Utilization of Flue Gas from Coal Burning Power Plant for Microalgae Cultivation for Biofuel Production

Mahendraperumal Guruvaiah, Keesoo Lee

Abstract*— Microalgae have high photosynthetic efficiency that can fix CO2 from the flue gas directly without any upstream CO2 separation, and along with produce biomass for biofuels application and reduce greenhouse gas emissions. Microalgae studies were conducted in a batch mode experiments at Power plant, Jefferson city, Missouri, USA. The experiments were conducted in different period (May to October, 2011) of time. The genus Scenedesmus sp was isolated from power plant habitat and used for this experiments and then comparative study done by flue gas ponds vs non flue gas treatment ponds. The microalga was cultured with different simulated flue gases containing 1% – 4% (volume fraction) of CO2. The results show that Scenedesmus sp were grown very efficient at 2% CO2 content. The maximal biomass productivity and lipid productivity were obtained when aerating with 2% of CO2. The lipids content ranged from 10 to 18 % of dry mass of biomass. Scenedesmus sp has a great potential for CO2 mitigation, environmental tolerance and biodiesel production.

Index Terms*— Biomass, CO2 Sequestration, Microalgae, Lipids.

I. INTRODUCTION

The commercial applications of microalgae include their use as food supplements, feedstuffs in agriculture, aquaculture and biofuels feedstocks. However, their microalgae has recently been used for removal of carbon dioxide (CO_2) produced by combustion of fossil fuels in thermoelectric power plants with the aim of contributing to a reduction in greenhouse gases and global warming (Ono and Cuello.,2004). Thermoelectric power plants based on fossil fuels are responsible for more than a third of the CO_2 emissions of the USA and about 7% of the total world emissions (Chang and Yang, 2003), producing as well sulfur and nitrogen oxides (SOx and NOx), which are known to inhibit the growth of microalgae. CO_2 fixation by photoautotrophic algal cultures has the potential to diminish the release of CO_2 into the atmosphere, helping alleviate the trend toward global warming.

To use the microalgae to fix CO_2 released from power plants via the exhaust gas and thereby mitigate the amount of carbon released into the atmosphere is an attractive design. Microalgae strains that grow well at CO_2 concentrations of 5-10% show drastic decreases in their growth rate above 20% [Watanabe et al. 1992].

Manuscript Received January, 2014.

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An important task therefore has been to identify strains that can cope with very high CO_2 concentrations and also have high growth rates. Screening has yielded microalgae strains that grow well in CO_2 concentrations between 30% and 70% saturation [Hanagata et al. 1992; Sung et al. 1999]. Controlling the pH changes in the culture and releasing CO_2 to the algae on demand, growth could be sustained even at 100% CO_2 indicated that by Olaizola (2003). It has been suggested that the hot flue gases introduced in the algal cell cultures may influence the temperature [Ono and Cuello 2007].

The vital need for substantive net reductions in CO_2 emissions to the atmosphere can be addressed via biological CO_2 mitigation, tied with transition to more extensive uses of biofuel and renewable energy sources. Microalgae have concerned a great deal of attention for CO_2 fixation and biofuel production because they can convert CO_2 and supplementary nutrients into biomass via photosynthesis at much higher rates than conventional biofuel crops [Amit Kumar, 2010]. In this paper, the criteria microalgae cultivation studies used by CO_2 sequestration from power plant flue gas systems will be discussed.

II. METHODS AND MATERIALS

A. Algal Strain Details

The culture of green chlorococcal alga *Scenedesmus* sp was isolated from Power plant at Chamois, Missouri. The culture was maintained at our laboratory. This strain contained two and four-cellular coenobia. The number of cells in the culture doubled every 3-4 days.

B. Algae Cultivation and Nutrition

The flue gas from coal-fired power plant was used to cultivate the microalgae (*Scenedesmus* sp) in deep circular ponds. The pond diameter was 4 meters and volume of each pond 4000L. The nutrient media used to grow the algae were F/2. The F/2 medium has two forms. F/2 A consists of ferric chloride, EDTA, cobalt chloride, Zinc sulfate, copper sulfate, manganese chloride, and sodium molybdate. F/2 B contains sodium nitrate, mono sodium phosphate, Thiamine Hydrochloride (Vitamin B1) Vitamin B12, Biotin. 129.03µl/L medium taken from part A and part B solution. Proline F/2 algae food was purchased from Aquatic Ecosystems (Apopka, Florida). Parameters like Optical density, Cell count, Biomass measurement, pH and lipid content were monitored on a 5 days once up to a month. The experiments were conducted in different period of time.

