

EARTH SCIENCES

OVERVIEW OF THE POTENTIAL OF MICROALGAE FOR CO₂ FIXATION

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Abstract

CO₂ forms the largest component in coal combustion flue gas (Xing Zhang, 2015). Carbon dioxide (CO₂) fixation is an important process in mitigating the harmful effects of climate change caused by greenhouse gas emissions. One promising method of CO₂ fixation is through the use of microalgae. These tiny organisms are capable of photosynthesis, converting light energy into chemical energy and fixing atmospheric CO₂ into organic compounds. Microalgae are known for their fast growth rates and high CO₂ assimilation rates, making them an attractive option for CO₂ mitigation. In fact, some species of microalgae can fix up to 10 times more CO₂ than land-based plants. Furthermore, microalgae can grow in a wide range of environments, including wastewater, saline water, and brackish water, making them versatile and sustainable. In addition to CO₂ fixation, Chlorella microalgae also remove other pollutants from flue gases, such as sulfur dioxide (SO₂) and nitrogen oxides (NO_x). These pollutants can be toxic and contribute to acid rain and smog. Chlorella microalgae are able to remove these pollutants through a process known as bioadsorption, where the pollutants are adsorbed onto the surface of the microalgae. This review presents an outlook on microalgal propagation systems for CO₂ sequestration.

Keywords: Microalgae, CO₂ fixation, flue gas, utilization, photobioreactor.

Introduction

Once the Chlorella microalgae have absorbed the pollutants from the flue gases, they can be harvested and treated with recycling water. The recycling water acts as a medium for the microalgae to continue photosynthesis and CO₂ fixation, as well as providing nutrients for growth. The treated microalgae can then be reused for further treatment of flue gases. The process of CO₂ fixation by microalgae involves several steps. First, the microalgae are cultivated in a suitable growth medium containing the necessary nutrients and CO₂. The microalgae then absorb CO₂ from the air or from a source such as flue gas from a power plant. The absorbed CO₂ is then used in photosynthesis, where the microalgae convert it into organic compounds such as lipids, proteins, and carbohydrates. No additional CO₂ is created, while nutrient utilization is achieved in a continuous fashion leading to the production of biofuels and other secondary metabolites. Therefore, microalgal-mediated CO₂ fixation coupled with biofuel production, and wastewater treatment could present a promising alternative to existing CO₂ mitigation strategies (Wang et al. 2008; Lam et al. 2012). Biological CO₂ fixation appears to be the only economical and environmentally viable technology of the future (Ho et al. 2011; Kumar et al. 2011).

In practice, the treatment of flue gases with recycling water after treatment with Chlorella microalgae involves several steps. Firstly, the flue gases are passed through a bioreactor containing Chlorella microalgae. The microalgae absorb CO₂ and other pollutants from the flue gases, and continue to grow and produce biomass in the bioreactor. Once the microalgae have absorbed the pollutants, they are harvested and treated with recycling water. The recycling water provides a medium for the microalgae to continue photosynthesis and CO₂ fixation, while also providing nutrients for

growth. The treated microalgae can then be reused for further treatment of flue gases, providing a sustainable and cost-effective solution. Past research initiatives suggest that practical CO₂ utilization using microalgae still requires innovative scientific and technological breakthroughs to render this a feasible technology. Unless coupled with other technologies or coprocesses, investments into microalgae R&D are unlikely to make a considerable contribution to solving the CO₂ problem globally. The use of microalgae can be classified as a direct CO₂ mitigation technology. Direct strategies usually encompass much higher economic projections, going into billions of dollars, as opposed to indirect approaches. Therefore, for this technology to be a success, future R&D should focus on achieving higher biomass productivities, culture stability over long periods of time, economical harvesting techniques and improved biomass to-fuels conversion technologies. The economics of microalgal CO₂ utilization may be improved by integrating this procedure with other co-processes. Potential co-processes include wastewater treatment, production of useful metabolites, as well as biofuels, animal feed and biofertilizer manufacturing (V. Bhola et al. 2011).

Microalgae

The use of Chlorella microalgae in treating flue gases with recycling water has several advantages. Firstly, it is a highly efficient process that can remove up to 90% of the pollutants from flue gases. Secondly, it is a sustainable process that does not require any chemicals or energy inputs. Thirdly, the harvested microalgae can be used for a variety of applications, such as biofuels or animal feed, providing a valuable resource. Microalgae are able to endure high concentrations of CO₂, and this inherent ability makes them very advantageous in utilizing CO₂ from flue gases of power plants. They are fast growers with biomass volumes

that double within 24 h. At a flow rate of 0.3 L/min of air with 4 % CO₂ concentration, most microalgal strains are able to achieve a carbon-fixation rate of roughly 14.6 gcm⁻²/day (Farrelly et al. 2013).

Photobioreactor (PBR)

Microalgal production using closed PBR technology has been implemented to overcome some of the key problems associated open pond production systems. A major advantage of PBRs when compared to open raceway systems is that they permit culture of single species of microalgae for prolonged durations with lower risk of contamination (Brennan and Owende 2010). Harvesting costs may also be significantly reduced owing to the higher cell mass productivities attained, and CO₂ is also utilized more effectively (Chisti 2007; Brennan and Owende 2010; Vasumathi et al. 2012). Despite the fact that a great deal of work has already been done to develop PBRs for microalgal cultures and effective CO₂ utilization, more efforts are still required to improve PBR technologies and know-how of microalgal cultures. Photobioreactor design and development is perhaps one of the first major steps that should be undertaken for efficient mass cultivation of microalgae for carbon mitigation (Ugwu et al. 2008). An increase in the maximum growth rate of microalgal species due to higher CO₂ concentrations has been investigated by many researchers (Cheng et al. 2006; Ono and Cuello 2006; Lo 'pez et al. 2010; Ho et al. 2011; Kumar et al. 2011). Microalgal- CO₂ fixation occurs via photoautotrophic growth. Therefore, the CO₂-fixation potential of microalgal species should positively correlate with their light utilization efficiency and cell growth rate. Increases in temperature (20 °C) can cause significant reduction in CO₂ solubility, which eventually leads to a decline in the photosynthetic efficiency.

