elimination capacity and removal efficiency of 12,217 $g_{carbon}/m^3_{reactor}$ day and 52.5%, respectively) were shown to be the operational mode with greatest potential for application on an industrial scale by the increased removal efficiency.

1. Introduction

Global atmospheric concentration of carbon dioxide increased markedly as a result of human activities [1]. Carbon dioxide is the most important anthropogenic greenhouse gas (GHG) and its concentration has increased from a pre-industrial value of about 280–379 ppm in 2005 [2]. The first regulations aimed at controlling atmospheric pollutants have already been implanted; the signing of the Kyoto Protocol in December 1997 is an historic step in reversing the increase in these emissions. The primary achievement of the Protocol is the commitment of countries referred in the Annex I to reduce their emission some 5% below their country specific 1990 level, in the period 2008–2012 with penalization clauses in case of non-compliance [3].

Biological carbon sequestration using technologies such as controlled photosynthetic reactions may help to alleviate GHG problems, by carrying out reactions in which the CO_2 is transferred to the aqueous phase of the system where microbial conversion occurs, resulting in the production of oxygen, biomass, soluble biopolymers, carbonate and bicarbonate and volatile organic compounds [4–6].

At this moment, the economic return for the operation of these systems may become feasible through the carbon credits [7] and by using the photobioreactor technology to produce biomass. The biochemical composition of the microalgal cells may be of commercial interest, possessing significant proportions of proteins, lipids, carbohydrates, pigments and nucleic acids, and could therefore be used as ingredients in foods destined for human consumption, animal feeds, extraction of biomolecules and in the production of biofuels [8–10].

In previous studies [11], we demonstrated that CO_2 removal by the cyanobacteria *Aphanothece microscopica Nägeli* in a bubble column photobioreactor was described by a first order kinetic model. In this study was determined that a 15% (v/v) content of CO_2 in the air inlet optimized CO_2 uptake performance. Furthermore, Jacob-Lopes et al. [12] showed that this inlet CO_2 concentration favoured the cyanobacterial growth when compared to a wide range of concentrations (3, 15, 25, 50 and 62%). In both studies, inlet airstreams with 15% CO_2 (v/v) were considered the best conditions for biomass growth and carbon dioxide removal, however, this condition leads to substantial losses of underutilized CO_2. So, operational strategies should be developed for improve the performance of the CO_2 utilization in photobioreactors.

Design and scale-up methodologies for photobioreactors have not been extensively described. Irrespective of the specific reactor configuration and operational mode employed, several essential issues need addressing: (i) effective and efficient provision of light;

* Corresponding author. Tel.: +55 1935213966; fax: +55 1935213965.
E-mail address: franco@feq.unicamp.br (T.T. Franco).

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Nomenclature

EC	elimination capacity (g/m^3 min)
RE	removal efficiency (%)
C_i	inlet CO_2 concentration (g/m^3)
C_o	outlet CO_2 concentration (g/m^3)
C_R	CO_2 concentration in the reactor (g/m^3)
Q	gas flow (m^3/min)
V_R	volume of the reactor (m^3)
V_T	sum of the volumes of the balance tank and the reactor (m^3)
r	CO_2 consumption rate (g/m^3 min)
$d(CO_2)/dt$	CO_2 consumption rate in the balance tank (g/m^3 min)
HRT	hydraulic retention time = V_R/Q (h)

(ii) supply of CO_2 while minimizing desorption; (iii) selection of strains with high growth rate, tolerance to CO_2 and temperature; (iv) analysis and definition of operational conditions and (v) scalable photobioreactor technology [13–15].

Thus the objective of the present study was to evaluate the capacity of the cyanobacteria, *Aphanothece microscopica Nägeli* to treat air containing 15% carbon dioxide in two types of photobioreactors, bubble column and airlift, under three different operational conditions: simple operation, air recirculation and two sequential reactors.

2. Material and methods

2.1. Microorganism and culture medium

Axenic cultures of *Aphanothece microscopica Nägeli* (RSMan92) were originally isolated from the Patos Lagoon estuary, Rio Grande do Sul State, Brazil (32°01′S–52°05′W). Stock cultures were propagated and maintained on synthetic BGN medium [16]. The incubation conditions used were 25 °C, photon flux density of 15 μmol m^{-2} s^{-1} and a photoperiod of 12 h.

2.2. Photobioreactors

The diagram of the experimental apparatus used is shown in Fig. 1. The photobioreactors were constructed in 4 mm thick glass with similar geometry, dimensions and working-volume (WV). The systems had an internal diameter of 7 cm, height of 70 cm and nominal volume of 2.4 L. In the bubble column reactors (BCR) air was supplied through a 7 cm diameter sinterized glass plate. For the airlift reactors (ALR), the dispersion system consisted of a 1 cm diameter air diffuser located in the centre of the column. In these reactors, a concentric tube with an internal diameter of 3 cm and height of 50 cm was also used, located axially in the centre of the column and fixed at a distance of 5 cm from the diffuser.

