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High Concentration of Carbon Dioxide Sequestrated by Microalgae in A Closed Raceway Pond Photobioreactor

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Abstract. CO_2 is the main greenhouse gas leading to global warming. Sequestration strategies of CO_2 have become a popular research topic around the world. Among them, CO_2 biofixation by microalgae is thought to be one of the most effective carbon sequestration means. The flue gas from power plant or waste gas from industry normally contains concentrated CO_2 with concentrations varied from 10% to 95%. In the present study, microalgae growth in a closed raceway pond aerated with high concentration of CO_2 (100%) was examined. The experimental results showed that in the closed raceway pond, microalgae can grow with 100% CO_2 and grow well under certain condition. The present study proved the feasibility of using microalgae for sequestration of concentrated CO_2 emitted from industrial plants.

Introduction

The increasing concentration of greenhouse gases in atmosphere causes serious global warming. CO_2, the principal greenhouse gas, accounts for about 77%. The combustion of fossil fuels in coal-fired thermoelectric plants and waste gas emission from industry are the main sources of global warming CO_2. In order to reduce the impact of CO_2 on environment, the way that the emitted CO_2 is captured from flue gas or industrial waste gases and further used for valuable application is considered as good strategy for CO_2 mitigation. Among all the strategies of application of high concentration of CO_2 (even 100%), such as chemical, physical and biological methods, biological methods especially the use of microalgae for CO_2 sinking, is the most promising alternative [1]. To produce 1.0 kg of microalgal biomass, about 2.0 kg of CO_2 is required. The high efficient utilization of CO_2 by microalgae can not only decrease the quantities of CO_2 emitted into air, but also cut down the cost of microalgal mass cultivation [2]. It is well known that closed photobioreactors can improve microalgal CO_2 fixation and high CO_2 partial pressure can enhance CO_2 dissolution. Combination of closed photobioreactors with high CO_2 partial pressure used for microalgal culture has been studied [3-5]. But microalgal culture in closed systems aerated with 100% carbon dioxide is seldom investigated because of the inhibition of high concentration of CO_2 on microalgae growth [6]. In the present study, a closed raceway pond was proposed and microalgal growth in the closed raceway pond aerated with pure CO_2 was examined.

Materials and Methods

Closed Raceway Pond(CRWP). A schematic diagram of CRWP is shown in Fig.1. The pond was of the raceway type, being 2 m long, 0.6 m wide, 0.3 m deep, with a single central barrier. The pond was made of polymethyl methacrylate, and a paddle wheel was used for mixing and stirring of the culture medium in stirring zone. Pure CO_2 was blown into the pond using a porous stone at aerating site. As

Fig.1 shows, the cover of CRWP was H-shaped, directly touching the culturing liquid surface and keeping gas bubbles going along with culture flow under surface of the cover to increase the gas residence time and enhance dissolution of carbon dioxide while paddle wheel stirring. The outlet of exhausted gas in CRWP was in the stirring zone. The baffle plate stuck to the cover and prevented gas bubbles direct short from aerating site to the gas outlet. The dashed line represents culture liquid surface, being in contact with the cover.

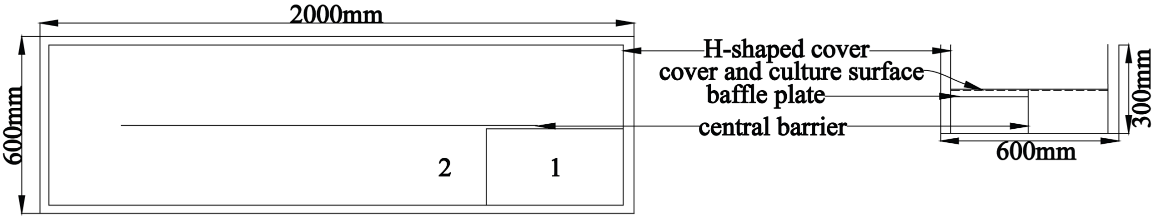

Fig.1. The schematic of closed raceway pond
1. stirring zone; 2.aerating site

Microalgal Cultivation. The strain *Chlorella vulgaris* was obtained from College of Marine Life Sciences, Ocean University of China. Algal cells were cultivated in the following medium (per liter), containing 1100 mg $(NH_2)_2CO$, 237 mg KH_2PO_4, 116 mg $CaCl_2\cdot 2H_2O$, 40 mg EDTA, 30 mg $FeSO_4\cdot 7H_2O$, 204 mg $MgSO_4\cdot 7H_2O$, and 1 mL of trace metal solution. The trace metal solution (per liter) includes 0.83 g H_3BO_3, 0.17 g $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$, 0.51 g $CoCl_2\cdot 6H_2O$, 3.3 g $MnCl_2\cdot 4H_2O$, 0.95 g $CuSO_4\cdot 5H_2O$, 2.7 g $ZnSO_4\cdot 7H_2O$. The flow velocity of culture medium in CRWP was 15 cm s^{-1} with 132 L working volume. The gas supply rate was measured using a quality flowmeter (LZB-3, Yinhuan, China) and was 40, 110 and 180 mLmin^{-1} at CO_2 concentration of 100%. The pond was incubated at 25 °C under continuous light illumination with cool white fluorescent lights above the cover in lab. The light intensity was determined using a light meter (Hansatech Instruments Quantitherm light meter thermometer, Norfolk, England) and was 110 μmol m^{-2} s^{-1}.

