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A Review on the Harvesting Techniques of Algae for Algal Based Biofuel Production

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Abstract—*Bio based fuel production is gaining importance since the last four decades due to its eco friendly characteristics. Bio based fuels are derived from renewable sources of energy and are carbon neutral. Algae is a potential renewable feedstock which when harnessed properly could contribute to a great extend on the growing demand of energy. The motivation for using algae as a feedstock is that microalgae can provide several different types of renewable bio fuels. These include methane produced by anaerobic digestion of the algal, biodiesel derived from micro algal oil and biohydrogen. In addition to oils, micro algal biomass contains significant quantities of carbohydrates, proteins and nutrients. Therefore, the residual biomass from biodiesel production processes can be used potentially as animal feed. Microalgae can grow in high rates which can be 50 times more than that of switch grass, which are the fastest growing terrestrial crops. Algal biomass is generally converted to energy products through thermo chemical and bio chemical conversions. Starting with a brief introduction on algae, this paper reviews the various harvesting techniques of algae used till date for bio based fuel production. This review work will aid the researchers in understanding the advantages and drawbacks of the various algae harvesting methods.*

Keywords*: Algae, biofuel, harvesting techniques.*

1. INTRODUCTION

The demand of energy consumption is increasing exponentially after the industrial revolution of 1760. However the production of usable energy is not at par with the demand. Fossil fuels are gradually diminishing and the present researchers and industries are focusing more on the area of cleaner and greener energy for a better future. Biomass feedstock is carbon neutral and is contributing significantly in covering the energy demand supply gap.

Energy sources are classified as primary sources and secondary sources. The primary energy sources are classified into renewable sources and non renewable sources. It has been established that the energy obtained from non renewable sources are limited and they are the prime source of green house gases which is a major concern for today's world [1]. Since fossil fuel has become a finite energy source, in the recent times researchers are focusing on production of renewable alternative energy sources.

The major sources of alternative energy are bio-renewable, hydro, solar, wind, geothermal and other energies, each of them having their own advantages and disadvantages, including political, economical and practical issues [2]. Renewable energy is a promising alternative solution because it is clean and environmentally safe. They also produce lower or negligible amount of greenhouse gases and other pollutants when compared with the fossil energy sources they replace [2]. Among the existing renewable alternatives to replace fossil fuels, production of bio based fuels from algae has raised great interest [3].

Microalgae are fast growing beasts with a voracious appetite for carbon dioxide. They have the potential to produce more oil on an area basis than any other feedstock being used to make biodiesel, and they can be grown on land that's unsuitable for food crops [4]. Algae have a very high content of oil area wise as compared to other oil crops. Table 1 shows the yields of various plants oil and algae.

Table 1: Yield of various plant oils [2].

Crop	Oil in liters per hectare
Algae	100000
Castor	1413
Coconut	2689
Palm	5950
Safflower	779
Soy	446
Sunflower	952

Microalgae are traditionally cultivated in race way ponds and photo bioreactors. For algae harvesting, at first flocculating agents are introduced in the algae culture. Then the water from the raceway ponds are pumped out using high power pumps. After that the algae culture is introduced in a sedimentation tank from where concentrated algae biomass is obtained. At the last phase, sun drying and oven drying of the concentrated algae biomass is carried out. This processed algae is then used for biofuel production. Harvesting of algae is an important process in algae biofuel production. In this review paper, stating the importance of algae as a source of biofuel, we are concentrating on the various harvesting and processing techniques of algae for biofuel production.

2. ALGAE AS A SOURCE OF BIOFUEL

Algae are simple organisms that are mainly aquatic and microscopic in nature. Microalgae are unicellular photosynthetic microorganisms. They live in saline or fresh water environments that convert sunlight, water and carbon dioxide to algal biomass [5]. Table 2 shows the oil content of some microalgae.

Table 2: Microalgae oil contents [2].

