Ecological Engineering 92 (2016) 106–110

Contents lists available at ScienceDirect

Ecological Engineering

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

Carbon dioxide bio-fixation by algae of high rate pond on natural water medium

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ARTICLE INFO

Article history:
Received 16 June 2015
Received in revised form 14 March 2016
Accepted 20 March 2016
Available online 6 April 2016

Keywords:
CO_2 fixation
Algae
High rate pond
Natural water medium
Eco-tech

ABSTRACT

Algae are one of the major concerns on the bio-fixation of greenhouse gas CO_2 and high rate pond (HRP) is the most efficient algal biomass production facility. This study tried to evaluate the potential of CO_2 mitigation by algae in the HRP with natural water medium which fits the ecological engineering concept. The results showed that the uptake rate could reach 162 mg/L/day and the consumption efficiency was kept up to 123%. Furthermore, through all our study the consumption efficiency remained almost constant. In addition, after the comparisons between our study and literature, we demonstrated (1) the mixed culture performed better than pure culture, (2) the natural medium absorbed CO_2 more than artificial medium and (3) consumption efficiency was more sensitive than uptake rate. Finally, the algal HRP showed the potential of CO_2 sequestration and algae might be an important alternative to reduce the greenhouse gas of atmospheric CO_2.

1. Introduction

The issue of greenhouse gas attracts an enormous attention worldwide recently. When atmospheric CO_2 concentration increased, it would gradually disturb the balance of global climate to cause unusual and astounding phenomena on earth. Therefore, we require the rapid development of bio-carbon-fixation technology to eliminate the adverse effects of CO_2, to transfer atmospheric CO_2 through the carbon cycle and to promote carbon balancing ecologically.

Currently, many innovative alternatives of physical, chemical and biological technologies of CO_2 mitigation are rapidly developed. Among those techs, bio-eco-technology is the most natural and ecological way to accomplish the designed targets by the utilization of "self-designed" bio-functions of nature. Algae application is widely accepted in practice as one of the best strategies in bioengineering. There are several reasons for this approach: (1) the best growth rate among the plants (Minowa et al., 1995; Demirbas, 2009), (2) low impacts on world's food supply (Schenk et al., 2008), (3) specificity for CO_2 sequestration without gas separation to save over 70% of total cost (Lee and Lee, 2003), (4) excellent treatment for combustion gas exhausted with NO_x and SO_x (DOE, 2006), (5) high value of algae biomass including of feed, food, nutrition, pharmaceutical chemicals, fertilizer, aquaculture, biofuel, etc. (Packer, 2009) Accordingly, algae production has a great potential for CO_2 bio-fixation process and deserves a close look.

High rate pond (HRP) and other photo-bioreactors are major algae production units in this world (Oswald, 1995; Um and Kim, 2009; Mata et al., 2010). However, many HRPs had been used around the world in wastewater treatment and industrial microalgae production for food supplements etc. Unquestionably it's a practical successful design in the field (Benemann, 2003) and is the most efficient production unit with the minimum energy cost to produce large amount of algae (Oswald, 1995). Moreover, HRP could meet the requirement of ecological engineering concepts to minimize the environmental impact (Oswald, 1995). Amazingly, there is very little literature on CO_2 fixation with HRP. Tsai et al. (2012) have indicated the HRPs can keep a neutral pH to provide dissolved oxygen, to promote total nitrogen/total phosphorous removal efficiencies and to demonstrate CO_2 was the main carbon source to accomplish high CO_2 uptake rate. Therefore, the primary objective of this research was to demonstrate the potential of HRP for CO_2 bio-fixation by algae.

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http://dx.doi.org/10.1016/j.ecoleng.2016.03.021
0925-8574/

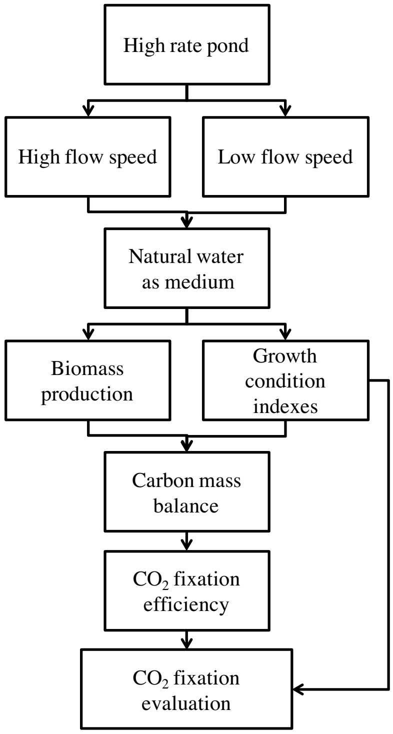

Fig. 1. Flow chart of methodology.

Table 1
List of operational parameters.

