Algae Oil as Future Energy Source in Indian Perspective

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Abstract- In view of increasing energy demand, climate change, increasing price of petroleum and most importantly the fossil fuel resources will be diminished rapidly. The transport fuels are needed to replace by bio fuel from renewable sources. Slow growth rate, low biomass, low productivity and requirement for agriculture land for cultivation restricts to use edible, non edible, waste cooking as bio fuel. The Microalgae appear to be the only source of renewable bio fuel that is capable of meet the global energy demands. Microalgae use sun light and CO2 for their growth. Oil productivity of many microalgae greatly exceeds the oil productivity of the other crops. This paper provides the best culture method, best harvesting method and optimum oil extraction method. The finding of this paper shows the present status of work done by various agencies and institutes in the area of algal oil development in India.

Keywords- Microalgae, Cultivation, Extraction, Harvesting, Engine, Fuel, Biodiesel

1. Introduction

Energy is a basic requirement for economic development. Every sector of Indian economy-agriculture, industry transport, commercial and domestic needs input of energy. The economic development plans implemented since independence have necessarily required increasing amount of energy. As a result consumption of energy in all forms has been steadily rising all over the country. This growing consumption of energy has also resulted in the country becoming increasingly dependent on fossil fuels such as coal, oil and gas. Rising prices of oil and gas and potential shortage in future lead to concern about the security of energy supply needed to sustain our economic growth. Increased use of fossil fuels also causes environmental problems both locally and globally. India is the fourth largest consumer of primary energy in the world. In India, the consumption of crude oil was 168.13 MT for the year 2010-2011. But 80% of this production was met by import [1]. Biodiesel, an alternate to non-renewable diesel fuel has attracted significant attention as a renewable & biodegradable fuel over the past years. Biodiesel is defined as a fuel comprised of monoalkylester of long chain fatty acids derived from vegetable oils or animal fats. The production of biodiesel from edible oil resources in India is almost impossible as primary need is to meet the demand of edible oil that is already imported. About 43% of edible oil is imported for catering the domestic needs. Therefore it is not possible to divert the edible oil resources for biodiessel production in the country. The most abundant non edible oil sorces are sal, mahua, neem, pongamia and jatropha, based on extensive research jatropha and pongamia have been identified as the potential feed stocks for biodiesel production in near future.The growth rate, land requirement for cultivation of jatropha, pongamia is very low which restrict us to use these non edible feed stocks. Presently microalgae is the focus as future source of biodiesel. Algal productivities can be twenty times that of oilseed crops on a per hectare basis and is thus a more viable alternative. Microalgae have faster growth rates than plants and are capable of growth in highly saline waters which are unsuitable for agriculture. They utilize a large fraction of solar energy making them effective solar to chemical energy converters [2-7]. Microalgae have greater photosynthetic efficiency than terrestrial plants and require very little simple nutrients supply for growth.The lipid content of microalgae,

on a dry cellular weight basis generally varies between 20% and 40%, however lipid contents as high as 85% have been reported for certain microalgal strains [8-10]. Microalgae have the potential to produce 25-220 times higher triglycerides than terrestrial plants [3, 6] and can be readily converted to biodiesel by the transesterification process [9,11]. As compared to biomass from trees and crops, microalgal oil is more economical in that transportation costs are relatively low [3]. Microalgae offer significant higher yield advantage over sunflower as potential feed stock for biodiesel production. [8].

Table 1. Comparison of oil yield and land area requirement for various oil crops [12]

S.No.	Crop	Oil yield (L/ha/yr)	Land area needed (M ha)
1	*Corn*	172	1540
2	*Soybean*	446	594
3	*Canola*	1190	223
4	*Jatropha*	1892	140
5	*Coconut*	2689	99
6	*Oil palm*	5950	45
7	*Microalgae*	136,900	2

The table 1 gives an idea about the oil production and land area requirement which shows that microalgae have the ability to yield about 1,36,900 L/ha/yr with a land area of 2Mha while corresponding non-edible oil like jatropha has the oil productivity of 1892 L/ha/yr but needs 140 Mha land. The productivity of other edible oils varies with land requirement but the oil is used for edible purposes not for biodiesel.

