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Feasibility of microalgal cultivation in a pilot-scale airlift-driven raceway reactor

Balachandran Ketheesan, Nagamany Nirmalakhandan *

Civil Engineering Department, New Mexico State University, Las Cruces, NM 88002, USA

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ABSTRACT

A *Scenedesmus* sp. was cultivated in a 23-L airlift-driven raceway reactor under artificial lighting and laboratory conditions, in batch and continuous modes. In batch mode, a maximum volumetric biomass productivity of 0.085 dry g L^{-1} day^{-1} was achieved under sparging at a CO_2-to-air ratio of 1%, and a maximum CO_2 utilization efficiency of 33% was achieved at a CO_2-to-air ratio of 0.25%. In continuous mode, the maximum volumetric biomass productivity was 0.19 dry g L^{-1} day^{-1}. Biomass productivities per unit power input achieved in this reactor configuration (0.60–0.69 dry g W^{-1} day^{-1}) were comparable to or better than those reported in the literature for different photobioreactor designs (0.10–0.51 dry g W^{-1} day^{-1}). Based on the energy-efficient productivity and the high CO_2 utilization efficiency demonstrated in this study, the proposed airlift-driven raceway design holds promise for cost-effective algal cultivation.

1. Introduction

Since 1950s, open raceway ponds have been accepted as the foremost choice for large-scale cultivation of microalgal biomass as they are less expensive to build and operate, and more durable than closed photobioreactors (Mata et al., 2010). In the traditional raceway design, culture depth and biomass concentrations have to be maintained low to ensure efficient penetration of sunlight. Large-scale raceways for algal cultivation have been operated with depths ranging from 30 to 50 cm (Brennan and Owende, 2010) while maintaining dilute algal cultures at concentrations less than 0.6 g L^{-1} (Tredici, 2004). Due to these limitations, traditional ponds suffer from large surface areas, low aerial biomass productivities, and high cultivation costs (Tredici, 2004). In traditional raceways, intensive culture mixing is the only viable option to enhance light utilization efficiency by creating high frequency of dark/light cycles (Vonshak and Guy, 1992); however, the paddlewheels commonly used in open raceways to keep the culture in suspension are energy-intensive (Mata et al., 2010) and have been recognized as a poor mixing device for light utilization (Richmond and Qiang, 1997).

In open raceways, the carbon requirement for algal growth has been provided via ambient air through surface aeration, often supplemented by sparging with CO_2 or CO_2-enriched air from the bottom of the raceway. Since the carbon content of biomass is about 50% (Becker, 1994), supply and transfer of CO_2 to the culture are key considerations in maximizing biomass production. Sparging systems commonly used in open raceways suffer from low bubble residence times due to the shallow depths and poor mass transfer rates, resulting in off-gassing CO_2 to the atmosphere and increased operating costs (Carvalho et al., 2006). Different approaches such as in-pond CO_2 transfer sumps (Park et al., 2011; Campbell et al., 2011) and CO_2 transfer stations adjacent to the raceway ponds (Putt et al., 2011) have been proposed to improve CO_2 transfer efficiency. In such designs, culture mixing and CO_2 supply have been considered as two independent functions.

The limitations of raceways have promoted the use of photobioreactors, such as bubble columns and airlift reactors that are capable of efficient mixing, CO_2 transfer rates, and light utilization. Volumetric algal productivities of photobioreactors (0.2–3.8 g L^{-1} day^{-1}) have been reported to be significantly higher than those of raceways (0.12–0.32 g L^{-1} day^{-1}) (Brennan and Owende, 2010). Airlift reactors capable of efficient mixing and higher gas-to-liquid mass transfer rates than traditional raceways have gained wide acceptance in algal cultivation (Miron et al., 2000).

A paddlewheel-free, airlift-driven raceway configuration for microalgal cultivation has been developed (Ketheesan and Nirmalakhandan, 2011). As a first step in its development, the hydraulics of this configuration in a 20-L laboratory scale system was evaluated, and its energetic advantage over the traditional raceway ponds was documented (Ketheesan and Nirmalakhandan, 2011). The present work is a proof-of-concept study to evaluate the feasibility of cultivating microalgae in this airlift-driven raceway configuration, to optimize the CO_2 level for algal growth in batch mode, to determine the volumetric algal productivity under continuous operation, and to compare the performance of the proposed system with that of photobioreactors. The intent of the

* Corresponding author. Tel.: +1 575 646 5378; fax: +1 575 646 6049.
E-mail address: nkhandan@nmsu.edu (N. Nirmalakhandan).

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