Characterizing Parameters of Microalgal Cultivation in CRWP. The dry weight (X, g L^{-1}) of algal cells was measured by filtering 30 mL of culture suspension through pre dried and weighted filters. After rinsing with distilled water, filters were dried at 105 °C for 12 h, and reweighed. The specific growth rate μ(d^{-1}) was calculated from the equation $\mu=(\ln X_t-\ln X_0)(t-t_0)^{-1}$, where X_0 was the initial biomass density at time t_0 and X_t was the biomass density at time t subsequent to t_0, and μ was determined by exponential regression of logarithmic portion of growth curve. The pH values (CN-113, Zhonghe, China) and DO concentrations (M700, Mettler Toledo, Switzerland) were recorded every day. The maximal PSII quantum yield(Fv/Fm) was measured by means of a pulse amplitude modulated fluorometer(PAM-2000), being Fv the maximal variable fluorescence of a dark adapted sample, and Fm the fluoresence intensity with all PSII reaction centres closed[7]. For chlorophyll determination, a known volume of microalgal suspension was centrifigued(2000 *g*, 5min) and all reside was frozen at -20°C and thawed at room temperature for at least three times, and then was extracted with ethanol absolute. Chlorophyll content was spectrophotometrically measured at two wavelengths(664.1 and 648.6 nm) and caculated with the following equation: chlorophyll content(ug/mL)= 5.24 $OD_{664.1}$+22.24 $OD_{648.6}$.

Results and Discussion

Microalgal Growth. The effect of gas flow rate on microalgal biomass is shown in Fig.2. During microalgal cultivation, microalgae directly entered into exponential phase without lag period, and the specific growth rate of microalgae aerated with 40, 110 and 180 mLmin^{-1} CO_2 was 0.4141 d^{-1}, 0.5363 d^{-1} and 0.4173 d^{-1}, respectively. The difference of specific growth rates demonstrated that increase of gas flow rates was not beneficial to microalgal growth. After 4 days of cultivation, microalgal biomass began to decrease under aeration with the flow rate of 40 mLmin^{-1}, which meant that the carbon dioxide supply can not meet the microalgal needs for growth. Time course of the microalgal chlorophyll and Fv/Fm is illustrated in Fig.3. The variation of chlorophyll content in microalgae cells cultivated under different gas flow rates was consistent with the corresponding microalgae growth, in the meantime, microalgal Fv/Fm almost kept stable during cultivation under aeration with different CO_2 supply flow rates, which meant that the maximum photosynthetic rate and chlorophyll production would not be inhibited by high concentration of carbon dioxide. The microalgae growth in CRWP aerated with different flow rates of 100% carbon dioxide indicated that microalgae was able to utilize pure carbon dioxide in photobioreactor constructed in the present study and can grow well under appropriate culture conditions.

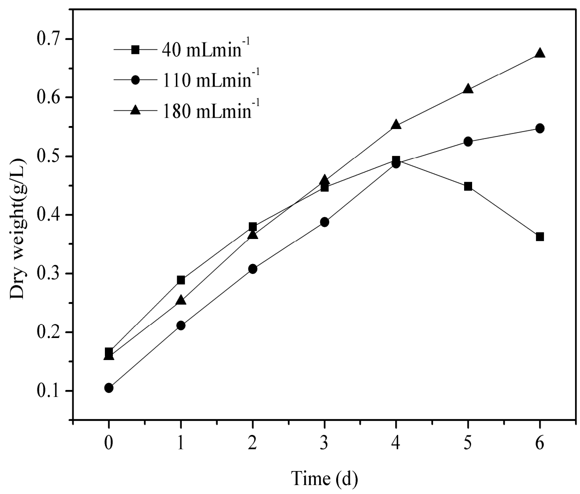

Fig.2. Microalgal growth curves in CRWP aerated with 100% carbon dioxide

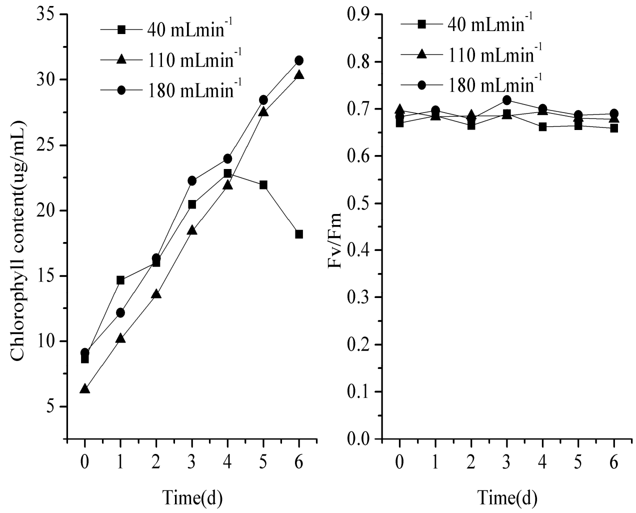

Fig.3. Microalgal chlorophyll and Fv/Fm in CRWP aerated with different gas flow rate