2. Microalgae

Microalgae are single-cell microscopic organisms which are naturally found in fresh water and marine environment. Their position is at the bottom of food chains. Microalgae are considered to be one of the oldest living organisms in our planet. There are more than 50,000 species of micro algae species exist, but only 30,000 are analyzed yet [13]. They are thallophytes - plants lacking roots, stems, and leaves that have chlorophyll as their primary photosynthetic pigment and lack a sterile covering of cells around the reproductive cells [14]. While the mechanism of photosynthesis in these microorganisms is similar to that of higher plants, microalgae are generally more efficient converters of solar energy thanks to their simple cellular structure. In addition, because the cells grow in aqueous suspension, they have more efficient access to water, CO2, and other nutrients. Generally, microalgae are classified in accordance with their colours. The current systems of classification of microalgae are based on a) kinds of pigments, b) chemical nature of storage products, and c) cell wall constituents [15].

Table 2. Oil content of some microalgae [12]

S.No.	Microalgae	Oil content (% dry weight)
1	Botryococcus braunii	25-75
2	Chlorella sp.	28-32
3	Crypthecodinium cohnii	20
4	Cylindrotheca sp.	16-37
5	Dunaliella primolecta	23
6	Isochrysis sp.	25-33
7	Monallanthus salina	>20
8	Nannochloris sp.	20-25
9	Nannochloropsis sp.	31-68
10	Neochloris oleoabundans	45-47
11	Nitzschia sp.	45-47
12	Phaeodactylum tricornutum	20-30
13	Schizochytrium sp.	50-77
14	Tetraselmis sueica	15-23

The above table shows that the Schizochytrium sp. has high oil content while Nitzschia sp. and Neochloris oleoabundans species have similar oil content.

2.1. Algae as Fuel in Indian Scenario

Extensive work has been done by Indian scientists on utilization of microalgae for food and the pharmaceutical applications. The lists of organizations/institutions who are working on various aspects of microalgae such as microalgae collected from natural vegetation which is used for the production of biogas and bio fuel in India are given in Table 3.

2.2. Advantage of Algae as Fuel

The advantages of culturing microalgae as a resource of biomass are [30]:

- Algae are considered to be a very efficient biological system for harvesting solar energy for the production of organic compounds.
- Algae are non-vascular plants, lacking (usually) complex reproductive organs.
- Many species of algae can be induced to produce particularly high concentrations of chosen, commercially valuable compounds, such as proteins, carbohydrates, lipids and pigments.
- Algae are microorganisms that undergo a simple cell division cycle.
- The farming of microalgae can be grown using sea or brackish water.
- Algal biomass production systems can easily be adapted to various levels of operational or technological skills

The above advantage shows that algae to become a future source of fuel in India. To become a successful fuel the algae has to undergo various process from harvesting to cultivation in a manner to get the max output.

Table 3. Status of R & D work on microalgae in India

No	Institution/Organization	Work on microalgae species	R & D area	Ref.
1	University of Madras, Chennai	*Sargassum*	Cultivation	[16]
2	University of Madras, Chennai	*Seaweeds*	Biogas production	[17]
3	University of Madras, Chennai	*Botryococcus braunii*	Cultivation in open raceway pond	[18]
4	Central Food Technological Research Institute (CFTRI), Mysore	*Botryococcus braunii*	Isolation and characterization of hydrocarbon	[19-21]
5	Vivekananda Institute of Algal Technology (VIAT), Chennai	*Microalgae a*	Development of technology to treat industrial waste water	[22-24]
6	Central Rice Research Institute (CRRI), Cuttack, Orissa	*Chlorella vulgaris*	Production	[25]
7	Vivekananda Institute of Algal Technology (VIAT), Chennai	*Micro algae a*	Biofuel production from diatom species	[26]
8	Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee	*Microalgae*	Conversion of Microalgal oil to biodiesel	[13]
9	CSMCRI, Bhavnagar	Gracilaria, Gelidium, Kappaphycus	Cultivation	[27]
10	Synthetic Biology & bio fuel Group (ICGEB, New Delhi)	Chlamydomonas, Chlorella sp and cyanobacteria	Growth and biofuel production	[28]
11	Vivekananda Institute of Algal Technology (VIAT), Kolkata	Green algae	Productivity of open pond micro algae production for algal oil	[28]
12	Vivekananda Institute of Algal Technology (VIAT), Rajasthan	Desmococcus olivaceous	Pulsed magnetic field (PMF) can be suitably integrated with the existing mass cultivation technology to enhance the bio-fuel quality of algal oil	[29]

