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Algal Biomass Production and Its Utilization

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Abstract

Algal biomass production is gaining traction as a promising source of bioenergy due to its rapid growth rate and ability to utilize carbon dioxide emissions. Algae, being photosynthetic organisms, require sunlight, CO_2, and optimal growth conditions for biomass increase. Temperature, light intensity, pH, aeration, mixing, and salinity play crucial roles in achieving optimum growth. Algae cultivation can occur in various water resources without competing with conventional agriculture. Microalgae, with their ability to double biomass in less than a day, offer advantages over terrestrial crops, including year-round harvesting and quick system repairs in case of failures. Two primary cultivation systems—open raceway ponds and photobioreactors—offer distinct advantages. Open raceway ponds are cost-effective but susceptible to environmental fluctuations and uneven light distribution. In contrast, photobioreactors provide a controlled environment, optimizing growth conditions such as CO_2 supply, temperature, light exposure, and mixing. While closed photobioreactor systems require greater upfront investment, they offer the potential for increased productivity and improved resource efficiency. The abstract underscores the potential of algae as a renewable energy source and highlights the importance of optimizing growth conditions and cultivation systems for maximizing biomass production. As the world seeks sustainable alternatives to conventional energy sources, algae present a compelling solution, offering rapid growth rates, carbon sequestration benefits, and versatility in cultivation methods. Continued research and development in algae cultivation techniques hold promise for scalable, ecofriendly bioenergy production. Algae are chlorophyll-bearing photosynthetic organisms capable of fixing carbon dioxide and producing oxygen. Currently, interest in the field of algae as a source of bioenergy has heightened as it is a rich source of various compounds and chemicals that function as a source of energy.

Keywords: algal biomass, flocculation, microalgae biomass, filtration, centrifugation

INTRODUCTION

Algae cultivation and biomass harvesting offer a plethora of advantages that make them a promising solution for various environmental and industrial challenges [1]. One notable advantage is the remarkable speed at which algae can grow, surpassing terrestrial plants by a factor of 100, and doubling their biomass in less than a day [2]. This rapid growth rate is particularly beneficial in mitigating carbon dioxide (CO_2) emissions, as algae can efficiently utilize CO_2 from combustion processes as a carbon source for their growth, with approximately 1.8 kg of CO_2 required for every kilogram of dry algal biomass produced [3, 4]. Furthermore, the versatility of algae cultivation is evident in their ability to thrive in diverse water resources, without competing for land or resources with conventional agriculture [5]. Unlike many terrestrial crops, microalgae biomass can be harvested throughout all seasons, providing a consistent and reliable source of raw material [6–8].

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Additionally, the resilience of algae cultivation systems is noteworthy, as any potential failure can be swiftly addressed and repaired within a matter of days—a capability that is unparalleled in terrestrial crop cultivation. These combined advantages underscore the potential of algae cultivation as a sustainable and efficient solution for a wide range of applications, from biofuel production to wastewater treatment and beyond [9–11].

LITERATURE REVIEW

Optimum Growth Conditions

As photosynthetic organisms, algae rely on sunlight and CO_2 for biomass growth. The ideal ranges for these factors are:

- *Temperature:* The prevailing species of microalgae typically withstand temperatures ranging from 16°C to 27°C during cultivation.
- *Light intensity:* Excessive light intensity, such as direct sunlight or placing a small container too close to artificial light sources, can lead to photo-inhibition. It is important to prevent overheating caused by both natural and artificial light sources. It is recommended to use fluorescent tubes that emit light in either the blue or red spectrum, as these are the most effective wavelengths for photosynthesis.
- *pH:* For the majority of cultivated algal species, the pH typically falls within the range of 7–9, with the most favorable pH range being between 8.2 and 8.7 [12].
- *Aeration and mixing:* Mixing is necessary to ensure that all cells of the population are equally exposed to light and nutrients and improve gas exchange between the culture medium and the air [13]. Depending on the scale of the culture system, mixing is achieved by stirring daily by hand (test tubes, Erlenmeyer's), aerating (bags, tanks), or using paddle wheels and jet pumps in open ponds (Figure 1).
- *Salinity:* Salinities of 20–24 gL^{-1} have been found to be optimum.

