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Analysis of Algae oil as a Future source of Energy in Indian Outlook

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Abstract

The fuels used for transportation are needed to substituted by biofuel from renewable sources. Low biomass and requirement of agriculture land for cultivation restricts to use non edible, edible, unwanted cooking wastes as bio fuel. The Microalgae seem to be the only source of renewable bio fuel, which is capable of meeting the global energy demands. Microalgae utilizes CO2 and sun light for their growth. Microalgae produces greater amount of oil as compared to other crops. This paper provides the appropriate culture method, harvesting method and optimum oil extraction method. This paper shows the current status of work done by several agencies and organizations in the field of algal oil development in India.

Keywords: *Harvesting Method, Microalgae, Cultivation, Engine, Biodiesel, Extraction, Fuel.*

1.Introduction

The development in the energy production will definitely contribute to the growth of economy and is considered to be of significant for country growth. For this to happen every sector of Indian economy-agriculture, transport sector and domestic needs input of energy [3]. These plans were implemented since India got independence, but these plans required greater amount of energy for this development. Energy became the basic requirement for all purposes, for example cooking, transport, industries etc. As a result, the consumption of energy have steadily increased in all forms over the country [1]. This energy consumption growth increase resulted in the country becoming increasingly dependent on fossil fuels in many cases such as oil, coal, and Natural gas. The increasing prices of oil and gas and their potential shortage in near future encouraged to concern about the security of energy supply required to sustain the country economic growth. Greater utilization of fossil fuels also causes several environmental problems both globally and locally. As per the Rigzone website survey, India ranked fourth and it is considered to be the fourth largest consumer of primary energy. The consumption of crude oil in India was of 168.13 MT for the year 2010-2011 and 183.79 MT for the year 2012-2013. One thing to make notice is that 80% of this production was met by the import [1]. An alternate to non-renewable diesel, Biodiesel fuel has achieved a significant attention in the country as a renewable & biodegradable fuel over the decade. Biodiesel normally comprised of monoalkylester of long chain fatty acids derived from animal fats and vegetable waste or oils. The production or extraction of biodiesel from edible oil resources is almost impossible and it cannot be considered as a primary need to meet the demand of edible oil which is imported already in firm [4]. Nearly 43% of edible oil is imported for the purpose of catering several domestic needs. Some of the most abundant non edible oil sorces are mahua, sal, neem, jatropha and pongamia. Based on the broad and extensive research, jatropha and pongamia have been considered as the potential feed stocks for biodiesel production on the ecperiments. The land requirement, growth rate and cost of cultivation of jatropha, pongamia is very low that restrict us to use these kind of non edible feed stocks [3]. Currently microalgae is the focus and has many possibility as future source of biodiesel. The productivities of Algal can be twenty times that of oilseed crops (Jatropha, pongamia) on a per hectare basis. Therefore, algal productivity is considered a more viable alternative. In addition, microalgae have faster growth rates than the highly saline waters plants that are inappropriate for agriculture. They use a greater fraction of solar energy(light) making them more effective solar to chemical energy converters [2-7]. Moreover, microalgae have greater photosynthetic efficiency than the terrestrial plants. And also they require little simple nutrients supply for their growth.Alagal lipid content on a dry cellular weight basis usually varies from 20% to 40%, despite certain algal variety possess an higher lipid content of 85%. In addition, microalgal stains have the ability to triglycerides 25-230 times higher than many terrestrial plants [5]. Triglycerides can be converted immediately to biodiesel by the transesterification process. The microalgal biomass transportation cost is comparatively low than trees, crops and shrubs. When sunflower is used as a potential feedstock for the production of biodiesel, microalgae is significant in its yield [6].

Table 1. Comparison of oil yield and land area requirement for some of the oil crops.

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

Table 2. Oil Content by percent in Some of the Microalgae

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

2. Mircoalgae

Microalgae is a single-cell microscopic organisms that are commonly found in marine and fresh water environment. Microalgae are at the bottom of the food chains. They are the eldest organisms living in the planet of earth. There are more than 40000 microalgae species are available according to the analysis, but only 30000 are found and analyzed [29]. They are called thallophytes (plants which lack stems, leaves, roots but use their cholorphyll as primitive pigment for photosynthesis).Microalgae always lack a sterile covering of cells and they are considered to be the simplest cellular structure. They perform similar to that of higher plants in case photosynthesis mechanism and converts the solar energy effectively. Moreover,they access to water, nutrients, Co2 because they are suspended in aqueous solution all time. They are classified based n their color generally [7]. The present system of classification is based on i) chemical nature of storage products ii) Pigment kind iii) cell wall constituents [28].

2.1 The advantages of culturing microalgae are,

- lage are considered to be a most efficient biological system to harvest solar energy and produce organic compounds utilizing solar energy.
- They have no vascular, lacking many complex organs for the reproduction process.
- Many of the species of the algae are induced for the production of valuable compounds such as carbohydrates, proteins, pigments and lipids.
- Algae undergoes simple cell division cycle.
- Microalgae production can be done using brackish or sea water.

