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Carbon sequestration using microalgae-a Review

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Abstract: Sustainability is a key principle in natural resource management and it involves effective utilization of natural resources. Across the world, industrialization and the consequent emergence of economies reliant on fossil fuels have inevitably resulted in the adverse condition of atmospheric warming known as the greenhouse effect. Anthropogenic carbon dioxide (CO_2) has been identified as one of the major causes. Out of several CO_2 sequestration methods, biological methods of sequestration using algae are energy efficient due to less energy requirement. Algae are autotrophic micro-organisms capable of converting CO_2 into carbohydrates and lipids in the presence of light by photosynthesis. Micro algae are cultivated for the treatment of domestic and industrial waste water and also for CO_2 sequestration. Many studies were carried out in the areas of CO_2 sequestration using algae. From those studies it was concluded that the algae can be effectively used for the treatment of wastewater and CO_2 sequestration. Hence, algal photosynthetic reaction may hold the key to reduce CO_2 emission in sustainable manner. Algae can be extensively used to capture CO_2 from power plants, steel, cement, oil, automobiles and many other industries and the resulting algal biomass not only be used for biofuel production but also for various industrial products like fertilizers and pharmaceuticals. Besides giving environmental and economic benefit, large scale algae cultivation can create a large number of jobs at different levels in the society.

Key words: CO_2 sequestration, Micro algae, Sustainability and biomass.

Introduction

Pollution has been found to be present widely in the environment. It causes acid rain, eutrophication, Haze, Biomagnifications and Global climate change etc,. The Earth's atmosphere contains a delicate balance of naturally occurring gases that trap some of the sun's heat near the Earth's surface. This "greenhouse effect" keeps the Earth's temperature stable. Unfortunately, evidence is mounting that humans have disturbed this natural balance by producing large amounts of some of these greenhouse gases, including carbon dioxide and methane. As a result, the Earth's atmosphere appears to be trapping more of the sun's heat, causing the Earth's average temperature to rises- a phenomenon known as global warming. Global climatic change is considered to be the sensitive and global warming could have significant impacts on human health, agriculture, water resources, forests, wildlife, and coastal areas. Atmospheric CO2 level keep increases until energy recovery done by fossil fuels[1-2]. Therefore, the use of fossil fuel is now widely accepted as unsustainable due to depleting resources and the accumulation of Greenhouse gases in the environment. Due to industrial revolution, the developed countries have emitted most of the anthropogenic greenhouse gases into the atmosphere. On the other hand the developing countries are the most vulnerable to climate change impacts because they have fewer resources to adapt socially, technologically and financially [3].

Greenhouse Gases and their Contributions

The effect of greenhouse gas not only depends on the quantity but also on their chemical nature. For example, the influence of methane and CFC are very high though they are present in lower quantities. Though water vapor dominates the greenhouse effect among the contributing gases, CO_2 plays a major role as it influences the increase of water vapor concentrations. The concentration of nitrous oxide began to rise at the beginning of the industrial revolution. Greenhouse gases such as CFC's are mostly synthesized by the use of refrigerants, aerosol propellants and cleaning solvents.

Table 1: Greenhouse gases and their contribution

Greenhouse Gases	Greenhouse Effect %	Natural%	Man-Made %
Water vapour	95.000	94.999	0.001
Carbon Dioxide	3.618	3.502	0.117
Methane	0.360	0.294	0.066
Nitrous Oxide	0.950	0.903	0.047
Misc.Gases	0.072	0.025	0.047
Total	100	99.72	0.28

(Table- 1) shows the various greenhouse gases and their contribution. From the above table, it is observed that, among all the greenhouse gases, contribution of carbon dioxide to the environment is considered to be the maximum [4].

Ways to Reduce CO_2

Most of the World's energy supply comes from fossil fuel as a result there is rise in the atmospheric CO_2 leading to Global Warming. Thus, it is very important to develop new methods ofCO_2 sequestration. At the same time, to develop an alternative clean energy sources which do not depend on fossil fuel and which have a tolerable environmental impact. Oceans play a vital role in absorbing the carbon dioxide present in the atmosphere. As absorption of carbon dioxide by ocean is a slow process and can take hundreds of years, this process cannot keep pace with the huge amount of the gas emitted every day. Plants use carbon dioxide during photosynthesis. From the recent researches the scientists had come across the technique of carbon dioxide sequestration and biofuel production from micro and macro algae. This method becomes one of the alternatives to combat climate change as higher plants have various limitations to be used as a model system for carbon sequestration and biofuel production. Numerous work have been done on carbon sequestration and biofuel production by algae but still it needs much research in order to meet the increasing demand for energy. We hope that in future it will replace the fossil fuel to larger extent and reduce the atmospheric CO_2 to combat Global warming[5]. The most important of these innovations is to increase CO_2 sinks through photosynthesis including increased carbon storage in standing tree biomass, substitution of fossil fuels with biofuels, increase in soil carbon sequestration and increase in soil primary productivity[6]. Microalgae can be extensively used to capture CO_2 from power plants, steel, cement, oil, automobiles and many other industries and the resulting algal biomass can not only be used for biofuel production but also for various industrial products.

