Micro-Algae Carbon Sequestration

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Abstract - *Extensive burning of fossil fuels since the Industrial Revolution has increased the concentration of CO2 in the atmosphere. This CO2 in the atmosphere is enhancing the Earth's natural Green House Effect and is resulting in Global Warming. Presently, it is not possible to completely abandon fossil fuels as 85% [1] of the energy demands are met by them. Development of Renewable Energy has been under progress over the years and is not likely to completely replace fossil fuels any soon. Consequently, we need to develop methods which can reduce CO2 emissions from existing point sources of pollution viz. fossil fuel-based power plants, until renewables take the lead. Carbon Capture and Storage (CCS) is one such method which can help reduce carbon emissions by 90% or more. In CCS, CO2 from power plants is captured and transported to a storage site, wherefrom it doesn't interact with the atmosphere. The major concern with CCS, is the high energy penalty and investment cost. Researches have been performed over the years aiming to reduce the associated energy penalty. A rather new technique of carbon capture involves the use of Microalgae. Microalgae are photosynthetic microorganisms which convert CO2 to carbohydrates in the presence of water, light and nutrients. This photosynthetic nature of microalgae enables us to capture CO2 from the flue gas of power plants. This paper attempts to give an overview of CCS and highlights the use of Microalgae as a promising alternative to conventional carbon capture technologies.*

Key Words: Global Warming, Carbon Capture and Storage, Post – Combustion Carbon Capture, Microalgae.

1. INTRODUCTION

Before Industrial Revolution people used to manufacture the products manually, which took a great deal of time and efforts. Generally, a particular family was involved in the manufacturing of a particular niche. The transportation both for humans and of goods was a challenge and communication was limited. Industrial revolution brought about some radical changes in the world. Mass production of products started taking place, in factories, where people used to work in synergy under the same roof. Industries were set up and machines were developed which did a large portion of work rapidly and accurately. Transportation and communication got improved by the advent of engines and telegraph. Engines, machines and automobiles greatly utilized fossil fuels such as coal and diesel for running. No doubt, Industrial Revolution was a 'revolution' in the mankind which improved the standard of living and resulted in the development of nations. However, many years into Industrial Revolution, we started seeing some of its detrimental effects – climate change, global warming, melting of glaciers, contaminated air, which for sure pose a threat to mankind.

From 1993 to 2019 the sea level rose by 9.5cm [2] and the global temperature rise was approximately 1°C [3]. The concentration of CO_2 in the air rose to 407ppm as recorded in 2018, from 200ppm in Ice Age [4], which is a direct consequence of industrialization. According to a study, the concentration of CO_2 would double and average temperature would rise by 1.5-3.0 degrees by the year 2030 if CO_2 continues to increase at the present pace. [5]

1.1 Global Warming and Greenhouse effect

A greenhouse, usually found in nurseries, is used to grow plants and vegetables during off season (Fig.2). A greenhouse is a glass enclosure inside which plants are kept and grown under controlled conditions. The Sun's thermal radiation falls on the glass, a little part is reflected and the remaining goes inside the greenhouse. A part of the thermal radiation which goes inside, is absorbed by the plants and the remaining reflects back. This reflected radiation in the absence of greenhouse would have escaped but in the presence of it, majority of the reflected radiation is re-reflected back inside and only a fraction escapes from the greenhouse. This results in an increase in the temperature inside the greenhouse which favors the growth of plants. (Fig.1)

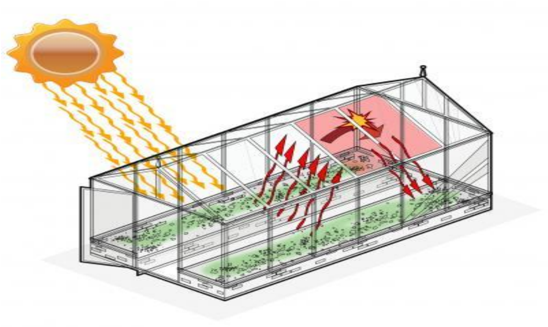

Fig.1- Green House Effect in a Green House [I1]

Fig.2 – A Green House in a Nursery [I2]

