A Sustainable Approach for Carbon Dioxide Fixation

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***Abstract*—Carbon dioxide is a green house gas that exists in earth's atmosphere. In recent decade's due to increment of population and rapid industrialization, the amount of CO_2 has increased significantly and has caused global warming and other problems. Different methods are used for reduction of CO_2 concentration in air one method is storing CO_2 gas below the ground, but this manner doesn't provide a long time solution, so in depth researches was conducted in the past years to investigate different methods of CO_2 treatment. A noble method is using microalgae to reduce CO_2 either from the atmosphere or fuel gases from energy plants. CO_2 is captured by microalgae through photosynthesis and is permanently stored in form of biomass. Microalgae can also be used for treating wastewater that contains some amounts of CO_2 and other compounds. Combination of CO_2 treatment, biofuel production and wastewater treatment may provide a very promising alternative to current CO_2 treatment strategies. This paper attempts to review the present day technologies for CO_2 removal with a special emphasis on employing microalgae.**

***Index Terms*—carbon dioxide, microalgae, photosynthesis waste water treatment.**

I. INTRODUCTION

CO_2 is a gaseous matter that allows sun light to reach the earth and captures some of the heat to keep the earth warm. However, the large growth of population which causes increment in transportation vehicles, cement production that depends on coal and petroleum coke, and the burning of fossil fuel in power plants, releases large amounts of CO_2 to the air.

Increment of concentration of CO_2 in air will cause more heat to be stored in earth atmosphere, which increases the temperature of the planet. This causes global warming. Scientists tend to agree that the amount of CO_2 level that keeps the earth unaffected is 350 parts per million (ppm), now the concentration of CO_2 has reached 387 ppm. In order to discover the most efficient and economical means of carbon capture, research and several technologies have been developed such as fuel-gas separation, oxy-fuel combustion and pre-combustion capture [10]. CO_2 is produced as a byproduct in the following process:

- Acidified hydration of limestone and dolomite which occurs in nature.
- In hydrogen production plant where methane is converted to CO_2.
- It is formed from combustion of fossil fuel and wood.
- A byproduct of fermentation of sugar in the production of alcoholic beverages.
- In the manufacture of lime as a byproduct from the thermal decomposition.

Microalgae are unicellular species that exist either individually or in groups. They are typically found in freshwater or marine systems. Unlike plants, microalgae do not have roots, stems and leaves. Microalgae are very important for life on earth as it produces approximately half of the atmospheric oxygen. Using microalgae in treatment of CO_2 has many advantages: (1) Microalgae has a higher production rate compared to other plants, especially marine microalgae that grows faster in salty water compared to fresh water algae, (2) Marin microalgae can be grown in close containers and the plant can be located in any location that is not use for other plant growing, (3) Cost effectiveness, due to low energy input, lower operation cost and useful byproducts, (4) The energy produced can be used to operate the system, in form of heat and electrical energy, (5) The rate of CO_2 fixation efficiency by algae is reported to be 26 kg/h in a 100000 L reactor, assuming 12 h-day, and (6) Microalgae has the ability to fix CO_2 using solar power with efficiency 10 times larger than other plants [11].

Research investigation reveal that it is more economical to combine CO_2 treatment with wastewater treatment [2], due to the following advantages: (1) Microalgae have a high efficiency in removal of nitrogen and phosphorus, and (2) it will lead to save chemicals such as sodium nitrate and potassium phosphorus, and (3) it will result in saving of the precious fresh water resources [8].

II. NEED FOR MICROALGAE APPLICATION

Carbon dioxide is similar to any other oxide that can be reduced to its elemental carbon by high temperature oxidation of hydrogen gas released from decomposition of methane, but this process is very complicated and expensive, as it requires large amount of energy to overcome the negative free energy in the compound.

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Another popular chemical reaction for CO_2 treatment is achieved by cyclic carbonation/de-carbonation reactions in which CO_2 reacts with solid metal oxide to yield metal carbonate, the reaction is represented by the following equation:

$MO + CO_2 \rightarrow MCO_3$

The disadvantage of this process is that if metal carbonate is heated more than its calcinations temperature it will decompose back to CO_2 and MO.

Furthermore, gas absorption processes are used to separate carbon dioxide from a gas mixture, where different types of alkanolamine solutions can be used in different types of absorption units [9]. Although this process is used widely around the world, but it has some drawbacks, for example: it is very important to select the right lamine solution for the process and also to provide the required area for liquid-gas interaction [7].