pH Value and Dissolved Oxygen(DO) Concentration. Fig.4 gives pH values and DO concentrations of culture in CRWP aerated with different gas flow rates. For the gas flow rate of 40mLmin^{-1}, the pH values kept gradually increasing with cultivation times, which meant that the dissolved carbon dioxide was absorbed by microalgae, and with microalgal propagation, the available carbon dioxide for microalgae growth decreased and pH values of culture increased. For the gas flow rates of 110 mLmin^{-1} and 180 mLmin^{-1}, the variation of pH values was similar. The pH values of culture decreased in the initial cultivation time and then nearly kept stable and ranged between 5.29 and 5.63, this result meant that the dissolution rate of carbon dioxide was enough to support the microalgal absorbing rate. K.Maeda et al. reported that the pH value below 6 inhibited microalgal growth[8]. But in the present study, no inhibition of microalgae growth was found. During the microalgae growth process, oxygen is produced as a by-product of microalgae photosynthesis, and if the oxygen is accumulated in the photobioreactor system, the excessive DO will result in photooxidation and photorespiration[9]. In the present study, the DO concentrations of culture in CRWP aerated with 40,110 and 180 mLmin^{-1} of 100% carbon dioxide were mostly around 10mg/L during the microalgae cultivation, which was a little higher than that of air-saturated CO_2 concentration. However, for the aeration of 180 mLmin^{-1} of 100% carbon dioxide, the DO concentration increased to about 17mg/L on the third and fourth day of cultivation and then decreased to about 10mg/L. Even during that cultivation time when the DO concentration was high as 17mg/L, the microalgae growth was not found to be inhibited by DO(Fig. 2) [10].

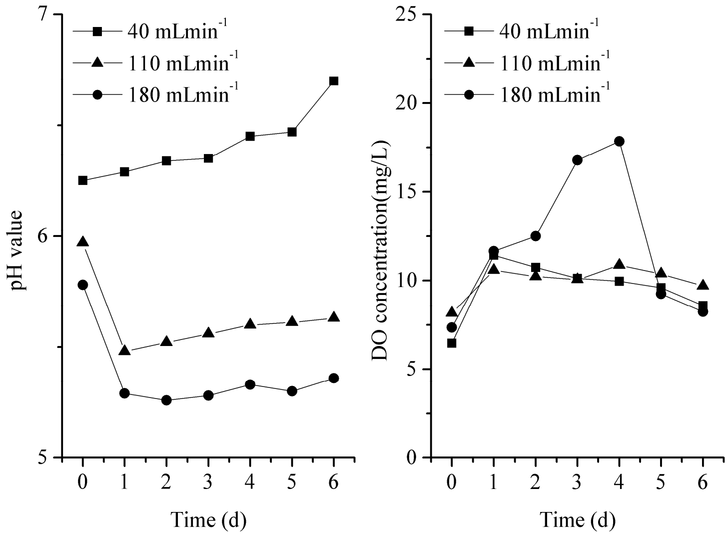

Fig.4. pH value and DO concentration curves in CRWP aerated with different gas flow rate

Conclusions

The present research examined microalgal cultivation in the closed raceway pond aerated with 100% CO_2. The microalgal growth, chlorophyll and Fv/Fm showed that microalgae can utilize pure CO_2 in the closed raceway pond, and the variation of pH values and DO concentrations further proved that CO_2 can be absorbed with high efficiency under the optimal culture condition. The present study proved the feasibility of using microalgae for sequestration of high concentration of CO_2 captured from industrial waste gas.

Acknowledgements

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References

[1]Kumar K, Dasgupta CN, Nayak B, Lindblad P and Das D:Bioresource Technology(2011).

[2]Sobczuk TM, Camacho FG, Rubio FC, Fernández F and Grima EM: Biotechnology and Bioengineering(2000).

[3]Morais MG, Costa JAV:Biotechnology Letters(2007).

[4]Tang D, Han W, Li P, Miao X and Zhong J:Bioresource Technology(2010).

[5]Ota M, Kato Y, Watanabe H, Watanabe M, Sato Y and Smith Jr RL:Bioresource Technology(2009).

[6]Rubio FC, Fernández F, Pérez J, Camacho FG and Grima EM:Biotechnology and Bioengineering(1999).

[7]Fu F-X, Warner ME, Zhang Y, Feng Y and Hutchins DA:Journal of Phycology(2007).

[8] K.Maeda, M.Owada, N.Kimura, K.Omata and I.Karube: Energy Covers. Mgmt(1995).

[9] Asterio Sánchez Mirón ACG, Francisco García Camacho, Emilio Molina Grima and Yusuf Chisti:Journal of Biotechnology(1999).

[10] Ana P. Carvalho LAM and F. Xavier Malcata:Biotechnol Prog(2006).

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