3. Cultivation of Microalgae & its methods

- These are the list of methods are used for the cultivation of microalgae :

3.1. Open Pond Culture

- The four major types of open ponds are Unmixed, Raceway, Inclined and Circular. Raceway pond method is the most commonly used for the culture of algae. Open pond methods are suitable only for small number of algae species which are capable to tolerate extreme environmental situations to the exclusion of major other algae species varieties [21]. These species has ability of faster development like chlorella and the species which require greater selective environmental like, dunaliella and spirulina.

3.1.1. Raceway Ponds

This method is greatly used for commercial cultivation of haematococcus, spirulina and dunaliella. Raceway ponds use paddle wheel, that mixes and circulates the biomass. This is a rectangular grid with recirculation channel with an closed loop on its side. Its productivity range is 14-50 g/m2/d and its productivity are improved by increasing the CO_2 mass transfer [11]. Also the astaxanthin composition can be increased by dual stage growth method [26].

Table 3. R& D Work Status for 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]

3.1.2. Unmixed ponds

This method is normally used for the culture of dunaliella salina. Unmixed ponds have very low productivity and it is less than 1 g/m2/d [14]. They are unsuitable for many of the algal species [30].

3.1.3. Circular Ponds

Circular ponds normally have high productivity range of 21 g/m2/d [24]. Higher amount of algal growth rates can be rendered by addition of organic carbon. The actual purpose of the organic addition is to assist respiration process in dark and to assist the algal cell growth rate at the bottom part of the pond, which is less exposed to sunlight. This pond is especially used for the production of chlorella. Circular ponds usually consists of a rotating arm used for mixing and production purposes [9].

3.1.4. Inclined pond

Inclined ponds normally consist of a inclined shallow trays and a thin layer of algae is allowed to flow to the bottom of the pond. The culture is collected and allowed to return to the top of pond. The total productivity of these ponds will be 31 g/m2/d [13].

3.2. Bioreactors (PBR)

The PhotoBioreactors(PBRs) has the ability to overcome the problems related with the open pond setup. PBRs include qualities like contamination, environments, uncontrollable, evaporation, low volumetric productivity, limited species suitability and the requirement of large area needed for culture. These can also be located at indoors with the provided artificial or natural light with a light distribution and connection systems [11]. And outdoors utilize sun light directly. PBRs are classified into four types: (1) Tubular bioreactor (2) Vertical bubble column or air lifter (3) Helical Photo bioreactor (4) Flat plate PBRs [12].

3.2.1. Tubular PBRs

These PBRs consists of plastic and glass tubes with a gas

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exchange vessels for the purpose of the addition of carbon di oxide and it includes exit gassing for O_2, a recirculation pump for purpose of mixing. It is mainly preferred due to its high surface to volume ratios, low cost and shear forces, wall growth absence, high efficiency of CO_2, and its capability to utilize sunlight. Tubular PBRs can be used individually or in an array for the optimal CO_2 consumption [25]. A Photo Bioreactor is usually operated as a continuous culture cultured during the daylight [17].

3.2.2. Vertical bubble columns or airlift reactors

This PBRs have gas bubbles injected to the bottom of the column [19]. Bubble may be simple bubble or draft tube airlift. This air craft reactors have greater aerial and volumetric productivity than the tubular PBRs previously discussed. An aerial productivity of quantity (93 g/m2/d) was the analyzed and reported value for P.tricornutum grown aircraft reactors [17].

3.2.3. Helical PBRs

Helical PBRs actually composed of sets of flexible translucent tube in parallel and is coiled helically in a cylindrically mesh frame. Gas exchange is achieved through an incorporated gas exchange system placed at top of a unit [21]. A heat exchange system introduced for the temperature control. High productivity with max range of 113.7 g/m2/d has been achieved and reported [18].

3.2.4. Flat plate PBRs

Flat plate PBRs usually made of thin rectangular translucent boxes having open at one end and have ribs that are running vertically from down to top. Mixing and aeration are achieved through a perforated tube passing along the entire bottom of the FBR [9]. Productivity up to 1.09 g/m2/d was achieved and reported with spirulina platensis through conducted experiments [18].

Table 4.Comparison of Raceway Ponds, Fermenters and Photobioreactors.

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. Demerits and Merits of PBRs

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 are produced by using methods like Flocculation, Direct filteration, Centrifugation, Ultrasound Technique, Positively charged surface. Because of its microscopic size, microalgal cells of size (2-200µm) is difficult for the recovery of microalgal biomass [23]. Approximately 20-30% of the production cost is incurred in the biomass harvesting [26].

