FEASIBILITY STUDY ON CARBON SEQUESTRATION USING ALGAE

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Abstract - *The increase in the atmospheric CO_2 has lead to severe impacts on the global climate change, which has made carbon sequestration the need of the hour. Among the different carbon sequestration techniques photosynthetic algal sequestration has gained importance due to the fact that the algal biomass formed as a product of carbon sequestration is very useful in many ways like generation of Bio-fuel , bio-ethanol, methane , hydrogen , power, nutrient food supplements and so on. But the cost of the project becomes very high. Therefore the optimum design of photo-bioreactors with optimum environmental conditions like light intensity, pH, Temperature, nutrients, concentration is to be found out for practical implementation. In this project these varying conditions are tested for the Carbon utilization rate and the optimum conditions are to be determined for a particular algae species called Chlorella vulgaris by setting up a lab scale photo-bioreactor and artificial supply of CO_2 is given. The maximum carbon fixation rate and the effectiveness of Carbon Capture for the particular species are to be studied in this project.*

***Key Words*: climate change, photosynthetic algal sequestration, photo-bioreactors, Chlorella vulgaris, carbon fixation rate .**

1.INTRODUCTION

The most commonly considered indicator of climate change and global warming is the surface air temperature. Atmospheric CO_2 and other greenhouse gases are primarily the result of combustion of fossil fuels. Atmospheric CO_2 had been balanced through various cyclic phenomena of the decreasing effect by photosynthetic fixation by plants and dissolving in the seawater and of the increasing effect due to releasing from decaying plants and the seawater. Due to the anthropogenic emissions, greenhouse gases in the atmosphere have been steadily increasing thereby causing great anxiety in global warming. The growing evidence that links carbon dioxide (CO_2) and global climate change highlights the need to develop cost effective carbon sequestration schemes. The main challenge of CO_2 capture and storage is the high cost of using current state-of-the-art technologies.

Various technologies have been used to mitigate the fossil fuel-fired power plant stack emissions including the (1) physical-chemical processes, such as wet or dry absorption and membrane separation techniques and (2) biological methods, in particular using microalgal photosynthesis. Chlorophyll in photosynthetic algae captures light energy, which is used to convert simple molecules (CO_2 and H_2O) into carbohydrates (sugars and starches) with the release of O_2. Microalgae are of particular interest because of their rapid growth rates, tolerance to varying environmental conditions and can also fix greater amounts of CO_2 per land area than higher plants. Capture and utilization of the carbon dioxide and other flue gases by microalgae has emerged as a promising technology to help reduce emissions from fossil fuel-fired powered plants. The carbon fixed by microalgae is incorporated into carbohydrates, lipids and proteins, so energy, chemicals or foods can be produced from algal biomass. The energy rich biomass is widely used as a source fuel (liquid and gaseous), health foods, animal feed and also in producing vitamins and pigments. Processes in conversion of algal biomass to such useful products would indirectly decrease dependence on fossil fuels.

2. MATERIALS AND METHODS

2.1 CULTURING ALGAE

5 ml of Chlorella vulgaris mother culture is suspended in 100 ml Bold's Basal medium in 250 ml flasks and kept in open air shaker at 100 rpm under 6 fluorescent lamps of light intensity 7000 Lux at Temperature of 26^0 C for 15 days and then Centrifuged at 25^0 C at 5000 rpm for 6 min .Then the required algae is loaded in photo-bioreactor.

2.2 EXPERIMENTAL SETUP

The lab scale photo-bioreactor consists of three cylindrical glass reactors of size 40 mm diameter and 500 mm height in which the alga is grown in the Bolds' Basal Medium with a free board of 10 cms. The three reactors are properly hold over a rectangular glass container of size 60 mm x 30 mm x 40 mm. CO_2 and Air stored in cylinders is supplied into the algae medium in a controlled way using regulators. The flow is measured using a flow meter and the required CO_2 –air ratio is maintained .The CO_2 and Air is mixed and collected using a Y-Joint and taken to the distributor where the CO_2 – Air mixture is distributed to three reactors. There is an air exit through which uncaptured gas escapes out. The alga is supplied with external light source containing 1 number of 45 watts Compact Fluorescent Lamp. The overall experimental setup is shown in Figure 3.1.