CO_2 Sequestration using Microalgae

Algae are recognized as one of the oldest life-forms[7]. They are primitive plants which lack roots, stems and leaves, have no sterile covering of cells around the reproductive cells and have chlorophyll a as their primary photosynthetic pigment[8.] Depending on the species, algae can range from 1 micron (µm) to a few hundred microns in size. As a point of reference, 1 micron (µm)=1/1000 of a millimeter (mm). Microalgae are one of the most important groups of organisms on the planet. It is estimated that microalgae produce approximately half of the atmospheric oxygen on earth, while consuming vast amounts of the greenhouse gas carbon dioxide. Microalgae have a rapid growth potential and many species have oil content in the range of 20–50% dry weight of biomass[9-11]. With respect to air quality maintenance and improvement, microalgae biomass production can effect bio fixation of waste CO_2 (1 kg of dry algal biomass utilize about 1.83 kg of CO_2) [9]. Nutrients for microalgae cultivation can be obtained from wastewater as a growth medium, there by treating the organic effluent from the agro-food industry [12]. Algal cultivation does not require herbicides or pesticides application[13].They can also produce valuable co-products such as proteins and also biomass residue after oil extraction which may be used as fermented to produce ethanol or methane[14] or fertilizer[12]. The potential application of microalgae is biofuel production, CO_2 fixation, bio hydrogen production and bio treatment of wastewater.

Technologies for Microalgal Biomass Production

Microalgae culture has been developed recently by one of the biotechnologiest[15]. Mass culturing of microalgae on a commercial scale has been performed successfully on species such as *Chlorella, Spirulina, Scenedesmus, Dunaliella salina, Haematococcuspluviali and Porphyridium cruentum*[16-17]. Although these microorganisms are abundant in nature they have not made the subject of scientific investigation. Another reason is that they have genetic ability to produce a wide range of compounds and chemicals that could be of great commercial value [18]. There are probably well over 30,000 species of microalgae, only a few hundred of which are cultured in laboratories at present. In general microalgae can be produced in open ponds or closed systems (such as photobioreactors) and the culturing methods used can be continuous, semi- continuous or batch [19].

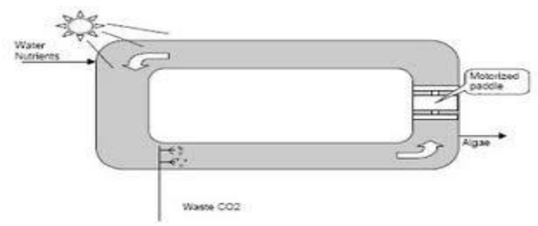
Photoautotrophic production

Currently, photoautotrophic production is the only method which is technically and economically feasible for large-scale production of algae biomass for non-energy production [20]. Two systems that have been deployed are based on open pond and closed photo-bioreactor technologies [21]. The technical viability of each system is influenced by intrinsic properties of the selected algae strain used, as well as climatic conditions and the costs of land and water [22].

Open pond system

Open ponds were extensively used in the past for the cultivation of algae (Figure- 1). Open ponds can be grouped into natural waters bodies such as lakes, lagoons, ponds and artificial ponds. The most commonly used system includes shallow big ponds, tanks, circular ponds and raceway ponds. Among the types of open ponds, raceway ponds are very common and they have been used for the mass culture of algae since 1950s. The advantage of open ponds is that they are easier to construct and operate, easy to clean after cultivation. However, major limitation in open ponds include poor light utilization by the cells, high evaporation rate, diffusion of carbon dioxide to the atmosphere, requirement of large land areas and prone to contamination which result in low biomass productivity [23-25].

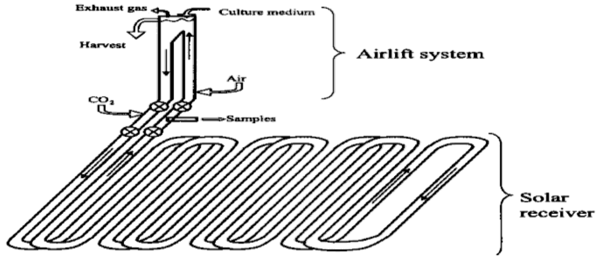
Figure 1: Open pond system



Closed pond systems

In order to overcome the limitations of open culture systems, attention is now given on the development of closed culture system (Figure- 2). Till now various types of closed system has been developed such as flat – plate photo-bioreactor, tubular, vertical column etc. In closed system biomass productivities are high and contamination rate are very less compared to open system. Most photo-bioreactors are characterized by largely exposed illumination surfaces. Closed photo-bioreactors are good for the immobilization of algae and biomass productivities are very high compared to the open system of cultivation [23-25].