Cultivation Systems

Algal biomass cultivation systems encompass various methods and setups designed to cultivate algae for biomass production. These systems can be categorized into open pond systems and closed photobioreactor (PBR) systems.

Open Raceway

In such ponds, algae, water, and nutrients move in a circular pattern resembling a racetrack. Paddlewheels facilitate this flow, ensuring that algae remain suspended in the water and are regularly brought back to the surface. Typically, the ponds are maintained at a shallow depth to ensure that algae receive adequate sunlight exposure. Sunlight can only penetrate the water to a restricted depth, necessitating this shallow configuration [14]. The ponds operate continuously, receiving a constant supply of CO_2 and nutrients, while water containing algae is consistently removed from the opposite end. This method boasts low production and operational expenses. However, the environment within and around the pond remains somewhat unregulated, which can potentially hinder production. Additionally, uneven light intensity and distribution within the pond serve as limiting factors [15].

Photobioreactor

PBR is an enclosed apparatus that offers a regulated environment, leading to increased algae productivity. Being a closed system, all necessary growth factors for algae are introduced and managed within the system as per their needs. PBRs allow for enhanced regulation of the culture environment, including CO_2 and water supply, temperature control, light exposure efficiency, culture density, pH levels, gas supply rate, mixing patterns, and more (Figure 2).

Harvesting and Dewatering of Algal Biomass

The standard algae cultivation has approximately 99.98% water and only 0.02% algae. Due to the high-water content, harvesting and dewatering algae can be very expensive and can account for 30% of total production costs and hence are very important for exploitation of algal fuel [16–19].

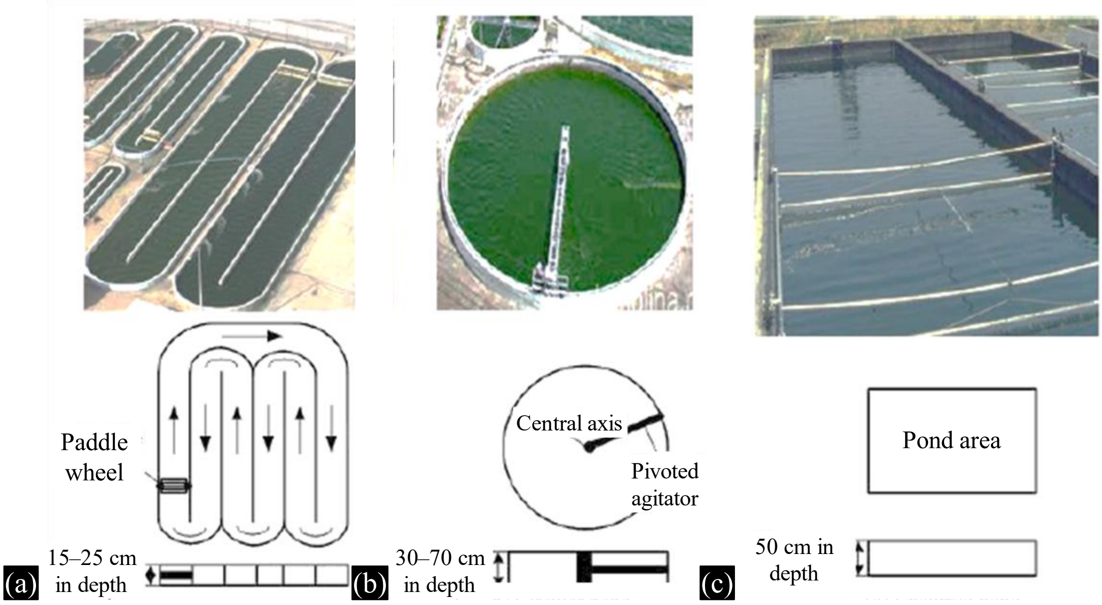

Figure 1. Three different designs of open pond systems [20]. (a) raceway pond, (b) circular pond, (c) unstirred pond

