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Development of a new airlift-driven raceway reactor for algal cultivation

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ABSTRACT

This paper presents the development and analysis of a new airlift-driven raceway reactor configuration for energy-efficient algal cultivation. A theoretical analysis of the energy requirements for traditional paddlewheel-driven raceway reactors and the proposed airlift-driven raceway reactors is presented. A hydrodynamic model was developed to predict the liquid circulation velocity in the reactor system based on theoretical energy balance. The predicted liquid velocity agreed well with experimentally measured liquid velocity with $r^2 = 0.89$. Based on the results of this analysis, the energy required for maintaining typical raceway velocity of 14 cm/s for mixing and keeping the cultures in suspension in a paddlewheel-driven raceway could be reduced by as much as 80% with the proposed configuration. Growth of *Scenedesmus* sp. was evaluated in a laboratory scale, 20 L version of the proposed reactor configuration using artificial lighting under ambient temperatures without any supplementary carbon dioxide sparging. The volumetric algal biomass productivity achieved in the proposed configuration (0.16 ± 0.03 dry g/L day) is comparable or better than that reported in the literature for paddlewheel-driven raceways.

1. Introduction

Open raceway ponds have been the most common choice for outdoor algal production because they cost less to build and operate although they have low biomass productivity compared to engineered photobioreactors [1]. In algal cultivation, the productivity of algal systems, and cost of reactor construction and operation are dependent on the mixing system employed. Mixing serves a variety of purposes, including prevention of cell settling, elimination of thermal stratification, distribution of nutrients and carbon dioxide, removal of photosynthetically produced oxygen, and improvement of light utilization efficiency [2]. To ensure adequate mixing, a minimum liquid circulation velocity should be maintained. Paddle wheel has been the most common way to maintain this velocity in open raceways.

Typical surface velocities suggested for outdoor raceway ponds are 0.15 m/s [3]; 0.18 m/s [4] and 0.3 m/s [5]. Richmond and Qiang [6] have pointed out that paddlewheel technology cannot meet certain growth requirements such as efficient utilization of light and extent of turbulent mixing to attain maximal productivity consistently. For efficient utilization of light, depth of algal ponds should be within certain limits, typically 12–15 cm [6], resulting in very dilute algal cultures. Notably, high frequency of light/dark cycle is highly recommended in algal culture when the growth is light-limited. In practical cases, utilization of high-intensity light would be enhanced only by inducing turbulent streaming in culture suspension [7]. In traditional raceways, it can be achieved only by increasing the liquid velocity, which requires additional energy input. Thus, one of the challenges in algal cultivation is to maintain adequate mixing and circulation velocity with minimal energy input.

In addition to the light needs, carbon source plays a vital role in biomass synthesis, as nearly 50% of the whole microalgal biomass is made up of carbon [8]. As such, several studies have focused on improving carbon dioxide addition to the culture. Benemann [9] have reported that supply and transfer of CO_2 accounts for nearly 1/3 the cost of algal cultivation. However, the critical concentration of CO_2 necessary for optimal growth of a particular microalga cannot be stated in general, as it depends strongly on the delivery system implemented in the culture vessel [10]. Transfer of CO_2 by bubbling CO_2 from the bottom of the reactor is the most frequent mode of operation. However, this method suffers from major drawback of inefficient gas-to-liquid transfer and loss of CO_2 to atmosphere [10]. Airlift systems have been used in tubular photobioreactors to enhance gas-to-liquid mass transfer and create liquid circulation in the reactor [11]. Airlift reactors have the potential to accomplish both pumping and gas transfer requirements in closed photobioreactor systems. However, the efficient use of airlift reactors in large-scale open raceways is not widely studied.

For sustainable microalgal cultivation, the overall net energy gain from algal biodiesel has to be positive. Based on conservative energetic analysis of algal biodiesel systems by Chisti [12], nearly

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