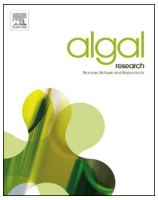
Algal Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Algal Research

journal homepage: www.elsevier.com/locate/algal



Experimental characterization and numerical simulation of the hydrodynamics in an airlift photobioreactor for microalgae cultures

Amaury Massart [a], Aldo Mirisola [a,*], Delphine Lupant [b], Diane Thomas [c], Anne-Lise Hantson [a,1]

[a] University of Mons, Faculty of Engineering, Energy Institute, Applied Chemistry and Biochemistry Department, 20, Place du Parc, 7000 Mons, Belgium
[b] University of Mons, Faculty of Engineering, Energy Institute, Thermal Engineering and Combustion Unit, 20, Place du Parc, 7000 Mons, Belgium
[c] University of Mons, Faculty of Engineering, Energy Institute, Chemical Engineering Department, 20, Place du Parc, 7000 Mons, Belgium

ARTICLE INFO

Article history:
Received 29 November 2013
Received in revised form 19 June 2014
Accepted 8 July 2014
Available online xxxx

Keywords:
Biomass productivity
Hydrodynamics
CFD simulation
Scenedesmus obliquus
Photobioreactor

ABSTRACT

The development of photobioreactors optimized to increase the biomass production from phototrophic microalgae cultures assumes a major concern for the economic viability of different processes (biofuel production, carbon dioxide mitigation, pigments …). The main aim of this study is to establish and validate a CFD hydrodynamic model for a flat panel airlift photobioreactor configuration. In this regard, experimental water flow rates induced in the riser of the reactor and the liquid circulation were compared to the CFD solution obtained thanks to the Fluent® software. The numerical simulation results were relevant. Subsequently, cultures of *Scenedesmus obliquus* (CCAP 276/3A) were achieved to determine an optimal injected air flow rate for our configuration of photobioreactor. This air flow rate was 1.5 $L \cdot min^{-1}$. Measurement of the mass transfer coefficient (k_La) of carbon dioxide in the culture medium was $3.10^{-4}\ s^{-1}$ and the mixing time for this optimal operating condition is 312 s.

1. Introduction

Microalgae, aquatic and photosynthetic microorganisms, are the subject of a growing interest in many research fields [1]. This biomass source can be converted into different biofuels such as biomethane (by anaerobic digestion), biodiesel (by neutral microalgal lipid extraction and transesterification), syngas (H_2/CO mixtures which can lead to hydrocarbons by the Fisher–Tropsh process) and bioethanol (by saccharide fermentation) [2–6].

The chemical industry is also very interested in this biomass, rich in pigments (chlorophyll, carotenoids) and antioxidant molecules (astaxanthin). Besides, the antibacterial and antiviral effects of certain microalgal biochemical compounds are of interest to the pharmaceutical industry [7].

Nevertheless, the main part of algal biomass is currently used for aquaculture and as a food supplement. The reason is that algae are an important source of proteins and polyunsaturated fatty acids [8].

A photobioreactor is a closed transparent device which maintains a controlled environment within the microalgal culture and ensures a higher biomass production than in open-pond systems [9,10].

Considering the reduced exchange surface with the atmosphere as a great advantage of this configuration, many parameters can be measured and controlled according to the specific needs of the cultured strain: CO_2 supply, water temperature, uniform distribution of illumination, cell density, pH, mixing ….

Another advantage of photobioreactors is their larger "surface/volume of culture" ratio and their improved efficiency as regards the distribution of illumination. These operating conditions and design explain the increase in biomass productivity and lead to an intensified and more sustainable process.

CO_2 transfer is also more efficient and evaporation losses are greatly reduced, as well as the contamination risk by other microorganisms. Unfortunately, the required capital and operating expenses for the installation of photobioreactors are much higher than for open-ponds [11].

