Assessment of Carbon Capture and Sequestration: An Investigation on Algae Growth Rate under controlled Environmental Conditions

Jeffrey Chauke, Lunghile Ndleve, Craig Griffiths, Brendon Hausberger, Kalala Jalama

Abstract—**Current challenges on CO_2 emissions and climate change require cost-effective techniques for carbon capture and sequestration. The aim of this study was to investigate algae growth under controlled environmental conditions for CO_2 sequestration. An algae strain from a local lake was used in this study and inoculation tests were performed at 22, 32 and 38ºC. The highest algae growth was observed around 22ºC.**

***Index Terms*—Carbon Capture, Algae, Sequestration.**

I. Introduction

CARBON dioxide emissions and global warming are among the major challenges that the world has ever been confronted with. Chemical and mechanical industries are the major contributors of carbon dioxide emissions due to their dependence on carbon sources such as coal, oil, natural gas for fulfillment of energy requirements. According to a report by Carbon Dioxide Information Analysis Center (CDIAC), CO_2 emissions have increased from 3 metric tonnes in 1751 to 8230 metric tonnes in 2006. It was estimated that CO_2 reached 390 ppmv in 2010 in the atmosphere relative to 280 ppmv in 1958 [1]. This clearly indicates a rise in the concentration of CO_2. Therefore, this environmental crisis presents a need for reduction of the concentration of CO_2 gas into the atmosphere. Capturing, transporting and storing of carbon dioxide require a physical means which is rather expensive. Bio-capture and sequestration are cost effective and most attractive options due to the fact that they are cheap and flexible relative to the other methods [2].

These techniques are broadly divided into physical and biological means. The latter involves algae organisms to sequestrate CO_2. The use of algae organisms comes with several advantages.

Algae have been reported to have an ability to fix CO_2 ten times greater than any terrestrial plants [1]. Kumar et al. [2] have reported that 1 kg of algal dry cells is capable of fixing 1.83 kg of CO_2 which, on an annually scale is around 54.9 – 67.7 tonnes of carbon dioxide that can sequestrated by just 30 – 37 tonnes of algae. Subsequently, the resultant biomass of the algae can be used for production of biofuels and other commercial and scientific important products such as bio-filters, food products and water quality purposes. There are enormous groups of algae species which have different characteristics altogether. Generally, algae have a wide range of habitat such as fresh water, marine water, in-deep oceans and rocky shores. The primary factors that influence the growth of algae directly or indirectly include sunlight, concentration of CO_2, pH, agitation and salinity [1]. Cultivation of algae through biological means involves two types of systems either open or closed. One of the shortcomings of the open system is the lack of the ability to control parameters such as availability of light, agitation, pH, temperature and nutrient concentrations. Another drawback is that there is very low residence time of sparged gas in the culture which gives a limited time for algal biomass to sequester CO_2. Open systems are also susceptible to contamination which reduces the biomass productivity and its uses for the production of commercially important products. Thus, this makes open system least viable system to sequester CO_2.Whereas, in a closed system the degree of control is very high and it is possible to control the crucial parameters that influences the grow rate of the culture [1].

This study aims at investigating the optimum conditions to sequestrate CO_2 using algae organisms in a semi-isolated bioreactor.

Manuscript received 4 July, 2016; revised August 10, 2016. This work was supported in part by the National Research Foundation (NRF)-THRIP and the Faculty of Engineering and the Built Environment at the University of Johannesburg.

J. Chauke is with the Department of Chemical Engineering, University of Johannesburg, South Africa (e-mail: chaukejs@gmail.com).

L. Ndleve is with the Department of Chemical Engineering, University of Johannesburg, South Africa (e-mail: lndleve@dual-h.com).

C. Griffiths is with Holland & Hausberger, Wild Fig Business Park, 1494 Cranberry Street, Honeydew, 2170, Randburg, South Africa (e-mail: cgriffiths@dual-h.com).

B. Hausberger is with Holland & Hausberger, Wild Fig Business Park, 1494 Cranberry Street, Honeydew, 2170, Randburg, South Africa (e-mail: bhausberger@dual-h.com).

K. Jalama is the Department of Chemical Engineering, University of Johannesburg, South Africa (corresponding author, e-mail: kjalama@uj.ac.za, phone: +27-11-559-6157).

II. EXPERIMENTAL DETAILS

Fig. 1 shows the bioreactor that was designed and used in this study.