Figure1.Experimental Setup

2.3 EXPERIMENTAL PROCEDURE

The cultured alga is transferred into the suspension medium in the rectangular tank. CO_2 and air mixture is supplied using sparger. In the presence of external light source, the growth of algae is found out for a period of 3 days for varying conditions of CO_2 concentration, CO_2 flow rate, light intensity, pH, temperature, nutrient concentration. The carbon utilization rate and carbon fixation efficiency is calculated for each case.

2.4. EXPERIMENTAL STUDY

A known volume of algae with initial known concentration (X0) of the starter culture is inoculated into the three reactors separately and several trials with varying conditions of CO_2 percentage, CO_2 flow rate, light intensity, and pH are done. In each trial the absorbance values for 730 nm and 750 nm are found using UV-Visible spectrophotometer. pH was measured using pH meter. Monitoring of pH was necessary to keep the culture in good condition. pH was measured 2 times a day and was maintained by the addition of 0.01 M NaOH was added. Light intensity was measured using Lux meter. The sensor was inserted into the outer surface of reactor holding algal suspension deep below and the reading is taken twice a day.

The cell growth is studied in all trials and the final concentration after 3 days is found from which CO_2 fixation rate and CO_2 capture efficiency is calculated.

2.5.Algal concentration determination

Known volumes of microalgal samples were filtered through membrane filters using vacuum suction whose initial weight is already known. Filters are dried in hot air oven at 105-110^0 C for 24 hrs then cooled to room temperature to get final weight.

Biomass (mg) = Final Weight –initial weight

Algae concentration (mg/l) = (Biomass/volume)*1000

2.6 Calibration between Optical Density and concentration of Algae

Four samples whose dry mass concentration is already known are taken. Absorbance values in Spectrophotometer are measured for wavelength of 438,678,730,750 nm. A graph is plotted and the value of k=concentration / Absorbance is found out and also the average values of concentration/Absorbance for all samples.

3.EXPERIMENTAL OBSERVATIONS

3.1 DETERMINATION OF ALGAL CONCENTRATION

Table 1. Determination of Algal Concentration

S.No	Initial Wt (g)	Final Weight (g)	Net Weight (g)	Algal Concentration (mg/L)
1	52.0900	52.0968	0.0085	170
2	56.6512	56.6613	0.0101	202
3	40.8610	40.8734	0.0124	248
4	51.4208	51.4280	0.0072	144

3.2 CALIBRATION BETWEEN OPTICAL DENSITY AND CONCENTRATION OF ALGAE

Table 2. Calibration between Optical Density and concentration of Algae

Samples	Concentration (mg/L)	Abs at 438 nm	Abs at 678 nm	Abs at 730 nm	Abs at 750 nm
1	170	0.9039	0.6802	0.6101	0.5936
2	202	0.9169	0.6795	0.6044	0.5864
3	248	1.1428	0.8040	0.7055	0.6870
4	144	0.8596	0.6426	0.5789	0.5723
Average k=Conc/Abs		198.25	269.75	303.44	310.5

Algal Cell Concentration (mg/L)
= 310.5 X Absorbance for Wavelength of 750 nm.

=303.5 X Absorbance for Wavelength of 730 nm.

3.3 VARIATION OF INFLUENCING PARAMETERS

The various influencing parameters are varied as shown in Table

Table 3 . Values of influencing parameters in each study

TRIALS	CO2 %	PH			Light Intensity in Lux		
		Rr 1	Rr 2	Rr3	Rr1	Rr2	Rr3
TRIAL 1	20	7.5	8.5	9.5	1000	1500	1000
TRIAL 2	11	7	8	9	2500	3500	2500
TRIAL 3	20	7	8	9	3000	4500	3000
TRIAL 4	15	7	8	9	2500	3500	2500
TRIAL 5	25	7	8	9	3500	4500	3500
TRIAL 6	15	7	8	9	3500	5000	3500

Experimental study 1

Table 4.Algal Growth for study 1

Time	Reactor 1		Reactor 2		Reactor 3	
	pH	Conc mg/L	pH	Conc mg/L	pH	Conc mg/L
Day 1	9.5	39.86	8.5	39.96	7.5	40.148
Day 2	8.15	42.85	7.7	50.301	7.07	41.34
Day 3	6.23	46.575	6.15	52.785	6.04	43.47
Day 4	5.85	51.23	5.80	57.75	5.79	45.954
Day 5	5.82	52.785	5.79	62.1	5.79	50.301

In trial 1 it is seen that the growth is linear upto a particular period of time and after that it is stationary. This is due to the fact that the Ph gradually reduced to around 5 which is acidic in nature, which hinders the growth of the algae.