Figure 2: Closed pond system



Microalgae tolerence of CO_2

Direct utilization of power plant flue gas has been considered for CO_2 sequestration systems [26].The advantage of direct utilization of flue is the reduction of the cost of separating CO_2 gas. Since power plant flue gas contains higher concentration of CO_2, identifying high CO_2 tolerant species is important. Although CO_2 concentrations vary depending on the flue gas source, 15 - 20% v/v is typically assumed. Several species have been tested under CO_2 concentrations of over 15%. For example, *Chlorococcum littorale* could grow under 60% CO_2using the stepwise adaptation technique [27]. The following (Table- 2) shows the CO_2 tolerance of various species.

Table 2: CO_2 tolerance of various species

Species	Known Maximum CO_2 uptake Concentration	References
Cyanidium caldarium	100%	28
Scenedesmus sp.	80%	29
Chlorococcum littorale	60%	27
Synechococcuselongatus	60%	30
Euglena gracilis	45%	31
Chlorella sp.	40%	29
Eudorina spp.	20%	29
Dunaliellatertiolecta	15%	32
Nannochloris sp.	15%	33
Chlamydomonas sp.	15%	34
Tetraselmis sp.	14%	35

Microalgae can assimilate CO_2 within various ranges of concentration from ambient (0.04%) to 100% v/v CO_2 by selecting adequate species.

Microalgae tolerance to Gases other than CO_2

Carbon dioxide, together with other flue gases such as nitric oxides (NO_x) and sulphur oxides (SO_x), which are said to be toxic to biological systems, is released from industries that burn fossil fuels [36-37]. The SO_x are oxidized to sulphates that accumulate, causing a decrease in pH and growth inhibition in microalgal culturing conditions [38]. Although some researchers have suggested that these toxic gases should be removed because they hinder the CO_2 mitigation for which the microalgae are being grown. Removal of these substances is costly, and would make the technology of the microalgae systems unaffordable. Algal tolerance to NO_x and SOx varies from species to species. Acidophilic microalgae strains are not inhibited by SO_x and NO_x[33]. Lee and co-researchers tested the tolerance of 250ppm of SO_x and 300ppm of NO_x using very high inoculums concentrations of microalgae; and adjusting both the gas flow rate and the pH during the first 8 hours of inoculation [39-40]. Regardless of the flow rate, *Monoraphium minutum* was found to be able to tolerate up to 200ppm SO_x and 150ppm of NO_x[41]. (Table- 3) shows the temperature and flue gas tolerance of various algal species.

Table 3: Temperature and flue gas tolerance of various algal species [42]

Algal species	Maximum temperature tolerance (°C)	Maximum CO_2% (v/v) tolerance	Maximum SO_x (ppm) tolerance	Maximum NO_x (ppm) tolerance
Cyanidium caldarium	60	100	-	-
Scenedesmus	30	80	-	-
Chlorococcum littorale	-	70	-	-
Synechococcus elongates	60	60	-	-
Euglena gracilis	-	45	-	-
Chlorella	45	40	-	-
Chlorella	-	15	-	100
Eudorina	30	20	-	-
Dunaliellatertiolecta	-	15	-	1000

Chlamydomonas	35	15	-	-
Nannochloris	25	15	-	100
Tetraselmis	-	14	185	125

From the table it is observed that at a temperature of 60°C, 100% CO_2 tolerance is observed for *Cyanidium caldarium*. From the results certain thermophilic micro-organisms are known to survive till temperatures of 60°C. It is suggested that the temperature dependent solubility of CO_2 gives an advantage to thermophilic algae to tolerate a higher concentration of CO_2 [42]. Most of the algae species have no tolerance on SO_x concentration expect *Tetraselmis species* which has the tolerance limit of 185 ppm. Species such as *Chlorella, Dunaliellatertiolecta, Nannochloris and Tetraselmis* has tolerance against NO_x.

Conclusion

Carbon dioxide sequestration can effectively carried out using algae to produce algal biomass and this can be converted in to biofuel. Algae shows reasonable tolerance to the temperature and co_2, hence sequestration is done with maximum efficiency. This can be used to reduce the green house gases and thereby global warming will be avoided. Using algal growth in photo-bioreactors requires some capital costs, but relatively low operating costs as compared to other CO_2 capture methods. Thus for effective carbon dioxide sequestration, microalgae can be used and this biomass can be converted into useful bio products.

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