C. Experimental Design

The flue gas from the power plant was diluted to 1%, 2% and 4% of CO_2 (volume of CO_2/volume of air mixture) using compressed air and supplied as CO_2 source for 3 hrs daily. The mixing and aeration was provided by bubbling the flue gas in to microalgae pond systems. The treatment of flue gas in two ponds and without flue gas treatment (control) two ponds were tested.

D. Microalgae growth analysis Microalgae cell count

Using the pipette, carefully fill the haemocytometer (Sigma Aldrich -Bright-Line, USA) by gently resting the end of the gilson tip at the edge of the chambers. The whole chamber has 9 squares. The four corner squares have 4x4 subdivisions. The center square has 5x5 subdivisions which are further divided into 4x4. Each square is $1mm^2$ and the chamber depth is 0.1mm; therefore the volume overlying each square is 0.1mm3 (or 0.0001ml = 0.1µl). Calculate the average number of cells per square (total cells counted/ number of squares used) and multiply by 10^4 and the dilution factor to cells per ml.

Dry cell weight

Algal dry cell weight was determined daily by filtering 10 mL of the culture sample onto Glass Microfiber Filters, GF/C (Whatman). The filtered sample was then washed with distilled water to remove adhering microalgae biomass, dried at 100°C for 24 h. The dried sample was immediately transferred to desiccators over silica gel for dehydration for at least 2 h before weighing. Cell or biomass dry weight productivity was calculated on a daily basis and/or at the end of the experiment.

E. Lipid extraction and determination

Freeze-dried algal mass was extracted with methanol containing 10% Dimethyl sulfoxide (DMSO) with slight modification of protocol followed by Chiara et al., 2002. The solvent with the biomass was heated at 45 °C and stirred for 45 min and the mixture was centrifuged at 3000 rpm for 10 min. The supernatant removed and the pellet was re-extracted with a mixture of diethyl ether and hexane (1:1 v/v). Added equal volume of water to the solvent mixture and supernatants so as to form a ratio of 1:1:1:1(v/v/v/v). The mixture was centrifuged again and the upper phase was collected. The water phase was re-extracted and the organic phases that contain total lipid were combined and evaporated to dryness under nitrogen protection. Total lipid with little solvent to dissolve was transferred to pre-weighed eppendorf tube, evaporated to dryness under nitrogen protection. Thereafter, the total lipids were measured gravimetrically after freeze drying for 24 h.

F. Biomass harvest

Microalgae biomass was harvested by flocculation with chitosan. The pH of the algae ponds was reduced to 7.0 using CO_2 addition and an aliquot of 0.4 ml of chitsoan solution (10 g of Chitosan/l of 0.1 N of HCL) was added per liter of algae pond water. The ponds were left undisturbed overnight for efficient flocculation. The top water was recycled for subsequent studies and flocculated slurry was collected in buckets and stored in refrigerator till further use.

G. Biomass Compositional analysis

CHN elemental analyses carried out using a Perkin-Elmer 2400 CHN Elemental Analyzer (Model No. 2400, Serial No. 138391). A known weight of samples (between 1.0- 3.0 mg) was placed in to the instrument. The analysis is done by catalytic combustion followed by a packed gas-chromatographic column separation and quantitative determination by thermal conductivity detector. Samples were oxidized at 925°C in a pure oxygen environment using several metal oxides as catalysts and reduction temperature was 640 °C. Acetanilamide was used as reference standard. The ash content analysis was carried out using ASTM standard D 1102 – 84 and the moisture content in biomass was carried according to ASTM standard E 871 – 82.

III RESULTS AND DISCUSSION

A. Composition of Flue gas

The CO_2, SO_2 and NOx concentration of the flue gas was analyzed periodically and it was observed that the composition may vary slightly with the quality of the coal used in the process. The detailed composition of the flue gas supplied to algal ponds is given in table 1. It can be observed that the average of maximum CO_2, SO_2 and NOx concentration were 14%, 280 ppm and 580 ppm respectively and the flue gas was cooled from 200 °C to 15-30 °C by mixing with compressed air.