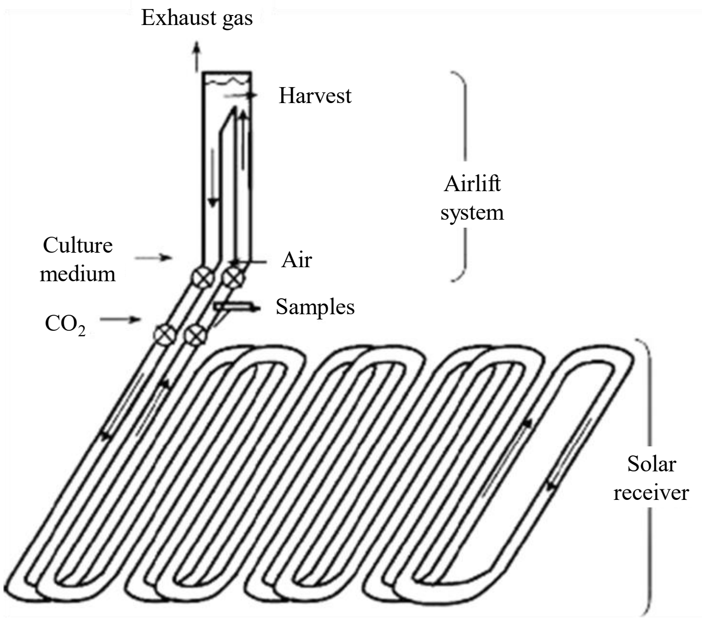

Figure 2. Tubular photobioreactor scheme with Airlift system [9].

Flocculation

Flocculation refers to the clustering together of algae cells, leading them to settle out of suspension. Typically, algae cells possess negatively charged surfaces, which can result in the formation of large aggregates or flocs when these charges are neutralized. Chemical flocculation involves the use of inorganic compounds such as aluminum sulfate, ferric sulfide, or lime to either neutralize or reduce the cell's charge, thereby promoting clumping (Figure 3).

Electrofloculation

Electrofloculation involves the creation of flocs within the culture by applying an electric current (Figure 4). This method can be employed even in large-scale cultures without requiring excessive electricity consumption.

Figure 3. Flocculation of microalgae.

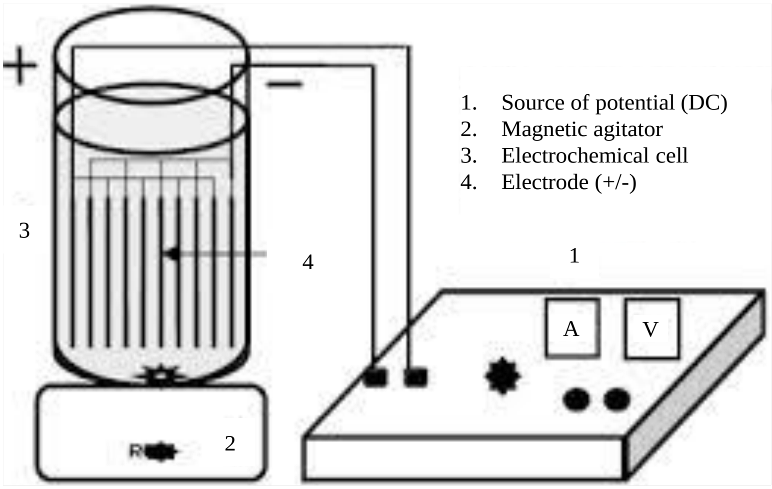

Figure 4. Experimental set up for Electro-flocculation.

Biofloculation

Flocculation can be induced by controlling nitrogen levels, adjusting pH, and regulating dissolved oxygen levels. Introducing another algae species, such as *Scenedesmus obliquus*, can also trigger flocculation. However, while cost-effective, this method can be time-intensive.