Microalgae	Oil content (wt% of dry basis)
Botryococcus braunii	25-75
Chlorella sp.	28-32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16-37
Dunaliella primolecta	23
Isochrysis sp.	25-33
Monallanthus salina	>20
Nannochloris sp.	20-35
Nannochloropsis sp.	31-68
Neochloris oleabundans	35-54
Nitzschia sp.	45-47
Phaeodactylum tricornuturn	20-30
Schizochytrium sp.	50-77
Tetraselmis sueica	15-23

For harvesting algae, the key ingredient is sunlight. Algae can grow practically anywhere where there is enough sunshine. Algae's chemical composition is proteins, carbohydrates, lipids and nucleic acids in varying proportions. While the percentages vary with the type of algae, there are algae types that are comprised up to 40% of their overall mass by fatty acids [6]. The most significant distinguishing characteristic of algal oil is its yield and hence its biodiesel yield. According to some estimates, the yield (per acre) of oil from algae is over 200 times the yield from the best-performing plant/vegetable oils [7].

The driving issues for the researchers to go for algae as a source of bio-fuel are as below:

- Algae are the fastest-growing plants in the world [2].
- Bio renewable sources (algae) produce lower or negligible levels of greenhouse gases and other pollutants when compared with the fossil energy sources they replace [8].
- They have the potential to produce more oil per acre than any other feedstock being used to make biodiesel, and they can be grown on land that's unsuitable for food crops [3].
- Microalgae commonly double their biomass within 24 h. Biomass doubling times during exponential growth are commonly as short as 3.5 h. Oil content in microalgae can exceed 80% by weight of dry biomass [9].
- Microalgal biomass contains approximately 50% carbon by dry weight [10]. All of this carbon is typically derived from carbon dioxide. Producing 100 t of algal biomass fixes roughly 183 t of carbon dioxide.

Fig 1 shows the various conversion processes and techniques of algae biomass and their resultant products.

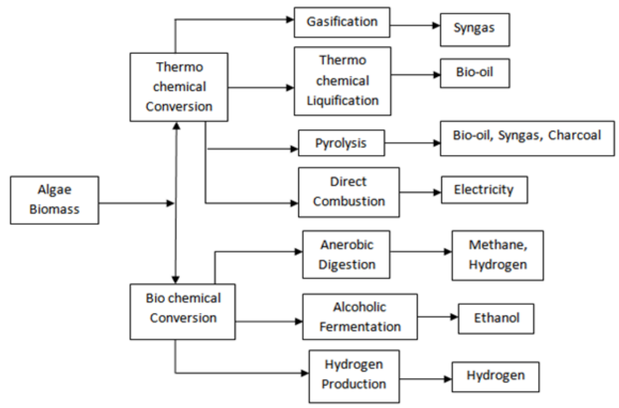

Fig. 1: Steps showing various algal biofuel conversion technologies [11].

3. HARVESTING TECHNIQUES OF ALGAE

Microalgae harvesting currently involves mechanical, chemical, biological and, to a lesser extent, electrical based methods. It is very common to combine two or more of these methods to obtain a greater separation rate at lower costs [12]. Efficient harvesting of algae biomass from cultivation froth is essential for mass production of biodiesel from microalgae. Techniques presently applied for microalgae harvesting are centrifugation, flocculation, filtration and screening, gravity sedimentation, flotation, and electrophoresis techniques [13]. Fig 2 shows the steps of microalgae harvesting and drying techniques. An ideal harvesting process should be effective for the majority of microalgae strains and should allow the achievement of high biomass concentrations, while requiring moderate costs of operation, energy and maintenance.

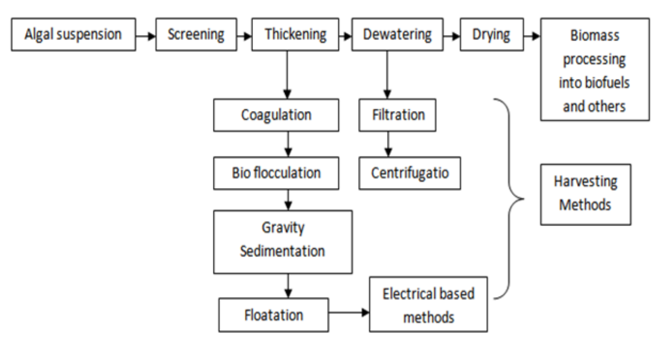

Fig 2: Steps of microalgae harvesting and drying techniques [12].

