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Carbon dioxide sequestration and its enhanced utilization by photoautotroph microalgae

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ABSTRACT

The ceaseless use of non-renewable fuels leads to the emission of CO_2 and other GHG's. Annual Greenhouse Gas Index by National Oceanic and Atmospheric Administration (NOAA) Earth System Research laboratory (ESRL) shows an exponential increase in greenhouse gases led by CO_2. Controlling CO_2 levels is dire need considering the current trends. The present review highlights different CO_2 sequestration (CS) methods including microalgae based CO_2 sequestration as the main focal point. It amalgamates the potential microalgae types, their cultivation conditions for lipid and biomass build-up at the expense of sequestered CO_2 from air when grown in closed systems. In convention, closed systems are photobioreactors. Photobioreactor design features such as agitation, aeration, and illumination, ought to be ideal for microalgae growth using substrate CO_2 economically. Suitable bioreactor design features are highlighted for high cell density microalgae cultivation in photobioreactor. Some successful configurations are also critically reviewed and highlighted for high CO_2 sequestration producing enhanced biomass and lipid. Stirred tank photobioreactor, when growing potential microalgae strain, is concluded as best configuration for achieving highest CO_2 sequestration rate and hence high cell density biomass with lipid biosynthesis. In addition, coherent and cost-effective CO_2 sequestration techniques using microalgae are required in order to increase the effectiveness of the cultivation process in photobioreactor.

1. Introduction

Increased GHGs in the earth's atmosphere is causing many drastic climatic changes including global warming. This is mainly due to industrialization, combustion of municipal solid waste and transportation. Rising CO_2 is contributing 76% share in global warming causing melting of glaciers and extinction of ice in the polar regions of the earth. It resulted in average earth's temperature rise of 1.4 °C in the period of 1993–2003. The combined effect of thermal expansion of sea, melting glaciers, ice caps and polar ice sheets, had caused an average rise in sea level of 1.8 mm/year (Pachauri, 2007). Global temperature rise causes uneven rainfall patterns which directly affects agriculture by decreasing crop production (Ruchita and Rohit, 2017). Biodiversity is affected due to presence of GHGs trapped in the troposphere which changes the characteristics of the soil, water, and air. Sustaining the microflora balance in the atmosphere requires removal of GHGs and adding oxygen via increased photosynthesis (APA, Relatorio, 2009).

International Energy Agency (IEA) and Natural Gas Intelligence (NGI), based on daily Gas Price Index (GPI) calculations, estimates the annual CO_2 emission to be 32.1 billion metric tons (Source: http://www.naturalgasintel.com). Generally, the concentration of CO_2 in the atmosphere can be reduced by using three major strategies that include reducing and controlling CO_2 emissions in the

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atmosphere; capture existing CO_2 for long-term storage; and by developing alternatives to carbon-based fuel. CO_2 sequestration techniques should be analyzed considering their efficiency, cost, environmental impact, and the stability of captured carbon with time.

The present review discusses various CO_2 sequestration processes with critical analysis for their applicability. The limiting factors must be known for analyzing the overall efficiency of any sequestration process being used. Most methods sequestrate CO_2 but it is present as intact molecule. However, biological sequestration by microalgae has better stability of captured carbon with time by transforming CO_2 to glucose via photosynthesis which is utilized further for the lipid biosynthesis. Therefore, current review also discuss about potential microalgae, its required growth condition, and the bioreactor types used for cultivation. Only drawbacks with microalgae are their slow growth rate and shear sensitivity (Tang et al., 2012; Michels et al., 2016; Rodriguez et al., 2016). Enhanced CO_2 sequestration rates are possible if high cell density microalgae is cultivated in novel photobioreactor. Therefore, this work also discusses critical engineering parameters to be employed in this photobioreactor to cultivate shear sensitive microalgae. Suitable illumination system; aeration and agitation assembly with their effective designs are discussed for cultivation of shear sensitive microalgae. This review is one of its kinds as it focuses all together a critical analysis of biological CO_2 sequestration using microalgae; engineering parameters used in novel photobioreactor to get high cell density resulting in enhanced CO_2 sequestration rate; and potential microalgae types to deliver high lipid content and other value added products along with CO_2 sequestration.

2. CO_2 sequestration processes

CO_2 sequestration processes are mainly of two types i.e. biological and non-biological. They are elaborated on the basis of carbon sinks for sequestration and their environmental impacts. Potential processes are described below.

2.1. Non biological sequestration processes

Non biological processes comprises of oceanic, geological and chemical sequestration. Their details are summarized below.

2.1.1. Oceanic sequestration

Ocean covering 2/3rd of the earth reserves highest CO_2 content i.e. 50 times more than atmospheric CO_2 (Raven and Falkowski, 1999). Oceanic carbon sequestration is facilitated by both biotic and abiotic processes. Abiotic process involves the direct injection of carbon dioxide into sea water. Injection made to maximum feasible depths of ocean for minimizing the CO_2 leakage. However, biotic processes are unique as they involve oceanic fertilization that favours further utilization for useful products (Lal, 2008). High salinity in oceanic water and high temperature negatively regulates the CO_2 solubility in marine water. Considering this, the ocean closer to equator line will have lowest carbon dioxide sequestration. Sequestrating CO_2 at depths of the ocean makes the process efficient but uneconomical due to high depth ($<$3000 m) pipelines.

2.1.2. Geological sequestration

Geological sequestration involves storage of carbon from the atmosphere via underground geological formations. This method has been used by numerous petroleum industries since the 1970s. It not only reduces greenhouse gas emission but also contributes in economic oil recovery process. A large volume of CO_2 usage and its leakage probability may only enhance the cost (Kovscek and Cakici, 2005; Gunter et al., 1997). Geological sequestration is preferred for a limited period CO_2 sequestration and short time storage.

2.1.3. Chemical sequestration

Chemical sequestration comprises of selective chemical reactions. CO_2 transforms to a modified and stable compound, carbonates of magnesium and calcium obtained from rocks (Maroto-Valero et al., 2005; Kojima et al., 1997). High volume reduction capability of sequestered CO_2 in this process makes it attractive. Engineers are working on optimizing the factors such as temperature, pressure, raw material generation and its chemistry to enhance rate of reaction at low cost so that it can become an industrially applicable strategy.

2.2. Biological sequestration processes

Biological sequestration techniques are categorized as oceanic fertilization, terrestrial sequestration via soil carbon and phyto sequestration. Carbon dioxide sequestration using microalgae cultivation is an efficient process which is also explained below in detail.

2.2.1. Terrestrial sequestration

Sequestration occurs via either phyto sequestration or soil carbon sequestration. Assurance of long term storage of carbon content and high volume carbon sinks are prime attraction. It provides sustainable CO_2 cycle between atmosphere and earth. Management of ecosystem such as enhanced plantation on global level prevents deforestation and hence improves the efficiency of this naturally occurring sequestration process. However, this dependency on environmental factors becomes a disadvantage too (Lal, 2008; Post et al., 2009).