Table 1
Comparisoion of various processes

Process	Reduction	De-carbonation	Gas absorption
Equipment cost	High	Medium	Medium
Energy consumption	High	Regular	Medium
Complexity of the process	High	High	High
Raw material	Available	Available	Available but must be selected carefully

Taking in consideration the advantages and disadvantages of the previous process, researches have been conducted to develop new methods for CO_2 fixation. Different studies and projects are held globally to investigate the possibility of treating CO_2 by microalgae, one of those studies is "Rew's algae project in Bergheim-Niederaussem. This project aimed to treat the fuel gas released from power plant using microalgae to convert CO_2 into algae biomass. As the Fuel gas from power plants are responsible for 7% of the world total CO_2 emission. The concentration of CO_2 in fuel gas reached up to 15%.

Two types of reactors where used to perform the process. A Bioreactor is an engineering device that is used to support a biologically active environment. It is a vessel in which a chemical process is carried out. These bioreactors are usually cylindrical and are often made of stainless steel and a Photobioreactor [1], which is a closed system that is used to grow phototropic organisms such as cyanobacteria, algae, or moss plants. These organisms use light through photosynthesis as their energy source and do not require sugars or lipids as energy source.

The process can be described as follow:

Fuel gas containing CO_2 is withdrawn from the plant and transported to the microalgae plant. If the flue gas contains large amount of water vapor it is first dried so the vapor will not condense in the pipes. The pipes are made of polyethylene (PE) to prevent corrosion due to presence of water vapor. The fuel gases are transferred from the plant to the green home through a 750m long pipe. The gases are first fed into a bubble reactor which contains microalgae suspension (saltwater with microalgae). This will absorb the CO_2 from the fuel gas until it gets saturated then the fuel gas is released by a chimney to the atmosphere.

The advantage of the bubble reactor is that only CO_2 will be fed into the green house. The CO_2 enriched algae suspension is fed into the green house that consist of photobioreactors that are made of clear transparent plastic hoses [3], that are fixed in V shape supports. The suspension is fed from above by a small hose and it is drained again by a hose from the bottom. The algae use CO_2 from the suspension for photosynthesis. Agitation by air is used to insure equal distribution of light everywhere in the photobioreactor [4].

The pH of the suspension indicates the amount of CO_2 present. The pH is measured continuously in the photobioreactors to determine the feed of the suspension required. The drained suspension is returned to the bioreactor and the density is measured if it contains large amount of algae than the algae is harvested and biomass products are produced. The system can produce 6000kg algae/year and captures 12000kg of CO_2.

The harvested microalgae can be used in hydrothermal carbonization, in which the biomass is heated under pressure, with water being added and oxygen removed to obtain different products. The biomass algae can also be converted into biodiesel and butanol.

The challenges associated with this method are that many researches must be done to develop required methods for the process. And the total energy balance should be positive and CO_2 must be reduced. Another challenge is selecting a suitable type of microalgae that can live and grow in the conditions provided. In addition the green house must be designed in a way that it provides the required air condition, hours of sunshine, light intensity and temperature [12]. It is also been absorbed that when the process is combined with waste water treatment it will be more economical.

III. Microalgae and Carbon dioxide

Microalgae are unicellular, plant like organisms that uses CO_2 in order to grow. CO_2 is captured by microalgae and photosynthesis is performed to convert CO_2 into organic compounds and biomass.

Various types of algae's require different condition for growth but the most important factors that will affect the growth of algae are temperature, light and concentration of CO_2, nitrate and phosphate.

A. Classification of microalgae

Microalgae are divided into three basic super groups based on their properties.

Primoplantae/ Archaeplastida

Members: Chlorophyta; Rhodophyta; Glaucophyta

Endosymbiont: Cyanobacteria.

These Algae have primary chloroplasts, i.e. the chloroplasts are surrounded by two membranes and probably developed

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through a single endosymbiotic event. The chloroplasts of red algae have chlorophyll a and c (often), and phycobilins, while those of green algae have chloroplasts with chlorophyll a and b. Higher plants are pigmented similarly to green algae and probably developed from them, and thus chlorophyta is a sister taxon to the plants; sometimes they are grouped as Viridiplantae.

Excavata and Rhizaria

Members: Chlorarachniophytes and Euglenids

Endosymbiont: Green Algae.