*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. Using Flocculants are more effective that has high molecular weights. By this process total biomass recovery is 20-30% [27]. 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 For example: Aluminium sulphate $Al_2(SO)_3$, ferric chloride $FeCl_3$, ferric sulphate $Fe_2(SO4)_3$, Lime Ca(OH)2) neutralize the negative charge on surface of cells and make them easier to harvest [20]. However, inorganic flocculants have some disadvantages like huge concentration of inorganic flocculants is required to cause solid-liquid discretion of the microalgae, thus producing a large amount of sludge, The technique is highly sensitive to pH level, Despite some coagulants may work for few microalgae species, they do not work for others, The final product is contaminated by the added Al or iron salts [28].

4.1.2. Chemical Flocculation (Organic chemicals)

Some of the organic flocculants like okra mucilage, modified cationic chitosan-polyacrylamide, chitosan, Greenfloc 120 and the combination of starch and chitosan are use for the purpose of harvesting algae from water. Organic flocculants considered to have advantage over the inorganic flocculants with regard to the dose used in order to flocculate the particle. The total amount of dosage varies from 0.2 to 0.4 g/l [14].

4.1.3. Microbial Flocculation

The microbe was feed with an organic substrate such as crude glycerol for harvesting algae. In this method, there is no damage for microalgae cells and the lipid composition is remaining steady [10]. It can be reuse to minimise the demand of H_2o, nutrients and carbon substrates. These experiments (0.1 g L−1) are still high when compared to the dry mass concentration of the microalgal suspension, which is in the order of 0.5 g L−1. Thus, further research is required to reduce the level of substrate and to reduce the mixing energy required for this process [29].

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 [10].

4.2. This method is normally used for harvesting of microalgal biomass, producing extended shelf-life concentrates for an aquaculture. The high gravitational and shear forces to microalgal cells causes damage to cell structure. Moreover, processing a huge amount of culture using centrifugation consumes lot of time[18].

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 [27-30].

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 [12].

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 [24].

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 [13].

5. Extraction Process

There are several techniques to extract oil from the algae. Among, there are four methods that 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 related to high pressure resulting in ruptures cells wells & it releases the oil. This technique is easy to implement and more importantly solvent is not required. This method extracts a large percentage (70-75%) of oils out of the algae biomass.

5.2. Solvent Extraction

Algal oil is used for extracting by using the chemicals. Organic solvents like benzene, hexane, cyclohexane, chloroform, acetone is mixed with microalgae biomass, they decompose microalgal cell walls and extracts oil because oil has greater solubility in an organic solvents. Solvents used are of relatively inexpensive and their results are reproducible and recycled [25]. The oil extracts to an amount of 60-70 %.

5.3. Supercritical Fluid Extraction

This method is very efficient than the previously followed traditional solvent separation techniques. Supercritical fluids are tend to be increased solvating power when it is raised above its critical temperature and pressure. They produces a more purified extracts which are free of harmful solvent residues, separation and extraction will be quick, as well as safe [19]. They can extract almost 100% of its oils all by itself. While in supercritical fluid carbon dioxide (CO_2) extraction, CO_2 is allowed to be liquefied under pressure and it is heated to the point, which has the properties of liquid and gas [18]. Then the liquefied fluid acts as the solvent in the extraction of the oil.

5.4. Ultrasonic-Assisted Extraction

This technique is always based on the Cavitation method. This process occurs when the vapour bubbles of a fluid form in a particular area, if the pressure of the liquid is below than its vapour pressure. These bubbles increases, when pressure maintained negative and compressed under the positive pressure, that causes a violent collapse of these bubbles. When bubbles collapses near the cell walls, damage may occur and cell contents are released out[8-12]. This process have advantage over the other extraction method. Some of the adavantages are, extraction time is reduced, solvent consumption will be reduced, penetration of solvent into cellular materials will be greater, increased release of cell contents into the bulk medium. They are able to extract almost 76-77% of the oils by itself [4].

Table 6. Comparison of several Extraction Process and its Yields.

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]

From the above it is clear that out of the methods discussed, solvent extraction and supercritical methods are considered to be of superior oil extraction method when oil yields and several factors are taken into an account.

Table 7. Extraction of Oil from the Microalgal Biomasses

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 data in the table depicts the various advantages and disadvantages of the both extraction methods. Based on certain factors the best method has to be selected. In coming years Algae and other non-edible oil like Jatropha, Pongamia and waste cooking oil can be used as future fuel sources in India.

6.Conclusion

In this paper, we have assessed several techniques and methods for the culture of algal oil and in addition, we have experimented several harvesting and extraction methods of algal oil. Of the various culture method like open ponds, fermenters methods and photo bioreactor, the photo-bioreactor method is considered to have greater adavantages than the other methods. Using this method have several merits like high surface to volume ratio, higher efficiency in CO_2 conversion, able to consume better, average operation cost and it possess less contamination as compare to other systems. Of all the techniques available, Flocculation is considered as the most promising technique for algae harvesting and in addition supercritical and solvent is used for extraction of algae oil. The development of algal oil is not developed across India and it is nascent. Some of institutes are conducting research are Anna University, IIT Roorkee, IIT Bombay and SRM University. So, in future there is possibility of diesel being replaced by algae oil and its biodiesel.

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