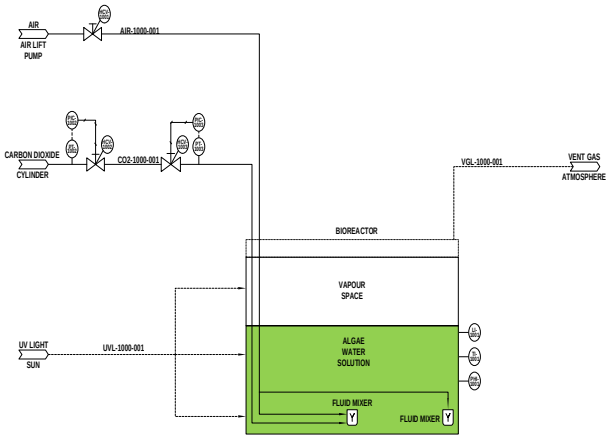

Fig 1: Bio-Reactor

Air and carbon dioxide were introduced to the system through line AIR-1000-001 and CO_2-1000-001 respectively. The flows were manipulated through HCV-1001 and HCV-1003 to achieve the desired mixing in the bioreactor made up of approximately 27 liters of algae in water. The fluid mixers at the bottom of the tank assist in distributing the gas into the bulk liquid. As the gas bubbles throughout the mixer it also initiates the mixing in the tank to increase the exposure of algae cells to the solar energy that comes through dotted line UVL-1000-001. The dotted line denotes the invisible ultra violet light that is radiated by the sun naturally. pH, temperature and level of the tank were monitored on a daily basis with an aid of the instruments shown on the right side of the tank. The vapour space of the tank has all the undissolved CO_2, product gas from photosynthesis reaction performed by algae and trace amount of other gases. The liquid level was kept constant and the flow rate calibrated before the actual process kicked off. The composition of the vapour space was analyzed using a gas chromatograph (GC) to assist in the estimation of how much CO_2 has reacted in the tank.

The first stage of the experiments involved culturing of small samples of algae, collected from a local lake, into 350 ml bottle jars to sustain all further experiments. Two types of algae-containing samples were prepared: i) fertilized samples that contained algae water from the lake mixed with fertilisers and tap water and ii) non-fertilized samples that only contained algae water from the lake mixed with tap water. For comparison purposes, other samples that only contained fertilized water and tap water were also prepared. All these samples were left to nourish for a period of a month with regular monitoring and maintaining of a fixed level of water by replacing the evaporated portion. It was observed that the fertilised algae water became greener than the non-fertilised water. The samples that only contained fertilised water, excluding algae and the tap water remained unchanged and no algae was formed suggesting that the growth that was noticeable on the fertilised algae water was brought about due to the algae presence. The fertilized algae samples were then selected for the rest the experiments and were expanded to bigger volumes as summarized in table 1.

TABLE I
SAMPLE EXPANSION FROM INITIAL CULTURE

Sample ID	Fertilizers(ml)	Tap Water(ml)	Algae Water(ml)	Total(ml)
Sample 1	150	1250	100	1500
Sample 2	150	1100	250	1500
Sample 3	430	570	500	1500
Sample 4	150	650	700	1500
Sample 5	151	648	701	1500

Additionally these samples were further grown for a period of a month and later used for inoculations purposes.

Inoculation involved selecting and injecting the greener sample into the bioreactor with sterilized water to make a total volume of 27 litres. The rate of CO_2 (0.856 l/min.) and air (1.583l/min.), and the quantity of fertilizer (3086 ml) added to the bioreactor were the same for each experiment but the following average temperatures were selected: 22, 32, 38 and 40°C. The rate of algae growth was determined by monitoring the change in mass content of the algae in the bioreactor by water evaporation of small samples taken from the reacting mixture at different time intervals.

III. RESULTS AND DISCUSSION

A. Initial culture growth

The expanded samples listed in table 1 responded differently. Sample 1 and 2 growth rates were slow while those for samples 3, 4 and 5 were significantly fast for the first two weeks. However, after this period samples 1 and 2 caught up with the rest of the samples and a peak in growth rate was reached. This was likely caused by the density effect of the culture in the volume. Below the optimum cell concentration, not all the light energy is caught by the cells whereas at above the optimum cell concentration, a larger proportion of the cell are in the dark due to self-shading and this was observed on sample 5. Sample 1 which had the least cells concentration was able catch up to the other samples which relatively had high cell concentration. High density of the cells improves the tolerance of carbon dioxide [3] and as a result, it can be expected that the denser the culture the better the sequestration. However, it is not effective to cultivate with denser algae cells due to the self-shading effect which reduces the productivity.