A wide variety of designs of photobioreactors exist. The most often encountered configurations are: flat panel, tubular and cylindrical photobioreactors (Table 1) [12].

To create ideal conditions inside a photobioreactor for microalgal cultivation, the hydrodynamics and the flow patterns, being keys for design and scale up, influenced by air injection, have to be thoroughly understood.

This paper will focus on flat plate photobioreactors which have been deeply investigated for the culture of photosynthetic microorganisms. The main advantage of this design is the widespread illumination surface compared to the volume of culture medium needed

---

[*] Corresponding author.
E-mail addresses: amaury.massart@umons.ac.be (A. Massart), aldo.mirisola@umons.ac.be (A. Mirisola), delphine.lupant@umons.ac.be (D. Lupant), diane.thomas@umons.ac.be (D. Thomas), anne-lise.hantson@umons.ac.be (A.-L. Hantson).
[1] Tel.: +32 65 37 44 19; fax: +32 65 37 44 53.

http://dx.doi.org/10.1016/j.algal.2014.07.003
2211-9264/© 2014 Elsevier B.V. All rights reserved.

Please cite this article as: A. Massart, et al., Experimental characterization and numerical simulation of the hydrodynamics in an airlift photobioreactor for microalgae cultures, Algal Res. (2014), http://dx.doi.org/10.1016/j.algal.2014.07.003

Table 1
Prospects and limitations of various closed culture systems for algae.

Culture systems	Prospects	Limitations
Vertical-column photobioreactors	High mass transfer, good mixing with low shear stress, low energy consumption, high potentials for scalability, easy to sterilize, readily tempered, good for immobilization of algae, reduced photoinhibition and photo-oxidation	Small illumination surface area, construction requires sophisticated materials, decrease of illumination surface area upon scale-up
Flat-plate photobioreactors	Large illumination surface area, suitable for outdoor cultures, good for immobilization of algae, good light path, good biomass productivities, relatively cheap, easy to clean, readily tempered, low oxygen build-up	Scale-up requires many compartments and support materials, difficulty in controlling culture temperature, possibility of hydrodynamic stress to some algal strains
Tubular photobioreactors	Large illumination surface area, suitable for outdoor cultures, fairly good biomass productivities, relatively cheap	Gradients of pH, dissolved oxygen and CO_2 along the tubes, fouling, requires large land space

for bioproduction. Flat plate reactors are made of transparent material for optimal use of light radiation. They consist of two parallel panels, with a thin layer of microalgal suspension flowing between both. Only a few centimeters separate the two panels to ensure efficient light transfer [13].

An airlift photobioreactor consists of a tank divided into two interconnected zones. The part where a gas mixture is injected is called "riser" (gas–liquid dispersion flowing upwards) while the other region with no gas injection is called the "downcomer". The movement of the liquid phase is induced by the difference between the apparent gravity of the gas–liquid dispersion in the riser and the liquid phase located in the downcomer [14].

The simplicity of this operating principle is a definite asset because of the high mass transfer coefficient (k_La_L) and the carbon dioxide supply to the microalgal suspension, along with dissolved O_2 removal. Moreover, the fact that the liquid is not in contact with any mechanical element reduces the shear stress and the risk of cell wall disruption.

These photobioreactors are divided into two groups: with an internal loop on the one hand, and with an external loop on the other hand (Fig. 1) [15].

Other designs based on this principle are available. For example, Fig. 2 [16] shows a flat airlift photobioreactor configuration with a multistage fractionation of the riser and a small section downcomer.

Complexity of flows inside the photobioreactor has led researchers to develop simulation models to understand the effects of hydrodynamics on algae growth. Determination of most important properties such as fluid velocities and flow rates, dead zone and particle trajectory identification … can be carried out. That is why Computational Fluid Dynamics (CFD) has been used to aid bioreactor design and operating condition optimization, thus limiting time-consuming experimental trials [17–21]. Akhtar [22] performed CFD simulations on a bubble column using the Volume of Fluid (VOF) multiphase model in the Fluent® software. Ebrahimifakhar et al. [23] have used CFD to investigate hydrodynamic parameters of two internal airlift bioreactors with different configurations. The reliability of using CFD simulations to generate trajectories of microorganisms in a draft tube column photobioreactor has been evaluated by Luo et al. [24].