Therefore maintaining the pH in the alkaline region is the must for maximum growth and therefore for maximum CO_2 capture.

Experimental study 2

Table 5. Algal growth for study-2

DAYS	Reactor 1 (pH= 7)		Reactor 2 (pH= 8)		Reactor 3 (pH= 9)	
	Concentration (mg/l)	light intensity (lux)	Concentration mg/l	light intensity (lux)	Concentration mg/l	light intensity (lux)
DAY 1	40.63	2500	39.50	3000	37.66	2500
DAY 2	55.15	2530	52.90	3220	50.38	2530
DAY 3	65.33	2750	63.93	3750	65.10	2630
DAY 4	111.71	2600	111.26	3150	104.6	2600
DAY 5	125.32	2530	135.3	3500	128.6	2520
DAY 6	168.75	2570	195.7	3330	171.0	2600
DAY 7	196.31	2580	204.3	3510	211.0	2600

In study 2 constant pH is maintained around 7, 8, and 9 in the reactors 1, 2 and 3 respectively The reactor with the highest light intensity showed the maximum CO_2 capture rate.. Therefore maintaining a pH of 9 and light intensity of 3500 is considered to be optimum.

Experimental study 3

Table 6. Algal growth for study-3

DAYS	Reactor 1 (pH= 7)		Reactor 2 (pH= 8)		Reactor 3 (pH= 9)	
	Concentration (mg/L)	light intensity (lux)	Concentration (mg/L)	light intensity (lux)	Concentration (mg/L)	light intensity (lux)
DAY 1	57.26	3200	41.48	4480	97.96	3100
DAY 2	54.23	3210	75.34	4480	88.75	3120
DAY 3	54.95	2900	67.96	4200	76.61	2920

In trial 3 due to some contaminations the growth is seen to be fluctuating and a steady increase in the growth could not be found out. So no inference can be taken from this trial.

Experimental study 4

Table 7. Algal growth for study-4

DAYS	Reactor 1 (pH= 7)		Reactor 2 (pH= 8)		Reactor 3 (pH= 9)	
	Concentration (mg/L)	light intensity (lux)	Concentration mg/L	light intensity (lux)	Concentration (mg/L)	light intensity (lux)
DAY 1	99.91	2550	93.26	3950	102.54	2560
DAY 2	108.93	2530	106.39	3480	112.22	2480
DAY 3	114.36	2580	143.81	3300	131.19	2570
DAY 4	146.9	2650	192.73	3700	169.21	2730

In Trial 4, the CO_2 utilization rate of 29, 60, 40 mg/l/day respectively in the three reactors is achieved for the first three days itself. The middle reactor with light intensity of 3500 lux and pH of 8 with a CO_2 % of 15% is higher than that of the trial 2 with CO_2 % of 10% . Therefore a CO_2 concentration of 15% is advisable than 10%.

Experimental study 5

Table 8. Algal growth for study-5

	Reactor 1 (pH= 7)		Reactor 2 (pH= 8)		Reactor 3(pH= 9)	
DAYS	Concentration (mg/L)	light intensity (lux)	Concentration (mg/ L)	light intensity (lux)	Concentration (mg/ L)	light intensity (lux)
DAY 1	45.24	3510	48.0	4520	43.10	3520
DAY 2	55.86	3480	59.23	4550	53.89	3510
DAY 3	61.23	3530	65.81	4510	58.56	3530
DAY 4	67.50	3520	76.39	4490	67.92	3500

In trial 5 even though the light intensity is increased, Since the CO_2 % is increased to 25% maximum growth is not achieved. So CO_2 % greater than 15% is not suitable for maximum growth. But still growth can be seen.