This effect is called the greenhouse effect and the Earth also behaves in a similar manner to maintain an optimum temperature for its lifeforms. The Earth has an atmosphere which is equipped with gases-**CO_2, H_2O, CH_4, N_2O** known as the greenhouse gases (GHG). The thermal radiation from the Sun penetrates the atmosphere and falls on the earth. A part of this radiation is absorbed by the earth and the remaining reflects back. However, the GHG in the atmosphere allow only a fraction of this reflected radiation to go out in space and re-reflect most part back towards earth. Thus, we can say that GHG let the thermal radiation from the Sun to enter the atmosphere but do not allow a majority portion of it to go back towards space. This re-reflected radiation is called the back radiation. This is the natural greenhouse effect and is vital for the earth to maintain an optimum temperature to support its lifeforms. The problem arises when the quantity of GHG in the atmosphere increase, which has been the case since Industrial Revolution. The increase in the CO_2 levels in the atmosphere because of the burning of fossil fuels, since Industrial revolution has enhanced the greenhouse effect wherein more than the required amount of thermal radiation is re-reflected which results in a global rise in temperature, which is called **Global Warming** (Fig.3). Global Warming is responsible for a rise in the sea level due to the melting of glaciers which causes frequent flooding in coastal areas. Climate change is also one of the effects of Global Warming. According to the Canadian Center for Occupational Health and Safety, Carbon Dioxide in small quantities in a room or in the environment is not necessarily harmful. However, a large amount can cause suffocation after displacing oxygen in the air [5]. We see that the primary factor resulting in enhanced greenhouse effect and thereby Global Warming, is the rise in CO_2 levels in the atmosphere. Since the industrial revolution, the burning of fossil fuels, deforestation and overpopulation has risen the amount of CO2 in the atmosphere by many folds, which has increased the global average temperature. If we could do something to reduce this emission of CO_2 into the atmosphere, we could stop the further Global Warming, if not revert it.

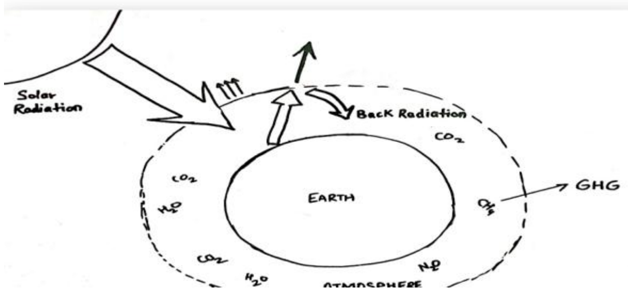

Fig.3 – Earth's GHE (Green House Effect)

1.2 Reducing CO2 emissions

The major CO_2 emitters include automobiles, industries and power plants which utilize fossil fuels. The burning of these fossil fuels results in the formation of CO_2 which is given into the atmosphere and is our concern. One could think of directly cutting off the CO_2 emitters as a solution to Global Warming, but that can't be the case owing to the rapid increase in the demand of energy. A good solution to curbing CO_2 emissions could be to develop alternate energy sources which do not emit CO_2. Mankind is already working towards and has developed such energy sources which are not harmful to the earth. However, the research and development would need time for the technology to replace fossil fuels. Another solution for reducing the CO_2 emissions could be that we keep on developing alternate energy sources but till the time they are capable of replacing fossil fuels, we develop technologies that reduce CO_2 emissions from existing emitters, which is the topic of interest for this text.

2. EXISTING CARBON CAPTURE TECHNOLOGY

Carbon Capture and Storage (CCS)

Carbon Capture and Storage (CCS) is a technology that prevents the CO_2 from large point sources of pollution like fossil fuel-based power plants, to go into the atmosphere. It involves the capture of CO_2 from the flue gases of power plants and then transporting and storing it to a particular site where it does not harm the environment. The aim is to prevent the discharge of large quantities of CO2 into the atmosphere from fossil fuel-based power plants. CCS is outlined in the 2008 Climate change strategy as one of the most promising technologies to meet our emission reduction goals. It is tested and proven and is recognized internationally. CCS applied to a fossil fuel-based power plant can reduce the carbon dioxide emissions of the plant by 80-90%. CCS involves three steps:

- **Capture:** The CO_2 in the flue gas of fossil fuel-based power plant is filtered and separated from other gases, i.e. captured.
- **Transportation:** Once separated, the CO2 is compressed and transported via pipelines, trucks, ships or other methods to a suitable storage
- **Storage:** The transported CO2 can then be stored either underground in geological reservoirs or underwater where it is not harmful to the environment.