The aim of the study is the optimization of the biomass productivity through the control of the hydrodynamic parameters. This paper has thus a twofold purpose: the validation of a numerical simulation model (CFD simulation) for the hydrodynamics inside the photobioreactor; and the estimation of an optimal injected air flow rate in the flat airlift photobioreactor for the mixing optimization (diminution of settling, shear stress on the microalgal cells). This leads to maximize the biomass productivity. The first part of the study required the use of the Gambit® software for the photobioreactor geometry creation and the mesh generation. The simulation was then carried out with Fluent® version 6.3.26. The model validation consists of the verification of water circulation inside the photobioreactor and the accuracy of the calculated water flow rates induced in the riser. For the second part of the study, experiments were conducted with the *Scenedesmus obliquus* algal strain cultured in a modified M8 medium.

2. Materials and methods

2.1. Geometry and mesh of the photobioreactor and CFD simulation

2.1.1. Airlift photobioreactor description

Based on the configurations described in the literature [16], a laboratory-scale rectangular photobioreactor has been built. The flow

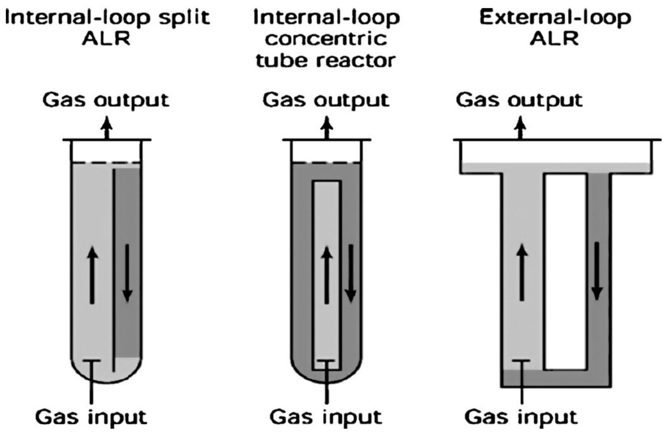


Fig. 1. Different types of airlift configuration [15].

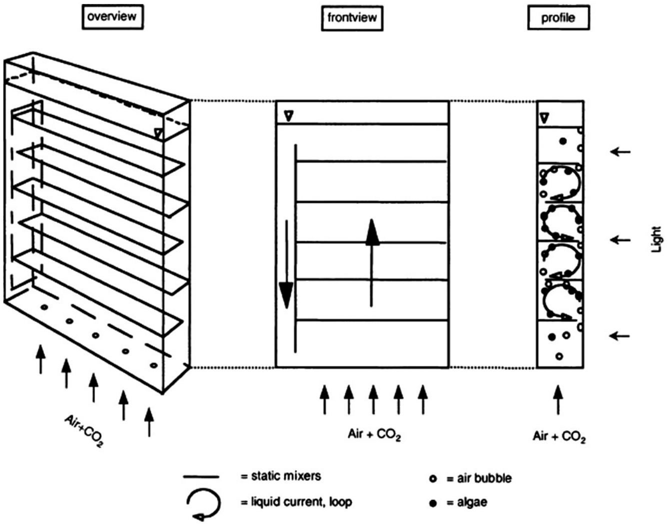


Fig. 2. Flat airlift photobioreactor [16].

Please cite this article as: A. Massart, et al., Experimental characterization and numerical simulation of the hydrodynamics in an airlift photobioreactor for microalgae cultures, Algal Res. (2014), http://dx.doi.org/10.1016/j.algal.2014.07.003