Table 1: The different composition of flue gases

Composition	Our study (power plant gas)	sub bituminous coal	Natural gas	Diesel fuel
CO_2 (%)	14.4	24	13.1	62
SO_2 (ppm)	282.1	929	0	113.1
NOx (ppm)	589.5	240	22.1	169.7

B. Growth evaluation

The algae ponds were supplied with the coal-fired power plant flue gas over the summer of 2011 (5 months- May, June, July, August and October) at Chamois MO (38.67 N, 91.76 W) and the biomass yield was monitored. The flue gas was used as such without any scrubbing or desulfurization. It can be observed from fig.1 that the addition of flue gas containing 2 % CO_2 has enhanced the biomass yield when compared to the control ponds without any flue gas.

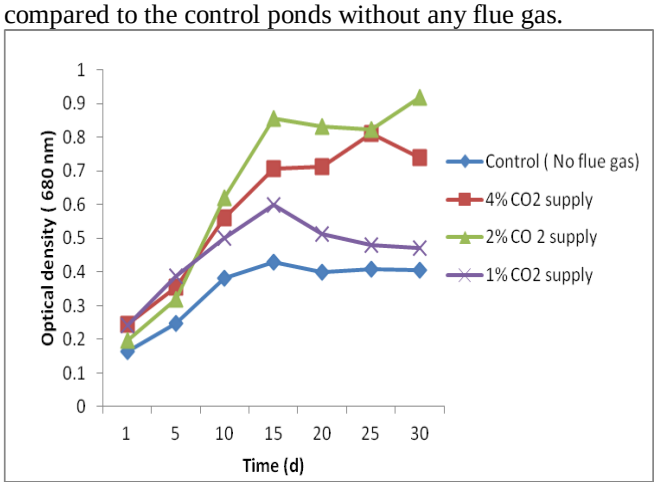

Fig 1: Cell density of different batch cultures during the treatment period

The earlier report was (Douskova et al 2009) that had tested direct flue gas from various industries as CO_2 source for algae production. Similar trend was observed throughout our study irrespective of monthly changes in ambient conditions. Physical parameters of algal ponds were given in table 2.

Table: 2 Physical parameters of algal ponds

Months	pH	Water temp	light (lux)
May	7.83	23.90	1266.40
June	7.07	28.91	1132.22
July	7.79	24.00	1106.00
August	7.64	29.95	1139.57
October	7.62	16.20	1099.48

C. Effect of CO_2 concentration on biomass and lipid productivity

In order to determine the effect of higher concentration of CO_2 in the flue gas on the biomass yield, the flue gas was diluted with air to final concentration consisting of 1%, 2% and 4% of CO_2 in the flue gas air mixture. It was observed from the flue gas containing 2% CO_2 performed better than the ponds supplied with 4% CO_2 flue gas and control. The possible reason for the anomaly can be either the drastic pH change associated or due to the relatively higher concentration of SO_2 and NOx supply. The pH drop of from 8.5 to 7.8 over the 3 hour duration of 4% CO_2 feeding might have stressed the culture when compared to the 2% CO_2 supply (fig.2).

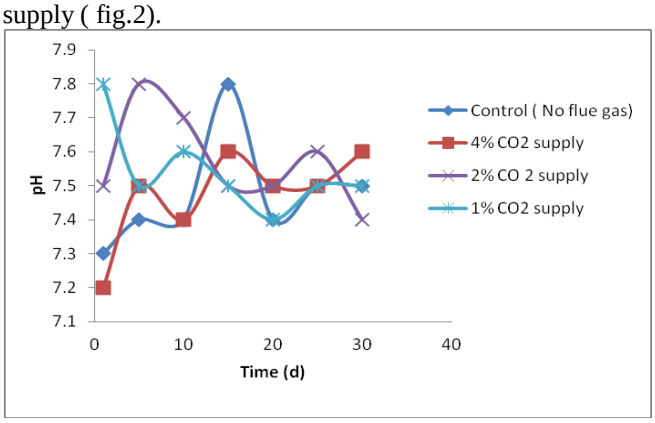

Fig 2: Changes of pH values of different batch cultures during the treatment period

The sunlight and ambient temperature were combined for the suitable growth of biomass and lipid production and carbon mitigation potential. Maximum algal biomass was (1.20 g/L) in 2 % CO_2 concentrations (Fig.3).