Post – Combustion Carbon Capture unit

There are three methods to capture CO2 in CCS, namely Pre - Combustion, Post - Combustion and Oxy-Fuel Carbon Capture (CC). The most widely used among them is the Post – Combustion CC wherein the carbon dioxide is captured after the combustion of fuel takes place. The reason for the widespread use of Post – combustion CC is that, it can be retrofitted with the existing fossil fuel-based power plants and in even industries and has a lower initial investment cost. Pre – Combustion capture can't be retrofitted with the existing power plants, which limits its use to newer power plants. Although, both Post – Combustion and Oxy – Fuel pose the same energy penalty on the plant, the investment cost for post combustion CC is lesser as compared to Oxy - Fuel CC [6]. A schematic diagram of a usual post-combustion carbon capture plant is shown in Fig.4

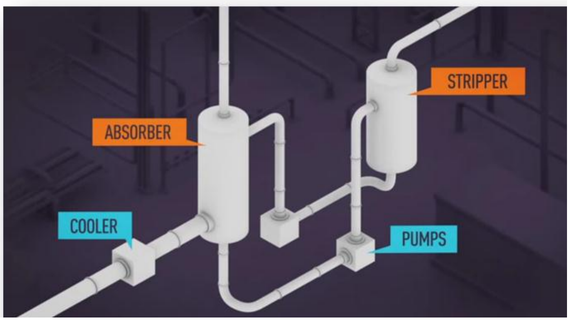

Fig.4- Post Combustion Carbon Capture Unit [I3]

The unit consists of a cooler which is used to cool down the flue gas, an absorber column which consists of an absorbent which absorbs CO2, a stripper which separates the mixture of CO2 and absorbent and some pumps. The fossil fuel is burnt inside the boiler of the power plant or industry where the heat produced is utilized and the flue gas is fed into the carbon capture unit. The temperature of the flue gas is very high and thus has to be reduced which is obtained with the help of a cooler. The cooled flue gas is then fed into the absorber column where a suitable absorbing liquid is used to absorb CO2 from the flue gas (Fig.5) and the remaining gases are directed towards the chimney as shown in Fig.7

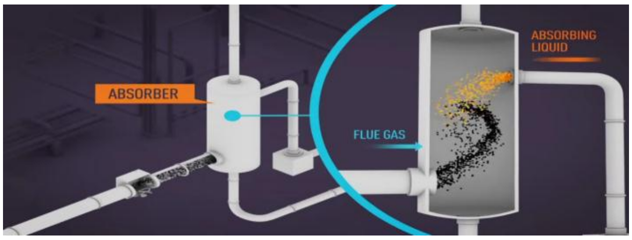

Fig.5 – Absorber Column in Post – Combustion CC [I4]

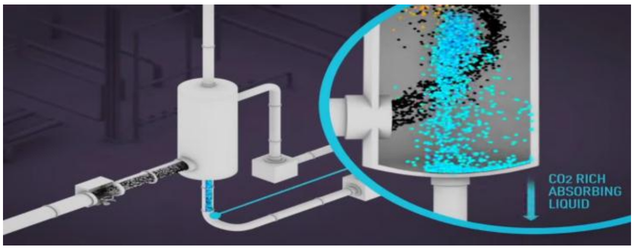

Fig.6 – CO2 rich absorbing liquid [I5]

The CO2 rich absorbent (Fig.6) then goes inside the stripper through pumps where it is heated (Fig.8). This heating separates the mixture into CO2 and absorbent again. The pure CO2 is then taken to a site of compression and the absorbent is again fed into the absorber column. This pure CO2 is compressed and transported to a site where it can be stored so that it doesn't escape into the atmosphere. The most commonly used absorbent liquid is the MEA (monoethanolamine)