3. Cultivation of Microalgae

The following methods are used for the cultivation of microalgae:

3.1. Open Pond Culture

There are four main types of open ponds: Raceway, Circular, Inclined, and Unmixed. Raceway pond is most commonly used for algae culture. Open pond are only suitable for a small number of algae species that can tolerate extreme environmental conditions to the exclusion of most other algae species. These species include fast grower, such as chlorella and species that require highly selective environmental, such as spirulina and dunaliella.

3.1.1. Raceway Ponds

It is widely use for the commercial cultivation of spirulina, haematococcus and dunaliella. These ponds utilize paddle wheel, which mix and circulate the biomass. It is a closed loop of rectangular grid with recirculation channel. Its productivity is 14-50 g/m2/d. its productivity can be increased by improving the CO2 mass transfer [31]. The astaxanthin content can be increased by two stage growth process [32].

3.1.2. Unmixed ponds

It is generally use for the culture of dunaliella salina. These ponds have low productivity of less than 1 g/m2/d [14]. These ponds are unsuitable for most of the algal species [33].

3.1.3. Circular Ponds

These ponds have high productivity as 21 g/m2/d [34]. Higher algal growth rates can be achieved by adding organic carbon. The logic of the organic addition is to support the respiration process in the dark or to support the algal cell growth at the bottom of the pond where there is less exposure to sunlight. This pond is mainly use for production of chlorella. These ponds use a rotating arm for production and mixing.

3.1.4. Inclined pond

These ponds consist of slightly inclined shallow trays, over which a thin layer of algae flow to the bottom where the culture is collected and return to the top. The productivity of these ponds is 31 g/m2/d [33].

3.2. Bioreactors (PBR)

The photo bioreactor (PBRs) is capable to overcome the problems associated with open ponds system. These include contamination, uncontrollable, environments, evaporation, limited species suitability, low volumetric productivity and the need of large area needed. They can be located indoors and provided with artificial light or natural light with light connection and distribution system and outdoors to use sun light directly. Photo bioreactors are mainly of four types: (1) Tubular bioreactor (2) Vertical bubble column or air lifter (3) Helical Photo bioreactor (4) Flat plate PBRs

3.2.1. Tubular PBRs

These system include glass and plastic tubes with gas exchange vessels for the addition of CO2 and the out gassing of O2 and a recirculation pump for mixing. It is widely used due to high surface to volume ratios, low shear forces, low cost, absence of wall growth, high efficiency of CO2 use efficiency and the ability to use sunlight. It can be use individually or arranged parallel for better CO2 consumption [35]. A photo bioreactor is typically operated as a continuous culture during daylight [36].

3.2.2. Vertical bubble columns or airlift reactors

These cylindrical PBRs have gas bubbles introduced at the bottom of the column and may be simple bubble, split cylinder airlift and draft tube airlift. this system have higher aerial productive and volumetric productivity than tubular PBRs. An aerial productivity of 93 g/m2/d (Corresponding to a volumetric productivity of 0.64 g/l/d) was reported for P.tricornutum grown in bubble column PBR [37].

3.2.3. Helical PBRs

This system composed of parallel sets of flexible translucent tube coiled helically around a cylindrically mesh frame. Gas exchange is accomplished via an incorporated gas exchange system at the top of a unit and a heat exchange system may be included for temperature control. High productivity up to 113.7 g/m2/d has been reported [38].

3.2.4. Flat plate PBRs

This system made of thin rectangular translucent boxes, which are open at one end and may have ribs running vertically from bottom to top. Aeration and mixing are provided via a perforated tube running along the entire bottom of the FBR [39]. Productivity up to 1.09 g/m2/d has been reported with spirulina platensis [38].

3.3.