B. Inoculation

Figure 2 represents two identical inoculations at a mean temperature of 22°C for 164 hours. The first run (1a) used sample 2 (table 1) and showed a linear algae growth with the time-on-stream (TOS). At the end of the experiments a growth 0.014 g of algae per ml was recorded. Sample 5 was used to repeat run 1 (run 1b) and also showed a linear algae growth with TOS.

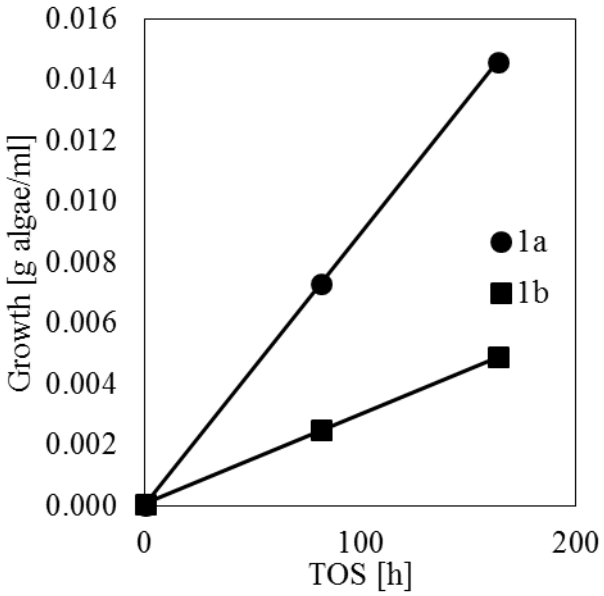

Fig 2: Inoculation 1 (mean temperature 22C)

The experiments conducted at 32 and 38°C also showed algae growth with TOS as summarized in table 2.

TABLE II
OVERALL RESULTS OBTAINED THROUGHOUT THE EXPERIMENTS

Run identity	1		2		3	
Average temperature [^oC]	22 (uncontrolled)		32		38	
Stock sample identity*	2	5	1	3	4	2
Inoculated mass [g]	0.53	2.07	10.05	2.38	4.82	7.55
10^5 x Inoculated density [g_{algae}/ml]	2	7	32	8	16	24
10^5 x Intermediate growth [g_{algae}/ml]	730	248	430	342	628	84
10^5 x End of run growth [g_{algae}/ml]	1458	489	828	676	1240	144
End of run growth factor**	858	74	27	89	79	7

*: summarized in table 1

**: calculated as $\frac{Initial\ M_{alg} + Final\ M_{alg}}{Initial\ M_{alg}}$

Samples 1 and 3 were used for the run at 32°C. The initial algae concentration for sample 1 was measured to be 0.000324 g algae/ml. The intermediate growth, over a period 80 hours, was 0.0043 g algae/ml and the final total growth at the end (after 160 hours) of the run was 0.00828 g algae/ml. Sample 3 with an initial algae concentration of 0.00000767 g algae/ml, had an intermediate growth of 0.00342 g algae/ml and total growth of 0.00676 g algae/ml. The run at 38oC used samples 2 and 4.These data suggest that that this strain is mesophilic (16-45°C).

The pH of the system was monitored during each experiment and the texture of the algae solution was used to develop a judgement on the growth and as a result of CO_2 sequestration. An average pH of 7.5 was observed throughout the inoculations and suggested dissociation of CO_2 compound in the solution. Optimum conditions for sequestration of CO_2 were observed for run 1 (with sample 2) which gave the highest algae growth factor.

IV. CONCLUSION

Carbon dioxide sequestration using microalgae was investigated in a semi-isolated bio-reactor. The temperature tested ranged from 22°C to 38°C where the other parameters were kept constant. All the runs demonstrated positive growth of algae which confirms the hypothesis that presence of carbon dioxide, light, water and nutrients availability enhances photosynthesis of algae cells.

The highest algae growth was observed for inoculation run which was subjected to uncontrolled temperature of 22°C.

References:

[1] A. Dahiya, 2015. Chapter 14 - Algae Biomass Cultivation for Advanced Biofuel Production. In: A. DAHIYA, ed, Bioenergy. Boston: Academic Press, pp. 219-238.

[2] K. Kumar, C.N. Dasgupta, B. Nayak, P. Lindblad, D. Das, 2011. Development of suitable photobioreactors for CO2 sequestration addressing global warming using green algae and cyanobacteria. Bioresource technology, 102(8), pp. 4945-4953.

[3] L. Xin, H. Hong-Ying, G. Ke, S. Ying-Xue, 2010. Effects of different nitrogen and phosphorus concentrations on the growth, nutrient uptake, and lipid accumulation of a freshwater microalga Scenedesmus sp. Bio-resource technology, 101(14), pp. 5494-5500.