3.1 Centrifugation

Among all the harvesting methods, centrifugation is the fastest of all. Centrifugation involves the use of the centripetal force for the sedimentation of heterogeneous mixtures with a centrifuge, and is used in industrial and laboratory settings. A centrifuge is a useful device for both bio lipid extraction from algae and chemical separation in biodiesel. Coupled with a homogenizer, one may be able to separate bio lipids and other useful materials from algae [15].

In the centrifugation process, at first the semi concentrated algae mass is obtained from the culture tank using a ball valve. Then, with the help of the flow regulator, rotary van pump and centrifuge, the concentrated algae mass is obtained from the exit flow. Fig 3 shows the setup of centrifugal harvesting of algae biomass.

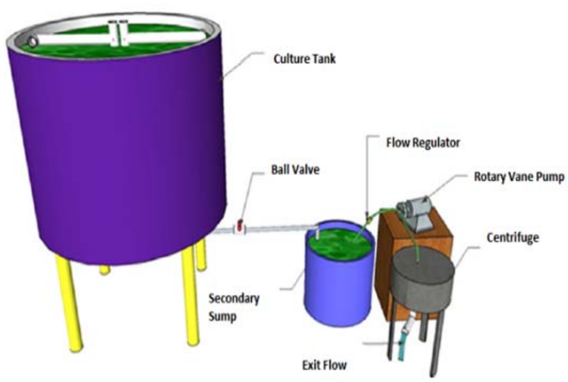

Fig. 3: Experimental setup for centrifugation [16].

Most microalgae can be recovered from the liquid broth using centrifugation. Laboratory centrifugation tests were conducted on pond effluent at 500–1000g and showed that about 80–90% microalgae can be recovered within 2–5 min [17]. Centrifugation is a preferred method for harvesting of microalgae biomass, especially for producing extended shelf-life concentrates for aquaculture but processing a large amount of culture using centrifugation is time consuming and costly [18]. Its drawback is that it is the most expensive due to its high energy consumption, which limits its application to high-valued products, such as highly unsaturated fatty acids, pharmaceuticals and other commodities [14].

3.2 Flocculation

Flocculation is a process in which dispersed particles are aggregated together to form large particles for settling [15]. There are various processes in which flocculation or coagulation can be carried out. For algae harvesting, the basic flocculation techniques used are auto flocculation, chemical coagulation and electrolytic process. Chemical coagulation is further classified into inorganic coagulants and organic coagulants.

3.2.1 Auto flocculation

Flocculation spontaneously occurs in microalgal cultures when pH increases above 9 [17]. This type of flocculation is often referred to as auto flocculation because it occurs spontaneously in microalgal cultures as a result of a pH increase due to photosynthetic CO_2 depletion. Auto flocculation is associated with the formation of calcium or magnesium precipitates.

3.2.2 Chemical flocculation

Adding chemicals to microalgal culture to induce flocculation is a common practice in various solid–liquid separation processes as a pre-treatment stage, which is applicable to the treatment of large quantities of numerous kinds of microalgal species [19]. Two very recent studies showed that the usage of cationic aluminum and magnesium backboned organoclays has potential to be used for microalgae flocculation [20, 21]. A wide variety of salts has been tested as coagulants for microalgal harvesting. Multivalent metal salts, such as $FeCl_3$, $Al_2 (SO_4)_3$ and $Fe_2(SO_4)_3$, have been effectively tested, as it is shown in Table 3.

Table 3: Microalgae biomass recovery by coagulation/ flocculation followed by sedimentation [12].

Microalgae	Coagulant	Recovery efficiency (%)
Chlorella vulgaris	Nano-aminoclays	99
Chlorella vulgaris	Chitosan	92
Chlorella sorokiniana	Chitosan	99
Chlorella minutissima	Fe2(SO4)3	80
Chlorella minutissima	AlCl3	80
Phaeodactylum tricornutum	Al2(SO4)3	83
Phaeodactylum tricornutum	Chitosan	91.8
Dunaliella salina	Electrolytic flocculation	98.9
Coelosphaerium sp.,	Electrolytic flocculation	96.3
Tetraselmins sp.	Electro-flocculation	87
Tetraselmins sp.	Electro-flocculation followed by gravity sedimentation	91

The disadvantage of flocculation is that it is not applicable for small scale applications. Moreover this technique is unfeasible for marine microalgae harvesting.