This is another technique for cultivation of microalgae. Two types of fermenter method are given as Heterotrophic and Mixotrophic. These are

3.3.1. Heterotrophic

While most algae grow phototrophically, some algae are capable of grow heterotrophically using organic substrates as sole carbon and energy sources. This mode of algae cultivation is well establishes and has several advantages over phototropic modes of growth. These include the large, existing fermentation technology knowledge base, high degree of process control for consistent, reproducible production, the elimination of light requirement, the independence from weather and climate condition, lower harvesting costs, sufficient oxygen is required for the catabolism of the organic substrate in heterotrophic culture of algae, hence O2 supply is often the single most limiting factor preventing high cell concentration and high growth rate [40, 43].

3.3.2. Mixotrophic

This method is nutritional mode in which photo assimilation CO2 and the oxidative catabolism of organic carbon sources precede simultaneously, therefore offering the potential of greatly increased productivity. For species which use both light energy and chemical substrate, this mode of cultivation offers a superior alternative to phototrophic and heterotrophic growth as both biomass and productivity increases. Productivity as high as 127 g/m2/d (day time) and 79 g/m2/d (night time) has been reported [41,42,43] Table 3 shows a comparison between all the available method for cultivation.

The comparison in table 4 shows that Photo bioreactor (PBR) is most suitable method for algae cultivation is as it has several merits like High surface to volume ratio, High efficiency of CO2 conversion, ability for better CO2 consumption, medium operating cost, less risk of contamination over the other systems.

Table 4. Comparison of Raceway, photo bioreactor and fermenters [43]

S.No	Parameter	Raceway ponds	Photo bioreactor	Fermenters
1	Cell density in culture	Low	Medium	High
2	Limiting factor for growth	Light	Light	Oxygen
3	Culture volume necessary to harvest unit weight of cells	High	Medium	Low
4	Surface area to volume ratio	High	Very high	Not applicable
5	Control of parameters	Low	Medium	Very high

S.No	Parameter	Raceway ponds	Photo bioreactor	Fermenters
6	Construction cost per unit volume of algae produced	Medium	High	Low
7	Operating costs	Medium	High	Low
8	Technology available	Readily available	Under development	Readily available
9	Risk of contamination	High	Medium	Low
10	Evaporative water losses	High	High	Low
11	Weather dependence	High	Medium	Low
12	Maintenance	Easy	Difficult	Require specialized maintenance
13	Susceptibility to overheating	Low	High	N/A
14	Susceptibility to excessive O_2 level	Low	High	N/A
15	Ease of cleaning	Very easy	Difficult	Difficult
16	Ease of scale up	High	Variable	High
17	Land requirement	High	Variable	Low
18	Suitability to different species	Low	High	Low

Table 5. Merits and Demerits of Photobioreactor [44]

S.No.	Merit	Demerits
1	High surface to volume ratios	Large land requirement
2	High efficiency of CO_2 use efficiency	evaporation of water
3	Low shear forces	Contamination of the cultures and low overall photosynthetic efficiency
4	Absence of wall growth	High capital
5	Ability to use sun light	High operating costs
6	It can be used individually or arranged parallel for better CO2 consumption	Design of a photo bioreactor is more complicated compared to other culture systems

4. Harvesting Techniques

Algae can be harvested by using Flocculation, Centrifugation, Direct filteration, Ultrasound method, Positively charged surface. Due to the microscopic size of the microalgal cells (2-200μm), recovery of microalgal biomass is very difficult [45]. Approximately 20-30% of the production cost is incurred in the biomass harvesting [46].

4.1.

A process of aggregating the microalgal cells to promote the cell size and hence ease separation, start with the addition of a material (a flocculant) into the medium, causing them to aggregate. Flocculants with higher molecular weights are generally more effective. By this process total biomass recovery is 20-30% [47]. The most effective flocculants are polymers, either natural or synthetic. Flocculation can be induced in many ways:

4.1.1. Chemical Flocculation (Inorganic chemicals)

Inorganic flocculants (ex: Aluminium sulphate Al2(SO)3 ferric sulphate Fe2(SO4)3 , ferric chloride FeCl3, Lime Ca(OH)2) neutralize the negative charge surface of the cells become easier to harvest. However inorganic flocculants have disadvantages, such as a large concentration of inorganic flocculants is needed to cause solid-liquid separation of the microalgae, thereby producing a large quantity of sludge, The process is highly sensitive to pH level, Although some coagulants may work for some microalgae species, they do not work for others, The end product is contaminated by the added aluminum or iron salts [48].