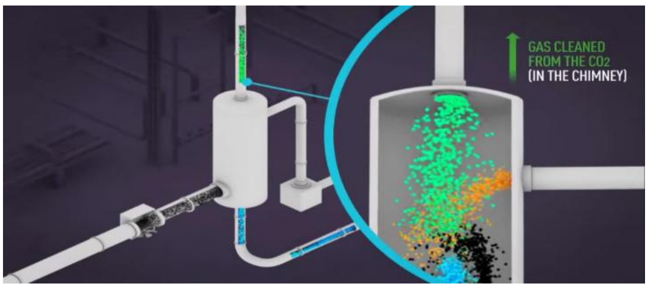

Fig.7 – Remaining Flue gases escape from the chimney [I6]

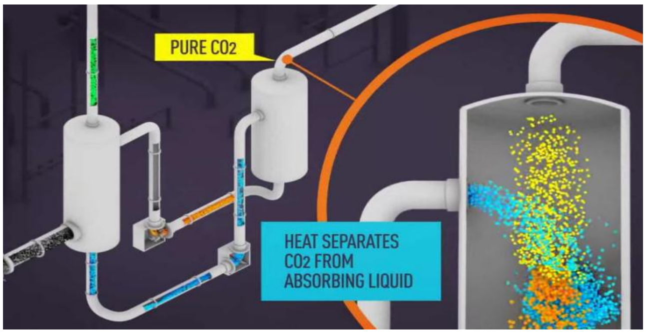

Fig.8 – Stripper regenerating absorbent [I7]

Advantages and Disadvantages of Post – Combustion Carbon Capture

As highlighted earlier the Post combustion carbon capture technology can easily be retrofitted with the existing power plants and even industries, which is its major advantage. Around 80-90% of CO2 can be captured but at the cost of large energy penalty.

The major shortcoming of every Conventional CCS technology including post – combustion carbon capture is the high energy penalty. For running the CC unit and thereby compressing the CO2, energy will be required by pumps, cooler and stripper, which will be taken from the plant's produced electricity. This will reduce the net power output of the plant and thus decrease its efficiency. Also, the use of absorbents like MEA (monoethanolamine) causes corrosion of equipment which increases the maintenance cost further.

3. MICROALGAE CARBON SEQUESTRATION

A rather new method of carbon capture which utilizes microalgae, has been into study in recent times, all over the world. Microalgae are photosynthetic microorganisms which make their food in the presence of light and chlorophyll. They utilize CO2, Water, Nutrients and Light to make carbohydrates, using which they grow (Fig.9). Microalgae are unicellular in nature and require the aid of a microscope to be seen. They are divided into five main groups, namely Chlorophyceae, Rhodophyceae, Phaeophycea, Cynophyceae and Bacillariophyceae, each group having different characteristics. Algae have high photosynthetic efficiency, high growth rates, CO_2 fixation ability as well as can be used as a biofuel to replace fossil fuels. In addition, some algae for instance, *Spirulina* also serve as dietary supplements. Owing to the advantages which it offers, the use of microalgae for capturing carbon in the form of CO2 from large point sources of pollution has gathered attention worldwide. Microalgae, in comparison to terrestrial plants have 10-50 times more capability to fix CO2 [7]. Approximately 1.83 kg of CO2 can be fixed for every 1 kg of dry microalgal biomass production [8]. All these studies highlight the fact that microalgae serves as a strong agent to sequester carbon.

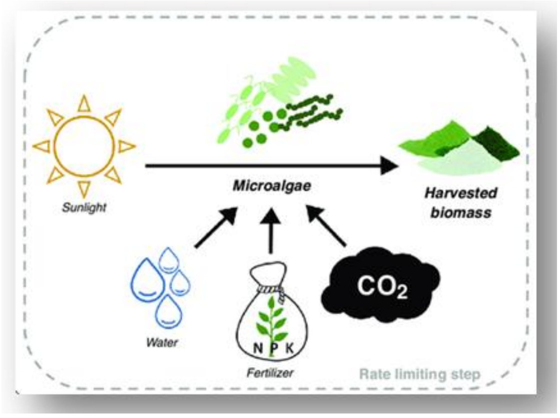

Fig.9 - Microalgae utilizes CO2, water, nutrients and light to grow [I8]