Magnetic Separation of Algae

This approach utilizes the principle of flocculation. Magnetic nanoparticles (MNPs) are added to the cell culture in suitable amounts, and an external magnetic field is then applied. The cells gather around the magnet, allowing for the separation of a clear liquid medium, from which biomass can be collected by decanting. This method is efficient and cost-effective, as the MNPs can be reused, and it requires less time as compared to other techniques.

Filtration

Filtration involves the passage of particles onto a screen, where substances are separated based on their size relative to the pore size of the screen. This technique is particularly useful for harvesting larger strains of algae. For instance, *Spirulina sp*. can be easily separated from the culture medium through simple filtration [21–24]. While filtration is a cost-effective and efficient approach for algae harvesting, it faces a significant challenge of filter fouling and clogging, which restricts its viability for large-scale cultivation [25].

Centrifugation

Centrifugation, a commonly employed separation technique in liquid-solid separations, relies on centrifugal forces to segregate substances based on their densities. The effectiveness of separation is contingent upon the size of the targeted algal species. Despite its high efficiency, centrifugation is deemed impractical for large-scale algae cultivation facilities due to the substantial capital and operational expenses involved [26, 27].

Attached/Biofilm-based Systems

These systems are designed to address the issue of high harvesting costs. In these culture systems, algae is encouraged to attach to a substrate. Once attached , cell proliferation occurs and a biofilm forms (Figure 5). This biofilm is ideal for harvesting because it is already held together and can be easily scraped from the substrate and separated from the culture medium [28, 29]. Dissolved Air Flotation unit is depicted in Figure 6.

Scope of Algae as a Source of Fuel

Algal biofuels can provide more than 90000 kg of fuel per hectare of land per year. Indian Oil Corporation Limited (IOCL) is one of the organizations leading research in this area and aims at producing 200000 tonnes per annum algal biodiesel in future and that will also produce a high value protein for animal feed as byproduct. IOCL is working in collaboration with organizations mentioned below to achieve its objectives:

- *National Resource Laboratory, USA:* For resource assessment;
- *Petro Algae:* For setting up pilot production unit;
- *NTPC:* For future scaling up in power plants.

An integrated biorefining scheme for algal biomass utilization is depicted in Figure 7.

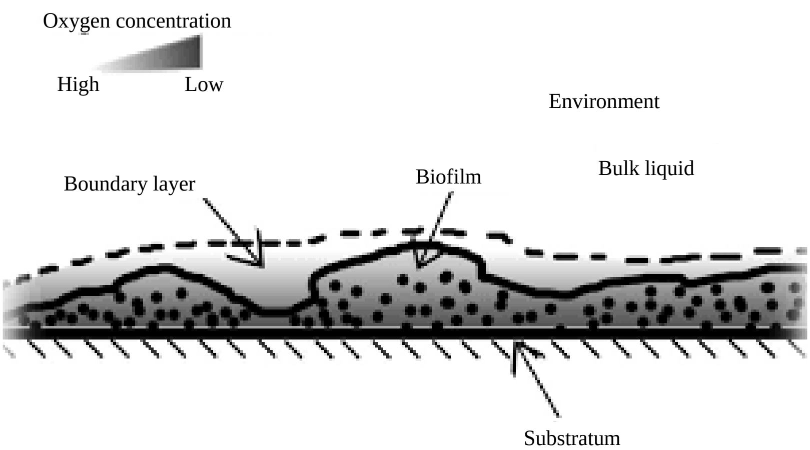

Figure 5. Diagrammatic representation of a typical biofilm.