4.1.2. Chemical Flocculation (Organic chemicals)

Organic flocculants (such as okra mucilage, chitosan, modified cationic chitosan-polyacrylamide, Greenfloc 120, combination of starch and chitosan) are use for harvesting algae from water. Organic flocculants have an advantage over inorganic flocculants with regard to the dose used to flocculate the particle. the total dosage varies from 0.2 to 0.4 g/l [34].

4.1.3. Microbial Flocculation

The microbe was feed with an organic substrate such as crude glycerol for harvesting algae. In this method, the microalgae cells will not damaged and the lipid composition is remaining steady. It can be reuse to minimise the demand of nutrients, water, carbon substrates. These experiments (0.1 g L−1) are still high in comparison to the dry mass concentration of the microalgal suspension, which is in the order of 0.5 g L−1. Therefore, further research is required to reduce the level of substrate and to minimise the mixing energy required for this process [39].

4.1.4. Electro Flocculation

In this method a electrically charge particle move in an electric field in which active coagulant species are produced by oxidation of a metal anode. This technique consume less energy, easy to control, not contaminate with toxic flocculants and algae separation efficiency is greater than 90%.this technique consume very little energy compare to other conventional harvesting technique. This method is easy to control [40].

4.2.

This method is preferred for harvesting of microalgal biomass, especially for producing extended shelf-life concentrates for aquaculture. the exposure of microalgal cells to high gravitational and shear forces can damage cell structure. In addition, processing a large amount of culture using centrifugation is time consuming and costly [48].

4.3.

In this process the microalgal biomass is directly using a microbial membrane that only allows algal cells to pass through. This technique requires backwashing to maintain the efficiency of the membrane filter and is time consuming [34].

4.4. Method

In ultrasound method the microalgal cells experience a force that drives them into the planes of pressure nodes when they are exposed to an ultrasonic standing wave. When the field is switched off, the aggregated cells settle rapidly because of the gravitational forces [49].

4.5. Charged Surface

In this method positively charged surface is used for harvesting. Positively charges material acts as a magnet to attract and aggregate microalgal cells for harvesting because microalgal cells are naturally negatively charged [34].

The flocculation is reported as the most promising method for algae harvesting. The flocculants uses in this method are polymers having higher molecular weights that can adsorb several particles at once.

5. Extraction of Oil

There are various methods to extract the oil from algae among them there are four method are well known for extraction mechanical press, Solvent extraction, Supercritical fluid extraction and Ultrasonic assisted

5.1. Mechanical Press

In this method microalgal biomass is subjected to high pressure resulted ruptures cells wells and release the oil. This method is easy to use and more importantly no solvent is required. In this methods, extract a large percentage (70-75%) of the oils out of algae biomass. [34, 50].

5.2. Solvent Extraction

Algal oil can be extracted using chemicals. Organic solvents (such as benzene, cyclohexane, hexane, acetone and chloroform) mixed with microalgae biomass, they degrade microalgal cell walls and extract the oil because oil has a high solubility in organic solvents. Solvents used in this methods are relatively inexpensive, result are reproducible and Solvent is recycled. The oil extracts by this method is 60-70 % [34, 51].

5.3. Supercritical Fluid Extraction

This method is more efficient than traditional solvent separation methods. Supercritical fluids have increased solvating power when they are raised above their critical temperature and pressure points. it produces highly purified extracts that are free of potentially harmful solvent residues, extraction and separation are quick, as well as safe for thermally sensitive products. This can extract almost 100% of the oils all by itself. In the supercritical fluid carbon dioxide (CO2) extraction, CO2 is liquefied under pressure and heated to the point that it has the properties of both a liquid and gas. This liquefied fluid then acts as the solvent in extracting the oil [34, 52-53].