These groups have green chloroplasts containing chlorophylls a and b. Their chloroplasts are surrounded by four and three membranes, respectively, and were probably retained from ingested green algae.

Chlorarachniophytes, which belong to the phylum Cercozoa, contain a small nucleomorph, which is a relic of the algae's nucleus.

Euglenids, which belong to the phylum Euglenozoa, survive primarily in freshwater and have chloroplasts with only three membranes. It has been suggested that the endosymbiotic green algae were acquired through myzocytosis rather than phagocytosis.

Chromista and Alveolata

Members: Heterokonts; Haptophyta; Cryptomonads; Dinoflagellates

Endosymbiont: Red Algae.

These groups have chloroplasts containing chlorophylls a and c, and phycobilins. The shape varies from plant to plant. They may be of discoid, plate-like, reticulate, cup-shaped, and spiral or ribbon shaped. They have one or more pyrenoids to preserve protein and starch. The latter chlorophyll type is not known from any prokaryotes or primary chloroplasts, but genetic similarities with the red algae suggest a relationship there.

In the first three of these groups (Chromista), the chloroplast has four membranes, retaining a nucleomorph in Cryptomonads, and they likely share a common pigmented ancestor, although other evidence casts doubt on whether the Heterokonts, Haptophyta, and Cryptomonads are in fact more closely related to each other than to other groups.

The typical dinoflagellate chloroplast has three membranes, but there is considerable diversity in chloroplasts within the group, and it appears there were a number of endosymbiotic events. The Apicomplexa, a group of closely related parasites, also have plastids called apicoplasts. Apicoplasts are not photosynthetic but appear to have a common origin with Dinoflagellate chloroplasts.

IV. Results and discussion

Comparing the different methods that are used for CO_2 fixation it is noticed that many ways are available and each process has certain advantages and disadvantages. Some require high amount of energy others require specific amount that should be provided carefully to get the required results. Moreover some require basic equipments and procedures others require complex equipment and processes. And from the techniques that have been disused, it seems that the new method which applies microalgae and which is being developed recently has many advantages over the other processes.

A. The advantages of using microalgae

- Algae grow very fast.
- Growing algae does not require vast tracts of land to rise.
- Algae use photosynthesis to convert sunlight into energy.
- Low energy requirement (low energy input).
- Reduction of sludge (unfriendly chemicals) formation compared to other treatments of waste water
- Less greenhouse gas production, as in other treatments of waste water [6], large amount of CO_2 is produced, but when using algae it is expected to consume more CO_2 than is released in the process.
- While algae grows in water, bacteria also grow, which helps in better removal of nutrients and absorbing CO_2.
- Produces useful biomass which can be used to produce biodiesel or bioethanol.
- Oil yield from algae is higher than traditional oil seeds.
- Algae produce 30-100 times more oil per acre than corn and soybeans.
- The energy produced can be used to operate the system, in form of heat and electrical energy.
- The cost of maintenance is less.
- Cost effectiveness [6], due to low energy input, lower operation cost and useful byproducts.

B. Treatment Challenges

- Treatment and process used needs to be optimized.
- Harvesting systems needs to be cost effective.
- Byproducts need to be exploited.
- Sometimes if CO_2 is not captured permanently by the microalgae it will be decomposed back to the environment.
- Optimizing both algae growth (water depth, nutrient addition rate, mixing, etc) and water treatment (remove nitrate and phosphate at optimal rate, etc).
- One of the reasons why algae oil is not commercialized is the high cost of the process, land cost, expensive bioreactors and cost involved in harvesting.
- Growing algae in water is difficult because as the algae grow it becomes thick and blocks out the light. To overcome this problem, light can be insulated inside the bio-reactors or the algae must be rotated periodically out of the water.
- It is difficult to cultivate large amounts of a specific type of microalgae.

V. Conclusion

Global warming has become a serious problem and many solutions are being suggested to treat this problem. One way is to reduce CO_2 gas which plays a role is causing this problem. CO_2 can be treated by different methods, for example storing the gas under the ground, reducing the gas into elemental carbon, gas absorption and cyclic carbonation/de-carbonation. Although those methods have some advantages but they don't provide a long term solution, so a new method that applies microalgae in treatment has been investigated and studied. Studies have shown that combining CO_2 fixation with waste water treatment provides a very promising alternative, with low cost and high advantages. The algae biomass produced after photosynthesis can be used to produce electricity, ethanol, methanol, biodiesel and other products.

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