Bioresource Technology 119 (2012) 300–305

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Development of a draft-tube airlift bioreactor for *Botryococcus braunii* with an optimized inner structure using computational fluid dynamics

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HIGHLIGHTS

- ▸ An airlift reactor was designed using computational fluid dynamics (CFD).
- ▸ An airlift reactor for algal culture was scaled up to 40 L using CFD simulation.
- ▸ CFD provides a powerful means for the design and scale-up of algal culture reactors.

ARTICLE INFO

Article history:
Received 13 April 2012
Received in revised form 24 May 2012
Accepted 24 May 2012
Available online 1 June 2012

Keywords:
Airlift bioreactor
Botryococcus braunii
Computational fluid dynamics
Scale up
Optimization of structural parameters

ABSTRACT

The key parameters of the inner structure of a cylindrical airlift bioreactor, including the ratio of the cross-section area of the downcomer to the cross-section area of the riser, clearance from the upper edge of the draft tube to the water level, and clearance from the low edge of the draft tube to the bottom of the reactor, significantly affected the biomass production of *Botryococcus braunii*. In order to achieve high algal cultivation performance, the optimal structural parameters of the bioreactor were determined using computational fluid dynamics (CFD) simulation. The simulated results were validated by experimental data collected from the microalgal cultures in both 2 and 40-L airlift bioreactors. The CFD model developed in this study provides a powerful means for optimizing bioreactor design and scale-up without the need to perform numerous time-consuming bioreactor experiments.

1. Introduction

Phototrophic bioprocesses have been shown to be powerful tools for the production of valuable compounds from microalgae, and numerous bioreactors were designed for the large-scale cultivation of phototrophic microalgae. Airlift column reactors are widely used in chemical, petrochemical, and bioprocess industries because of their simple construction, inexpensive operational cost, and low energy input requirements (Pollard et al., 1998; Heijnen et al., 1990). Recent research reported the successful utilization of airlift reactors in microbial fermentation for the production of chemical, such as 1,3-dihydroxyacetone, ethanol, and poly 3-hydroxybutyrate (Hu et al., 2011; Lennartsson et al., 2011; Pradella et al., 2010). Airlift reactors allow for rapid mixing while producing weak shear stress, which makes them suitable for microalgae cultures (Xu et al., 2009; Camacho et al., 2011; Luo and Al-Dahhan, 2004; Yu et al., 2009). Light plays a significant role in the photoautotrophic cultivation of microalgae, and its availability in airlift bioreactors is influenced by the aeration rate, gas holdup, and the velocity of the liquid (Sanchez Miron et al., 1999; Li et al., 2011; Pruvost et al., 2006). In order to provide sufficient light for microalgae, it is necessary to design and optimize the internal structural parameters of the airlift bioreactor to improve mixing, light penetration, and gas injection (Degen et al., 2001; Barbosa et al., 2003; Vega-Estrada et al., 2005). In an airlift bioreactor with a concentric draught tube, the riser comprises the dark zone, and the downcomer comprises the photic zone (Barbosa et al., 2003). The light/dark cycle originates from the movement of the cells in and out of the photic zone, and the frequency of the light/dark cycle can significantly affect the efficiency of light utilization and algal growth and metabolism in airlift bioreactors (Vega-Estrada et al., 2005).

Abbreviations: A_d, cross-section area of the downcomer; A_r, cross-section area of the riser; P, cell density; V_g, gas holdup; h_0, clearance from the upper edge of the draft tube to the water level; h_1, clearance from the lower edge of the draft tube to the bottom of the reactor; t_c, cycle time; t_d, duration of the downcomer period; TKE, turbulence kinetic energy; ε, ratio between t_d and t_c; g, gravity acceleration; F, interfacial momentum exchange term; τ, viscous stress tensor; ρ, fluid density; α, volume fraction; t, flowing time of fluid; u, fluid velocity vector.

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0960-8524/$ - see front matter
http://dx.doi.org/10.1016/j.biortech.2012.05.123