5.4. Ultrasonic-Assisted Extraction

This method based on Cavitation. Cavitation occurs when vapour bubbles of a liquid form in an area where pressure of the liquid is lower than its vapour pressure. These bubbles grow when pressure is negative and compress under positive pressure, which causes a violent collapse of the bubbles. If bubbles collapse near cell walls, damage can occur and the cell contents are released. This have advantage over other extraction method such as extraction time is reduced, reduced solvent consumption, greater penetration of solvent into cellular materials, improved release of cell contents into bulk medium. This can extract almost 76-77% of the oils all by itself [34].

Table 6. Comparison of various extraction processes

Extraction method	Basic principle	Advantages	Yields (%)	Disadvantages	Ref.
Mechanical Press	In mechanical press the microalgal biomass is subjecting to high pressure which ruptures cell wells and release the oil	Easy to use, no solvent involved	70-75	Large amount of sample required, recovery rate is slow, easy to use	[34,50]
Solvent extraction	Organic solvents(such as benzene, cyclohexane, hexane, acetone and chloroform) mixed with microalgae biomass, they degrade microalgal cell walls and extract the oil because oil has a high solubility in organic solvents	Solvents used are relatively inexpensive, result are reproducible, Solvent is recycled, time is less	60–70	Most organic solvent are highly flammable, toxic, solvent recovery is expensive, large volume of solvent is required	[51]
Supercritical fluid extraction	Supercritical fluids have increased solvating power when they are raised above their critical temperature and pressure points. it produces highly purified extracts that are free of potentially harmful solvent residues, extraction and separation are quick, as well as safe for thermally sensitive products.	Non-toxic (no organic solvent residue in extracts), green solvent, non-flammable and simple operation	100	High power consumption, expensive/difficult to scale up at this time	[52,53]
Ultrasonic-assisted	Ultrasonic-assisted extractions method based on cavitation. Cavitation occurs when vapour bubbles of a liquid form in an area where pressure of the liquid is lower than its vapour pressure. These bubbles grow when pressure is negative and compress under positive pressure, which causes a violent collapse of the bubbles. If bubbles collapse near cell walls, damage can occur and the cell contents are released	Reduced extraction time, reduced solvent consumption, greater penetration of solvent into cellular materials, improved release of cell contents into bulk medium	76-77	High power consumption, difficult to scale up	[34]

It is clear from the above table that out of the methods discussed, solvent extraction and supercritical methods are superior oil extraction method when oil yields and other factors are taken into consideration.

Table 7. Extraction of oil from microalgal biomass [54]

Solvent extraction	Supercritical CO_2 extraction
Presence of solvent is inevitable, residual solvent concentration (usually in the order of ppm) depends on the solvent used	Procedure is completely free of solvents and thus extracts are very pure
Heavy metal contamination is also unavoidable and depends on the solvent, solvent recycling procedure, source of raw material and what the machinery parts are made from	Free of heavy metals, not extracted, even if they are present in the raw material. There are no heavy metal present in CO_2 or the equipment
Inorganic salt content is also difficult to avoid	Free of inorganic salts
Solvents have poor selectivity, during solvent removal, polar substance form polymers which lead to discolouration of the extract and poor flow characteristic	CO_2 is highly selective, so there is no change of polar substance forming polymers
Both polar and non polar colour are extracted	Only non-polar colours get extracted
Solvent removal requires extra unit operations, which results in higher cost and lower recoveries	No extra unit operations required and yield is very high

The above table shows the various advantages and disadvantages of both the extraction methods. On the basis of certain factor the best method can be choose. In coming years Algae, Non edible oil like Jatropha and Pongamia can be used as future fuel in India. [55]

6. Conclusion

In this paper we have assess several method regarding the culture of algal oil and also we have gone various harvesting, extraction methods of algal oil. Out of the various

culture method like open ponds, photo bioreactor and fermenters method, the most suitable method for algae cultivation is photo bioreactor. It has several advantages over other method are high surface to volume ratio, High efficiency of CO2 conversion, ability for better CO2 consumption, medium operating cost, less risk of contamination over the other systems on the basis of harvesting Out of the methods available, the flocculation is reported as the most promising method for algae harvesting and the supercritical & solvent is most suitable for extraction of algal oil. The development of algal oil as fuel is at nascent stage in India. The research is going on in several institutes like IIT Roorkee, University of Madrass and various other institutes. So in coming future algal oil and its biodiesel will be an alternative fuel to diesel

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