The entire carbon capture process using microalgae, is based on its photosynthesis. Flue gas from a fossil fuel-based power plant can be supplied into a media containing nutrients and microalgae. Microalgae will then utilize CO2 present in the flue gas, in the presence of light and culture media to make carbohydrates using photosynthesis. It then uses these carbohydrates to grow and duplicate. The CO2 which would have gone into the atmosphere otherwise, is now utilized by the algae to produce biomass. A greater microalgal biomass production signifies a greater CO2 capture. The obtained biomass can then be harvested to be used as a biofuel or dietary supplement. It should be noted that, the flue gas contains several components apart from CO2, viz. NOx, SOx, mercury and other toxic pollutants. These pollutants need to be filtered out before supplying the flue gas into the microalgal culture medium, for algae's efficient growth. Presence of any toxic substance in the flue gas may greatly inhibit the growth. The temperature of the flue gas, ranges typically from 120-140°C, which is sufficient for microalgae's death. Thus, flue gas also needs to be cooled down before it is supplied into the culture.

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Fig.10 – Open Photobioreactor (Open Pond) [I9]

Microalgae culture can be performed in an open pond or a closed photobioreactor (PBR). In open pond systems algae are grown in large open and shallow containers (Fig.10). The flue gas can be supplied into the culture, using the CO2 from which microalgae grows. Open Pond Systems provide a larger surface area to the light to fall and hence result in greater CO2 fixation. However, large land area requirement, contamination from external agents and water loss due to evaporation are some of the major drawbacks of open pond systems. Closed PBR (Fig.11) are more attractive for use than open pond systems because they offer more control over cultivation parameters. Closed PBR are not subjected to evaporation losses as well as contamination from external agents. It was also made evident in _ that PBR resulted in a greater biomass production rate than open ponds.

Fig.11- Closed Photobioreactor for growing Microalgae [I10]

4. FACTORS AFFECTING BIOMASS PRODUCTION

The amount of biomass produced is a direct measure of the amount of CO2 captured. A greater biomass production would imply a greater CO2 fixation. The growth of microalgae depends on a number of factors ranging from the type of microalgae strain used to temperature, pH, Light intensity etc. Following paragraphs summarize the effects of such factors on biomass production.

4.1 Effect of Microalgal Strain on Biomass Production:

The right selection of microalgal specie for a particular set of culture conditions, determines the extent to which CO2 sequestration would be successful. An ideal microalgal specie should be the one which has high tolerance towards - high CO2 concentrations, toxic pollutants, temperature, pH and should require limited nutrients to grow. Microalgal species Scenedesmus obliquus, Botryococcus braunii, Chlorella vulgaris and Nannochloropsis oculata are the most promising species for carbon sequestration [9]. The biomass production using a particular microalgal specie, will depend on the growth conditions like temperature, pH and CO2 concentrations as well as on the type of PBR used. With varying conditions the growth rate would change and hence carbon capture efficiency.

4.2 Effect of CO2 concentration on biomass production:

The CO2 concentration in the flue gas of a power plant ranges from 10% to 20%. In order to capture the CO2 from the flue gas, the microalgae specie used in the capture process should be able to tolerate these levels of concentration. For a particular microalgal specie growing at some growth conditions, the growth rate will be different for different CO2 concentrations and at a particular concentration would be maximum. For instance, a study reported that Scenedesmus dimorphus exhibited biomass production of 4.51 and 3.82 g/L/day respectively under 10% (v/v) and 20% (v/v) of CO2 respectively, but achieved maximum biomass of 5.17 g /L/ day with 2% (v/v) CO2 [10]. This suggests that initially an increase in CO2 concentration has a positive impact on growth but then with further increase the growth starts reducing. The decrease in the growth rate at high CO2 concentrations is mainly due to the increase in pH which comes along.

4.3 Effect of pH on biomass production:

Each Microalgal specie grows well in an optimum pH range. Synechococcus sp. and Spirulina Platensis grow at optimal pH 6.8 and pH 9, respectively, meanwhile Chlorella sp. can tolerate pH below 4 [11],[12]. Flue gas from power plants usually contains high concentrations of NOx and SO2, which reduce the pH of culture medium. NOx doesn't significantly inhibit the microalgae biomass production as it also acts as a source of nitrogen, required as a nutrient by the algae. However, flue gas with SO2 concentration above 60 ppm is inappropriate to be used for microalgae cultivation [13]. With the presence of 100-250 ppm of SO2 in flue gas, the pH may reduce to 2.5-3.5, due to the formation of bisulfite (HSO3-), sulfite (SO32-) and sulfate (SO42-) in the medium [13][12].The pH of the culture media also reduces due with increasing CO2 concentration. Some microalgae species are unable to withstand the acidic condition resulted from carbonic acid formed by CO2 dissolution in medium. Sodium hydroxide and calcium carbonate are usually added to adjust pH, reaching its optimal range.