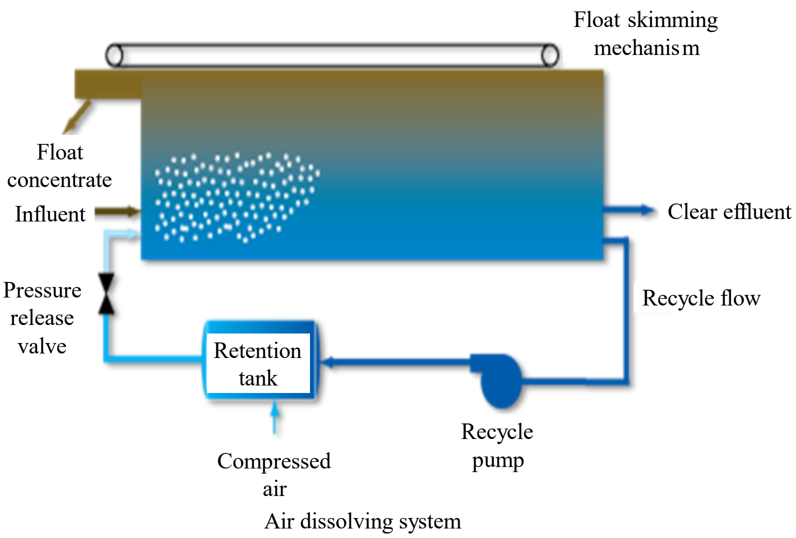

Figure 6. Dissolved air flotation unit.

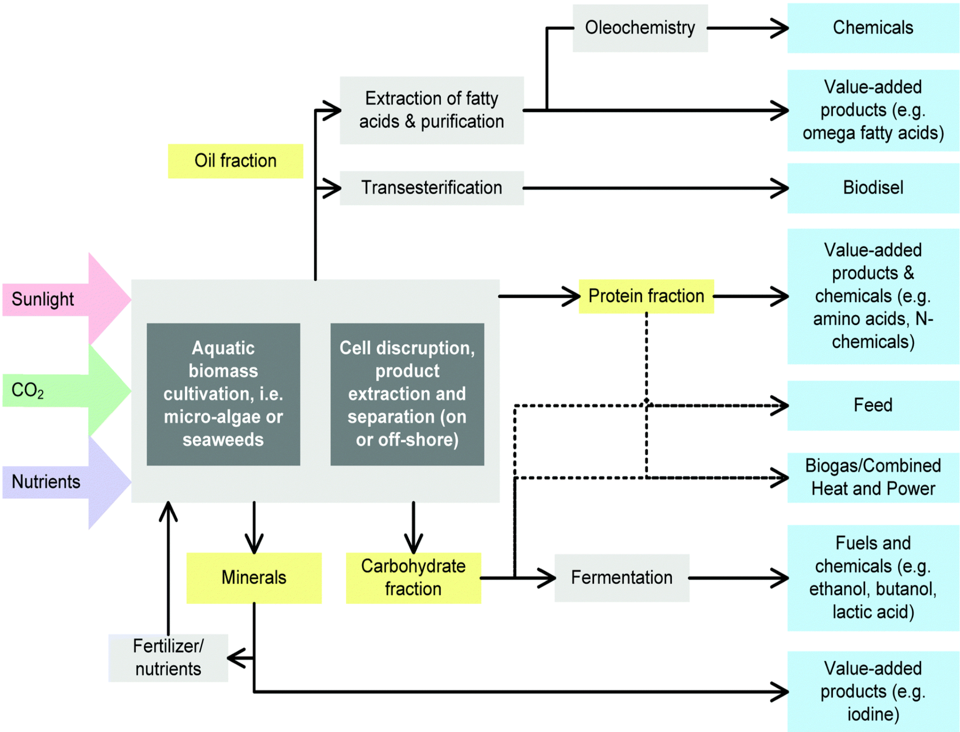

Figure 7. An integrated biorefining scheme for algal biomass utilization [30].

CONCLUSION

The review of literature highlights the significant advantages of algae cultivation as a promising source of bioenergy. Algae offer unparalleled growth rates, utilizing CO_2 emissions and thriving in various water resources without competing with conventional agriculture. Moreover, microalgae biomass can be harvested year-round, providing a consistent supply for bioenergy production. Importantly, the flexibility of algae cultivation allows for rapid system repairs in case of failures—a feat impossible with terrestrial crops. Furthermore, the comparison between open raceway ponds and PBRs underscores the importance of optimizing cultivation systems to maximize productivity and resource utilization. While open raceway ponds offer cost-effectiveness, PBRs provide a controlled environment, enhancing growth conditions and ensuring efficient biomass production.

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