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Enhanced removal of carbon dioxide and alleviation of dissolved oxygen accumulation in photobioreactor with bubble tank

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ABSTRACT

Reduction of carbon loss from the effluent is one of the most important aspects of photobioreactors design. In this study, a novel gas sparger of bubble tank was adopted in a photobioreactor to enhance carbon dioxide (CO_2) mass transfer rate as well as alleviate dissolved oxygen (DO) accumulation. The results showed that low DO level in the culture can be obtained due to the turbulent hydrodynamic condition provided by the bubble tank. The effects of CO_2 concentration, flow rate of influent, and light intensity on CO_2 removal efficiency were investigated. The maximum CO_2 removal efficiency was 94% at flow rate of 30 mL min^{-1}, light intensity of 179 μmol m^{-2} s^{-1} and CO_2 concentration of 10%, implying that the novel gas sparger is a promising alternative for CO_2 removal from CO_2-enriched air by cultivating microalgae in the photobioreactor.

1. Introduction

The accumulation of CO_2 in the atmosphere emitted from combustion of fossil fuels plays a major role in causing and accelerating the greenhouse effect and ocean acidification (Chi et al., 2011). A mid-sized 500 MW coal-fired power plant produces approximately 11400 metric ton (MT) CO_2 per day (Chi et al., 2011). CO_2 biofixation by microalgae is a promising alternative solution to attenuate excessive carbon dioxide emissions. Carbon dioxide can be converted into organic compounds by using the Calvin cycle of photosynthesis pathway in microalgae species, with each kilogram of algal dry cell weight fixing 1.83 kg CO_2 (Kim et al., 2012; Kumar et al., 2011). Certain microalgae strains such as *Nannochloris* sp. (Yoshihara et al., 1996), *Tetraselmis* sp. (Matsumoto et al., 1995) have a high tolerance with minor components of the flue gas, including sulfur oxides, nitrogen oxides and heavy metals. Furthermore, microalgae with higher proliferation rate tend to have less food competition and generate biomass with higher rate of lipid, which is considered as the third feedstock for biodiesel as well as other commercially and scientifically important products such as biofilters, food products and water quality testing materials (Brennan and Owende, 2010; Chisti, 2007).

The mass transfer rate and mixing condition are the critical parameters in photobioreactors design for CO_2 removal by microalgae. The mass transfer rate of CO_2, nutrient distribution and algal cell suspension distribution as well as the light availability were influenced greatly by mixing efficiency in the photobioreactor (Zhang et al., 2002; Ugwu et al., 2008). Moreover, the dissolved oxygen accumulation combined with high light intensity may cause photooxidative damage to algal cells (Chisti, 2007). Improvement of mixing condition, which currently depends on the type of photobioreactors and aeration systems, could efficiently alleviate the situation of dissolved oxygen accumulation. Turbulent flow in the algal cultures can be obtained by mechanical stirring using paddle wheels, impellers, buffers and air bubbling directly or indirectly via airlift systems (Ugwu et al., 2008). However, mechanical stirring equipments may add the complexity to the photobioreactor and increase the cost. Furthermore, CO_2 removal by bubbling air into the photobioreactor is probably not efficient because it only improves the mixing condition by increasing the aeration rate. The mass transfer rate is strongly affected by the interfacial area, which mainly depends on the airflow rate and the average bubble diameter (Talbot et al., 1990). Meanwhile, the mass transfer rate was determined the types of sparger or diffuser and the gas flow rate (Zhang et al., 2002). Generally, bubbling system is the most frequently used approach (Kumar et al., 2010). However, bubbling CO_2-enriched air into the culture medium is not particularly effective because 80–90% CO_2 will be lost into the atmosphere (Putt et al., 2011). To avoid those drawbacks, investigations have been conducted on microporous membranes of hollow-fiber form with a large interfacial area of contact available for gas exchange (Mansourizadeh and Ismail, 2011). However, the high cost of hollow fiber membrane limits the technical and economic feasibility of large scale systems. Meanwhile, hollow fibers with typical inner diameters pose a high risk of being biofouled, which consequently leads to frequent stops for cleaning.

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