Operational parameter	HRP	CSTR
scale	lab	lab
detention time	10 days	10 days
Reactor design	Paddle wheel with recirculation	4 L up-flow flask
water level	15 cm	–
water volume	199 L	4 L
feeding	Batch feed daily	Batch feed daily
Feed filter size	1 × 1 mm (mesh No. 18)	0.45 μm
mixing speed (surface speed)	15/30[a] cm/s	magnetic mixer
light intensity	55.94 ± 2 μmol s^{-1} m^{-2}	27.06 ± 2 μmol s^{-1} m^{-2}
operation period	22 months	30 months

[a] reactor 1 is 30 cm/s and reactor 2 is 15 cm/s.

2. Materials and methods

2.1. Experimental setup

The methodology is illustrated in Fig. 1. This study is to simulate the ecological function of algae in water body such as a river or lake to fix the greenhouse gas CO_2. Looking through the current technology, HRP is the simplest symbiosis system, meets the requirement of ecological engineering concepts (Oswald, 1995) and is the best choice to imitate nature system in lab. Two bench scale HRPs were set up in the Sustainable Resources and Sustainable Engineering research lab (SRSE-LAB), the department of soil and water conservation, National Chung-Hsing University, Taichung, Taiwan. Both reactors were operated at 10 days detention time under the room temperature and other operational factors including the light intensity were listed in Table 1.

The nearby stream water was used as medium for HRP. The stream water was screened by 1 × 1 mm sieve (mesh No. 18). All the reactors were continuously illuminated with the fluorescent tube panels day and night for the autotrophic growth. The experiment was designed without any extra nutrition or CO_2 addition to mimic the natural ecosystem. The gradient of impact factor is necessary in the study to find out the performances in the different scenarios. There were two surface flow speeds of 30 and 15 cm/s of paddle wheels as the speed gradient for the HRPs of reactor 1 and 2 respectively. The dominant species were *Chlorella*, *Oscillatoria*, *Oedogonium*, *Anabaena*, *Microspor*a and *Lyngbya* from the nearby stream. The algal ingredients of carbohydrate and protein were shown as average 0.03, 0.06 g/L, respectively through whole study period. The important environmental indexes including of pH, alkalinity, chemical oxygen demand (COD), and algae biomass indexes of total suspended solids (TSS), volatile suspended solids (VSS) were continuously monitored with the standard method (APHA, 1985) and presented as monthly average. The measured growth environmental parameters of the natural freshwater medium were shown in Table 2. The detail contents could be found in the supplementary data of this manuscript. For comparison, we referred the results of the continuous stirred tank reactor (CSTR) as a conventional standard reactor in the same study period with the same medium.

Table 2
Characteristics of natural medium.

parameter	mean	range
Alkalinity (mg $CaCO_3$/L)	127 ± 13.4	83–147
pH	7.4 ± 0.19	7–7.7
DO (mg/L)	6.3 ± 0.93	4.6–7.7
TN (mg N/L)	7.1 ± 1.53	5.3–11.0
TP (mg/L)	0.55 ± 0.138	0.30–0.89
COD (mg/L)	6 ± 2.9	1–10

2.2. Calculation of mass balance

CO_2 consumption process was computed by mass balance of carbon. These processes were widely used (Weissman and Tillett, 1992; Green et al., 1995; Sawyer et al., 2003). (i) the CO_2 uptake rate, indicated as mass of adsorbed CO_2 per unit of reactor volume-time to express the measurement as the term specified. (ii) the CO_2 consumption efficiency, defined as the adsorbed CO_2 weight/algal biomass ratio.

2.3. CO_2 bio-fixation index

There were several ways to express the CO_2 bio-fixation (1) by volume, such as% of injected CO_2 (Ramanan et al., 2010); (2) by weight/volume ratio: g/m^3/day (Jacob-Lopes et al., 2009), g/L/day (Kurano et al., 1995) and mg/L/h (Cheng et al., 2006) which we defined as CO_2 uptake rate; (3) by weight/weight ratio: CO_2/biomass ratio (Kurano et al., 1995) which we specified as CO_2 consumption efficiency. Since we did not add any CO_2 gas into the reactors and algae withdrew the CO_2 from air by themselves, the index by volume is not appropriate; we used CO_2 uptake rate and CO_2 consumption efficiency in this study.

3. Results and discussion

3.1. CO_2 uptake rate

CO_2 uptake rate is on weight/volume ratio basis as aforementioned and the unit is mg/L/day. After going through the carbon balance calculation process and taking the direct measure of TSS and VSS to present biomass, CO_2 uptake rates were exhibited as Table 3. There were 162 mg CO_2/L/day and 94 mg/L/day in reactor 1 and 2, respectively. Since feeding and growth environment were similar in both reactors, the uptake rate of reactors would be highly depended on the growth biomass. Thus the algae biomass was expressed as TSS and VSS in Fig. 2 and 3 respectively. In the