Experimental study 6

Table 9. Algal growth for study-6

	Reactor 1 (pH= 7)		Reactor 2 (pH= 8)		Reactor 3 (pH= 9)	
DAYS	Concentration (mg/L)	light intensity (lux)	Concentration(mg/L)	light intensity (lux)	Concentration (mg/L)	light intensity (lux)
DAY 1	60.62	3500	73.01	5400	65.31	3500
DAY 2	130.60	3500	96.35	5150	88.41	3550
DAY 3	141.20	3420	141.64	6200	87.40	3520
DAY 4	184.56	3500	187.23	5400	114.27	3510

In study 6 , unexpectedly , the first reactor with pH =7 gave maximum growth. This may be due to the fact that thorough mixing was taking place in the first reactor .So complete suspension of algae is far more important because more contact area for algae is achieved. This parameter is more influencing than other parameters.

4 RESULTS AND DISCUSSIONS

The CO_2 fixation rate and CO_2 fixation efficiency are calculated in each trial. The following results were obtained as shown in Table 10.

Table 10. Results in each study

TRIALS	CO_2 Fixation Rate (mg/L/Day)			CO_2 Fixation Efficiency in %		
	Reactor 1	Reactor 2	Reactor 3	Reactor 1	Reactor 2	Reactor 3
1	5.91	10.15	4.65	0.005	0.008	0.004
2	50	57	51	0.04	0.048	0.043
3	Observations are inappropriate					
4	29	60	40	0.0246	0.052	0.0346
5	13.6	17.35	15.17	0.0115	0.0147	0.013
6	75.74	69.801	29.92	0.129	0.119	0.05

It can be seen that in all the studies the centre reactor results shows maximum CO_2 utilization. So we can say that upto 4500 Lux photo inhibition did not take place so increase in the light intensity has promoted the algal growth. It can be seen that without maintaining constant pH, the medium changes to acidic therefore growth is slown down. Therefore maintaining constant pH is essential. Maintaining a pH of 9 is better than pH=7 in all the trials. Maximum CO_2 utilization is seen in 15% CO_2 supply. When the total flow rate is reduced proper mixing did not take place and the alga starts to settle down. So maximum growth did not take place. Therefore proper mixing or gas transfer is required for good algal growth. Without considering the last trial ,the maximum growth is obtained in trial 4 under the conditions of CO_2 % =15%, pH = 8, Light intensity of 3500 Lux and CO_2 flow rate of 0.0167 l/min and is found to be 60 mg/L/Day. But due to some unknown reasons in the final trial maximum growth was obtained in pH = 7, with CO_2 flow rate of 0.025l/min, CO_2 % =15 and light intensity of 3500 lux. . Since this value is very much less due to various reasons like very less Gas Transfer, little mixing ,etc , it needs further thorough study considering more time interval for growth.

5 CONCLUSION

From our study we can understand that

- Maintaining a constant pH within the range of 8 to 9 is best suitable for the algal growth.
- As the light intensity increases the growth rate also increases upto the maximum light intensity of our study 5000 lux. Since we have not tested with higher light intensities, the photo inhibition range of light is not found out.
- Maximum CO_2 capture is obtained when the CO_2 % is about 15% and 10% also comparatively gave good results .Therefore we can say that CO_2 % within the range 10- 15% is optimum. Since the flue gas from the industries contains CO_2 % of range 10 to 15%, this microalgal carbon capture technology will be well

applicable. But the growth of algae in the presence of SOx, NOx has to be further studied.

- As the CO_2 flow rate is reduced the capture efficiency increased almost five times. This is due to the fact that the retention time of CO_2 gas gets increased as the flow rate is decreased. Therefore increasing the retention time of CO_2 plays a very major role in the algal carbon sequestration technology. Further improved techniques or design is suggested for increasing the retention time of CO_2.
- In all the trials it is seen that thorough mixing of the algal cells in the media enhances the growth rate. This important influencing parameter overcomes rest all parameters as it is seen in trial 6. Therefore thorough mixing of the algal suspension is the key parameter in microalgal carbon sequestration.
- Another important parameter yet to be analyzed is the presence of predators like bacteria, fungi, etc. It is clearly seen in trial 3 that the growth rate is greatly affected due to the presence of contamination. Therefore, for field applications, the photobioreactor free from any contamination is suggested.

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