3.3 Electrical based processes

Electrical approaches to microalgal harvesting are not largely disseminated. Nonetheless, these methods are versatile, as they are applicable to a wide variety of microalgal species [22]. As microalgal cells are negatively charged, when an electrical field is applied to the culture broth, the cells can be separated [13].They can form precipitates on the electrodes (electrophoresis), as well as accumulate on the bottom of the vessel (electro-flocculation). On the other hand, electro-flotation mechanism only differs from dissolved air floatation (DAF) in the way of the bubbles are made. Hydrogen bubbles are formed through water electrolysis, which can be cheaper than conventional DAF [23]. The generation of these bubbles can be done at the anode and coupled with the electro-coagulation that occurs through the electrolytic oxidation that happens at the cathode [24]. This process is described as electro-coagulation-flotation (ECF) [24].

3.4 Gravity sedimentation

Gravity sedimentation is a technique that separates a feed suspension into a concentrated slurry and clear liquid. Harvesting by sedimentation at natural gravity can be accomplished via lamella separators and sedimentation tanks. Lamella separators can offer an increased settling area compared to conventional thickeners due to the orientation of the plates [25]. The microalgal suspension is pumped continuously, while the slurry is removed discontinuously. The separation of microalgae by sedimentation tanks is an inexpensive process. However without the addition of flocculants, the reliability is low [26].

3.5 Flotation

Flotation as a method of removal of microalgae from aqueous solutions can be considered more advantageous and effective than sedimentation [27]. Flotation can be described as a physiochemical type of gravity separation in which air or gas is bubbled through a solid-liquid suspension and the gaseous molecules are attached to the solid particles. These particles are carried to the surface of the liquid and accumulate as float, which can be removed [27]. There are three main flotation techniques that entail bubble generation. These are dispersed air flotation, dissolved air flotation and electrolytic flotation. A comparison of all the harvesting methods is done in table 4 emphasizing on the advantages and disadvantages of the methods.

Table 4: Advantages and disadvantages of harvesting methods applied to microalgae biomass [12].

Harvesting method	Advantages	Disadvantages
Chemical coagulation/ flocculation	Simple and fast method. No energy requirements.	Chemical flocculants may be expensive and toxic to microalgae biomass.
Auto and bioflocculation	Inexpensive method. Allows culture medium recycling. Non-toxic to microalgae biomass.	Changes in cellular composition. Possibility of microbiological contamination.
Gravity sedimentation	Simple and the inexpensive method.	Time-consuming. Possibility of biomass deterioration. Low concentration of the algal cake.
Flotation	Feasible for large scale applications. Low cost method.	Generally requires the use of chemical flocculants. Unfeasible for marine microalgae harvesting.
Electrical based processes	Applicable to a wide variety of microalgae species. Do not require the addition of chemical flocculants.	Poorly disseminated. High energetic and equipment costs.
Filtration	High recovery efficiencies. Allows the separation of shear sensitive species.	The possibility of fouling/clogging increases operational costs. Membranes should be regularly cleaned.

4. CONCLUSION

Various microalgae harvesting techniques has been reviewed. Centrifuge method is found to be the fastest of all. Laboratory centrifugation tests conducted on pond effluent at 500–1000g and showed that about 80–90% microalgae can be recovered within 2–5 min. Gravity sedimentation method was found to be reliable and cheaper than other methods, but without the use of flocculants it efficiency is very low. The cost of production and harvesting of algae is higher which makes it expensive than petroleum fuels, the cost of production of algal oil must be reduced to compete it with petro diesel. New and novel methods must be designed for harvesting the algae efficiently in terms of time vis-à-vis amount of collected algae.

5. ACKNOWLEDGEMENT

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