Green microalgae that are effective carbon sequestrators generally belong to the genera *Chlorococcum*, *Chlorella*, *Scenedesmus* and *Euglena*. A study by Kurano et al. (1995) showed that *C. littorale* was able to reach a maximum cell concentration of 4.9 g L⁻¹ at a 20 % CO₂ concentration. When exposed to CO₂ concentrations of more than 20 %, a short lag phase was observed prior to active photosynthesis. It must be noted that the performance of microalgal strains does not solely depend on CO₂ concentrations, but also on culture and experimental conditions, such as culture medium, temperature, light intensity as well as reactor design. Variation in any of these conditions could have an effect on the CO₂-fixation efficiency of the strains (Ho et al. 2011).

Challenges and economics associated with microalgal CO₂ sequestration

There are numerous hurdles that need to be overcome before microalgae can be employed to significantly reduce CO₂ emissions at a commercial level. Strain selection and design of the culturing system are key factors in maximizing CO₂ mitigation rates. Even though open systems are much more cost-effective compared to closed PBRs, it is difficult to maintain culture purity in such systems. Closed systems are efficient vessels for sustaining axenic cultures as well as minimizing CO₂ loss to the atmosphere. However, cleaning and sterilizing of large-scale PBRs is difficult,

and this then poses a problem in the production of high value-added products. Land availability for set-up of propagation vessels also becomes a problem in developing countries (V. Bhola et al. 2011). For example, Kadam (2001) demonstrated that 1,000 ha of land area will be required for the construction of open ponds to mitigate CO₂ emissions from a 50-MW power plant. Carbon-fixation rates for microalgal cultures differ under varying operational conditions. Geographical considerations must also be taken into account: fluctuations in temperature and solar irradiation over the seasons. Tropical areas are often considered most suitable for microalgal cultivation. To maximize the overall economic and environmental efficiency of microalgal CO₂ sequestration, culturing systems should be located as close as possible to the point source. Furthermore, a comprehensive plan should be compiled for the large-scale production of microalgae. This scheme should encompass modeling and LCA of the overall process. Failure in doing so could render many algal production systems unsustainable. It should also be noted that potential leaks from large-scale algal systems could cause ecological damage by eutrophication (Pires et al. 2012; Farrelly et al. 2013).

Biomass recovery poses a challenge in microalgal biomass production processes. Common harvesting practices include flocculation, filtration, flotation and centrifugal sedimentation. Some of these procedures can be highly energy intensive. Selecting an appropriate harvesting technology during microalgal cultivation is crucial to economic production of microalgal biomass (Brennan and Owende 2010). The choice of harvesting technique is dependent on microalgae characteristics such as size, density and the value of the target products (Packer 2009; Brennan and Owende 2010). Flocculation is a popular technique as it is straightforward and cost-effective. This harvesting mode uses multivalent cations to overcome the overall negative charge present on the surface of microalgae. Multivalent metal salts (ferric chloride, aluminum sulfate and ferric sulfate) and polymers (polyelectrolyte and chitosan) are usually effective flocculants. An ideal flocculant is one that can be applied at low concentrations, inexpensive, non-toxic, and further downstream processing is not adversely affected by its use. For effective microalgal harvesting, flocculation is often combined with "floating." This simple technique allows microalgae to float on the surface of the medium and can be easily removed as scum (Packer 2009). Life cycle analysis (LCA) essentially covers cultivation, harvesting, lipid extraction and finally product formation. Wastewater emissions as well as waste (solids or wastewater) treatment is generally not covered in a LCA study (Khoo et al. 2011).

Conclusion

In conclusion, the use of *Chlorella* microalgae in treating flue gases with recycling water is a promising approach for reducing air pollution and greenhouse gas emissions. The theoretical basis of this approach is based on the ability of microalgae to photosynthesize and fix CO₂, as well as remove other pollutants from flue gases through bioadsorption. The practical basis involves several steps, including passing the flue gases

through a bioreactor, harvesting the microalgae, and treating them with recycling water. While there are challenges to be addressed, the potential benefits of this treatment approach make it an important area of research and development in the fight against climate change. For effective CO₂ sequestration, an in-depth knowledge of flue gas composition and biology of microalgal cells would be required. Temperature, pH, SO_x, NO_x, heavy metals, light, culture strain and density, as well as CO₂ mass transfer and O₂ accumulation are major factors that affect CO₂ sequestration and biomass production. LCA is imperative to ascertain economic feasibility and environmental sustainability of algal CO₂ sequestration systems. For example, harvesting and dewatering are processes that are highly energy intensive; thus, research efforts should focus on developing an optimal harvesting strategy. Furthermore, strategic engineering decisions should be taken into consideration to realize effective microalgal CO₂ sequestration systems. Microalgal cultivation requires the development of suitable reactors with features such as high S/V ratio, mixing, mass transfer, scalability and ease of operation. Airlift bioreactors that distribute light through optical fibers could be a possible solution (this increases the ratio between the illumination surface and reactor volume).

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