In the systems with air recirculation, the BCR and ALR were connected through a pump to a 13.25 L balance tank. The balance tank was used to increase the initial CO_2 mass and was maintained in the dark, to avoid photosynthetic reactions. The flow leaving the tank was directed back to the reactors, resulting in a closed circuit. In the sequential reactors the gases exiting from the first column were fed to the second reactor.

2.3. Kinetic data

For each reactor, the experiments were carried out under three operational conditions: (i) simple operation, (ii) operation with air recirculation and (iii) operation with two sequential reactors. The tests were carried out using the bioreactors operating in an intermittent regime, fed with 2.4 L synthetic BGN medium. The experimental conditions were: initial cell concentration of 100 mg L^{-1}, isothermal reactor operating at 35 °C, photon flux density of 150 μmol m^{-2} s^{-1} and continuous aeration at 1 VVM (volume of air per volume of culture per minute) with air containing 15% CO_2. The kinetic data were monitored with respect to cell concentration, pH and CO_2 concentration every 12 h of cultivation during the growth phases of the microorganism. The tests were carried out in duplicate and the kinetic data referred to the mean of four repetitions.

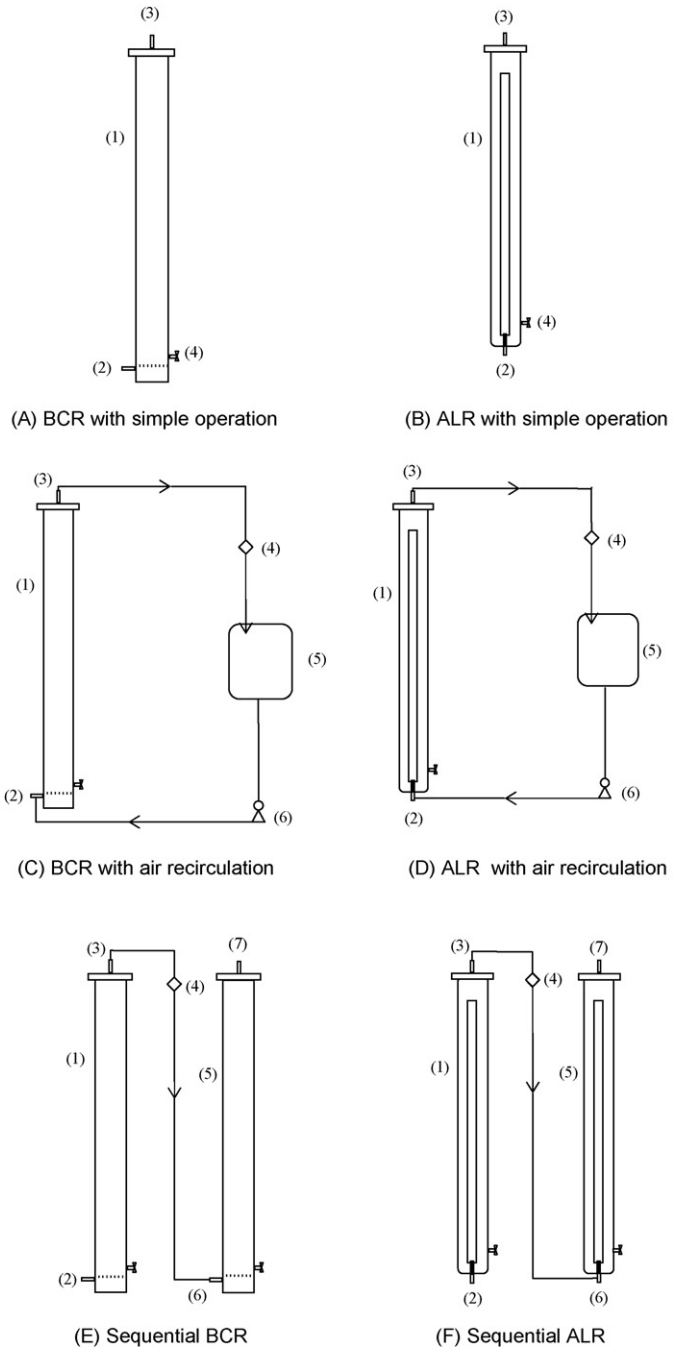

Fig. 1. Experimental apparatus. (A and B): (1) reactor; (2) gas entrance sampler; (3) gas exit sampler; (4) liquid sampler. (C and D) (1) reactor; (2) gas entrance sampler; (3) gas exit sampler; (4) air dehumidifier; (5) balance tank; (6) pump. (E and F): (1) reactor 1; (2) gas entrance sampler; (3) gas exit sampler; (4) air dehumidifier, (5) reactor 2; (6) gas entrance sampler; (7) gas exit sampler.