Effect of temperature on biomass production:
In general, the optimum temperature range for growing microalgae lies between 15-26°C. Low temperature of culture medium is unfavorable for the enzyme activity of ribulose bisphosphate carboxylase oxygenase, leading to reduction in photosynthesis rate. Moreover, high temperature inhibits microalgal metabolic rate and reduces the CO2 solubility [13][12]. Low CO2 solubility causes photorespiration whereby the RuBisCo enzyme will bind with O2 rather than CO2, in consequence reducing carbon bioconversion rate by 20-30% [14]. The temperature tolerance range of different microalgal species is shown in Table.1.

Effect of Light Intensity on biomass production:
Algae with 'light-harvesting component (phycobilisomes)' grow optimally at low light intensities (10 mmol m2 s-1), whereas most 'dinoflagellates' prefer high light intensities (60-100 mmol m2 s-1) [15]. Chlorella and Scenedesmus sp. grow optimally under light intensity of 200 mmol m2 s-1. Higher light intensities favor microalgal growth because of higher photosynthetic rate. In addition, with higher intensity, the light is able to penetrate through the high density microalgae culture, which favors its growth. However, the light intensity should not be too high to cause photoinhibition. A high photosynthetic rate is usually achieved by low and medium light intensities incorporated with other appropriate growth conditions.

Effects of Nutrients on biomass production
Carbon, nitrogen and phosphorus are the three essential nutrients for microalgal growth. Carbon is provided by CO2 from flue gas or atmosphere. Apart from carbon, microalgae use nitrogen and phosphorous for their metabolic activities. Ammonia acts as the major source of nitrogen. Phosphorus is available in the form phosphate and normally supplied in excess as it is not readily bioavailable. Other inorganic salts and trace elements like metals and vitamins are usually added into the medium for effective photosynthetic activity.

The following table lists some microalgal strains and their optimal temperature, pH, and CO2 concentration ranges.

Microalgae Strain	Temperature Range(degree Celsius)	pH Range	CO2 Concentration (%)
Chlorococcum sp.	15-27	4 to 9	70
Chlorella sp.	15-45	3 to 7	60
Euglena gracilis	23-27	3.5	100
Goldieria sp.	Up to 50	1 to 4	100
Viridiella sp.	15-45	2-6	5

Table.1

5. CONCLUSIONS

Reducing CO2 emissions from fossil fuel-based power plants has become a major challenge for the mankind. Although, Post – Combustion carbon capture can be retrofitted to existing power plants, it still poses a large energy penalty. Micro – Algae carbon sequestration can prove to be a good alternative to capture carbon as compared to conventional carbon capture technologies. The amount of CO2 sequestered using Microalgae carbon sequestration depends directly on the growth of algae. Various factors including temperature, pH, CO2 concentration, nutrients etc. influence the growth of microalgae. Thus, for capturing carbon using microalgae we need to maximize growth by closely controlling the factors on which the growth of microalgae depends. A perfect combination of temperature, pH, CO2 concentration etc. for a particular microalgal strain would result in maximized growth and hence maximized CO2 capture. *Chlorella* seems to be a good option available to capture CO2 using microalgae since it has a high tolerance to pH, Temperature and CO2 concentration. The produced biomass can be used as a feedstock or a biofuel which is an added advantage. Although, microalgae offer the ability to exploit them for CO2 capture, maintaining ideal conditions for microalgal growth is quite difficult at the present stage of research. Advancements in Micro-Algae Carbon Sequestration research are required which aim at providing ideal growth conditions to the selected microalgal strain so that maximum CO2 is captured. Also, improved PBR designs and use of high efficiency pumps can help Micro-Algae Carbon Sequestration technology to take lead against the existing carbon capture technologies.

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BIOGRAPHIES

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