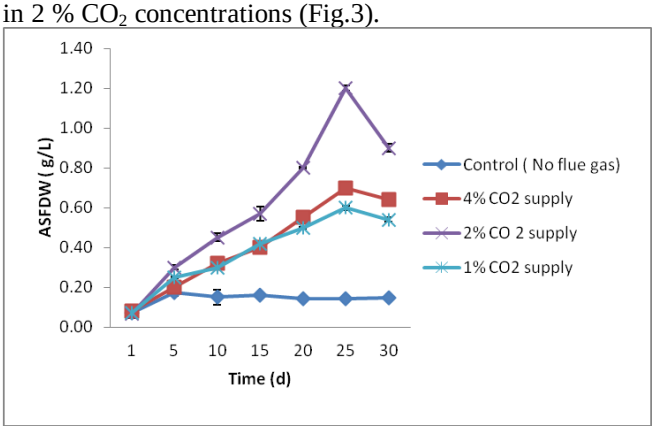

Fig 3: Ash free dry weight of different batch cultures during the treatment period

Lipid productivity was estimated for control and 1, 2 and 4 % CO_2 supply. The lipid yield was calculated more than 15 % from the dry biomass (Fig.4). Further improvement of lipid and biomass may be the effect of nitrogen starvation strategies and modification of cultivation system on the performance of lipid production and CO_2 fixation from the indigenous microalga.

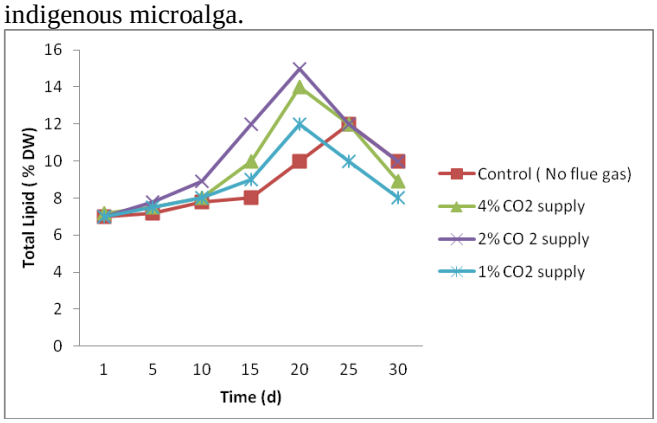

Fig 4: Total lipid of different batch cultures during the treatment period

D. Biomass composition analysis

The proximate composition of biomass grown at different concentration of flue gas was given in table 2. It can be observed addition of flue gas has increased the ash content of the biomass. It is also interesting to observe that increasing the CO_2 with flue gas the decrease in the biomass productivity. The composition were analyzed from microalgal biomass and presented in table 2.

Table 2. The composition of microalgal biomass from power plant flue gas

Composition	Control (No flue gas)	1% CO_2	2% CO_2	4% CO_2
C	28.58	29.75	28.23	31.70
H	3.76	3.60	2.61	3.34
N	4.54	4.95	4.20	5.45
Protein	28.38	30.94	26.25	34.06
Moisture	10.45	10.63	10.21	10.14
Ash	30.13	33.32	34.57	32.39

IV. CONCLUSION

Carbon capture and sequestration by using microalgae from power plant combustors. Microalgae are able to capture of CO_2 from a wide variety of flue gases from coal burning power plant. *Scenedesmus* sp was used for this experiments and then comparative study done by flue gas ponds vs non flue gas treated ponds. This strain was grown in very efficient at 2% CO_2 content. Maximum algal biomass was (1.20 g/L) in 2 % CO_2 concentrations and lipid productivity more than 15 % were obtained. *Scenedesmus* sp has a great potential for CO_2 mitigation with flue gases, environmental tolerance and biodiesel production.

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AUTHOR PROFILE

Dr. Mahendraperumal has his basic education in the field of Plant Biotechnology has done his Ph.D. in Botany specialization of Phycology and diversity, molecular studies of microalgae in the year 2007 from Centre for Advanced Studies in Botany, University of Madras, Chennai, India. He was awarded Post-doctoral fellowship at Applied Biological Sciences, Laboratory for Algae Research and Biotechnology, Arizona State University, USA from 2008-2010. His research activities have focused on algal strain isolation, identification and evaluation and the cultivation of algae in both the laboratory and outdoors. He was moved as Post Doctoral Fellow, Dr. Juregen Polle lab at Brooklyn College of CUNY, Brooklyn, New York, USA from July 2010 to September, 2011. He is intensively involved in sample strains from a wide variety of environments for maximum diversity and develops small scale, high-throughput screening technologies for biofuels production and other products. Another year research experience from Post doctoral fellow at Lincoln University of Missouri, USA. To study the feasibility of using carbon dioxide (CO_2) in flue gas from Power Plant to feed algae. Presently, he is working as a Senior Scientist in the Bioconversion Technology Division of SPRERI, Anand, Gujarat.

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