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Reduction of water and energy requirement of algae cultivation using an algae biofilm photobioreactor

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ABSTRACT

This paper reports the construction and performance of an algae biofilm photobioreactor that offers a significant reduction of the energy and water requirements of cultivation. The green alga *Botryococcus braunii* was cultivated as a biofilm. The system achieved a direct biomass harvest concentration of 96.4 kg/m^3 with a total lipid content 26.8% by dry weight and a productivity of 0.71 g/m^2 day, representing a light to biomass energy conversion efficiency of 2.02%. Moreover, it reduced the volume of water required to cultivate a kilogram of algal biomass by 45% and reduced the dewatering energy requirement by 99.7% compared to open ponds. Finally, the net energy ratio of the cultivation was 6.00 including dewatering. The current issues of this novel photobioreactor are also identified to further improve the system productivity and scaleup.

1. Introduction

Cultivation of algae is a promising method for producing renewable hydrocarbon feedstock for biofuel production as (i) select algae species can produce about two orders of magnitude more oil per acre than from soybeans, (ii) algae cultivation does not require arable land, and (iii) can use marginal sources of water not suitable for drinking or irrigation (Chisti, 2007). However, a cost effective algae cultivation technology that can be scaled up to sizes large enough to make a significant contribution in reducing our dependence on foreign oil has yet to be realized (Chisti, 2007; Molina Grima et al., 2003). In part, this stems from cultivation of dilute biomass concentrations in conventional systems, such as raceway ponds as well as flat plate and tubular photobioreactors (PBRs), where algae cells are suspended in the liquid phase (Pulz, 2001). These technologies require (i) in excess of 6000 gallons of water to cultivate 1 gallon of algae oil, (ii) a large amount of energy for pumping and circulating a dilute algae suspension as large as 385.71 MJ/kg of cultivated algae, and (iii) energy intensive dewatering and biomass concentration processes for downstream use of the biomass resulting in energy requirements of up to 82 MJ/kg algae biomass produced (Jorquera et al., 2010; Chisti, 2007; Molina Grima et al., 2003; Uduman et al., 2010). To address these challenges, this study reports the design, operation, and performance of a novel photobioreactor based on algal biofilm cultivation that reduces the water and energy requirements of algae cultivation for economic and sustainable biofuel production.

2. Current state of knowledge

2.1. Current algae cultivation technologies

The type of system used for cultivating algae depends on the requirements of the organism being cultivated and on the nature of the product being harvested. Most current technologies cultivate the algae as planktonic cells, suspended in liquid nutrient media. These include open systems such as raceway ponds and closed systems such as flat panel and tubular PBRs which are being used for high value products such as β-carotene, astaxanthin, and C-phycocyanin which have prices ranging from $310 to $10,000/kg (Brennan and Owende, 2010). In the case of biofuel production, strict limitations on the cost as well as the energy and water requirements are imposed due to (i) low value of biofuel as a product, (ii) biofuel production requiring larger than unity net energy ratio (NER), and (iii) potentially large scale of operation.

Raceway ponds are constructed as artificial ponds having a depth of about 0.3 m (Chisti, 2007). The algae cultivated in these ponds are kept suspended through continuous agitation with a paddlewheel (Chisti, 2007). The main advantage of these systems is that they are relatively inexpensive to build and operate. In raceway ponds, the maximum biomass concentration ranges from 0.1

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