A Comprehensive Overview on Various Method of Harvesting Microalgae According to Indian Perspective

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***Abstract--* The global demand of fossil fuel is increasing day by day due to urbanization, industrialization and increasing global population. Moreover, worldwide reserve of fossil fuel is vanishing at an alarming rate. Concentrating on the limited stock of fossil fuel, several effort have been started to search for sustainable renewable bio fuels like bio ethanol and biodiesel. Biodiesel extracted from the microalgae is an most promising source to cope up the global demand of fossil fuels. One of the major problems associated with the conversion of algae into biodiesel is the harvesting of algae. Harvesting of algae can be carried out by number of methods such as; sedimentation, flocculation, flotation, centrifugation and filtration or a combination of any of these. This paper discloses various method of harvesting microalgae from a aqueous solution for the production of biodiesel. Among the various method of harvesting, floatation is the most promising method for harvesting microalgae.**

***Keyword- Microalgae, Biodiesel, Harvesting, Flocculation, Centrifugation, Flotation, Filtration*.**

I. INTRODUCTION

Fossil fuel primarily consists of hydrocarbon. Fossil fuel extraction from the earth is more expensive and dangerous. Moreover, worldwide reserve of fossil fuel is vanishing at an alarming rate. Cost also accumulates due to the transportation and processing required to convert fossil fuel into usable fuel such as gasoline and jet fuel [1]. India's growing demand for petroleum-based fuels associated with its growing economy and population presents challenges for the country's energy security given that it imports most of its crude oil from unstable regions in the world. This and other considerations, such as opportunities for rural development and job creation, have led to a search for alternative, domestically produced fuel sources [2]. Due to forces such as climate change, the instability of petroleum prices, and technological advancements, biofuels are being considered as a viable energy alternative. Biofuels made from food source have proven controversial due to the fluctuating costs of feedstocks, the adverse environment impact presented by those feedstocks, and their effect on food prices and world hunger [3]. Thus it is clear that, biofuels made from the food source will not cope up the growing demand of India's fuel and power generation challenges.

Research and development had identified that algae is one of the most promising alternative source for producing biodiesel due to its high production potential. Industrial production of algae suitable for producing renewable oil require large scale growth process using selected high lipid containing microalgae strain, recovery of produced biomass from dilute solutions, separation of desired product from the biomass and various purification steps[4] .

Harvesting microalgae is one of the most challenging tasks. Harvesting of algae from water or other liquids is currently a difficult process due to the physical properties and nature of algae [5]. Major problem associated with the microalgae are its size, tendency to grow as single cells and low density. Thus the main objective of the present paper is to provide a brief overview on various method of harvesting a microalgae from a aqueous environment.

II. ROADMAP FOR CONVERTING MICROALGAE INTO BIODIESEL

Conversion of microalgae into biodiesel compromises of 4 stage, including algae cultivation, biomass harvesting, oil extraction and oil and residue conversion. Each of the first four stages is further broken down into basic, individual, or multiple processes to explain the primary components of algal biofuel production that may have positive or negative environmental externalities [6].

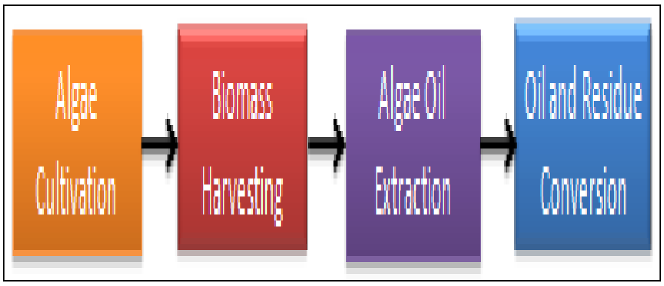

Fig. 1. Stage for converting Microalgae into Bio Diesel

Algae to biodiesel production stages are summarizes as follow:

A. Algae Cultivation

Algae grow more faster than food crops and can produce hundreds of time more oil per unit area then conventional crops such as rapeseed, palms, soya bean or jatropha[7] . In order to flourish, algae need water, carbon dioxide, and essential nutrients (sulphur, potassium, metal etc) which are collectively referred to as the culture medium; algae cultivation facilities need land or other area to occupy; and, in most cases, algae need light to drive photosynthesis [8]. In general, there are two types of algae culture systems: open culture systems and closed culture systems. Open culture systems are open to the atmosphere. They have the advantage of being relatively inexpensive to construct. However, open culture systems are subject to atmospheric temperature fluctuations, are susceptible to contamination issues, and suffer substantial losses of water due to evaporation. In contrast, closed culture systems are closed to the atmosphere and therefore provide the advantages of a controlled environment, lower evaporative water loss, and fewer contamination issues. However, many closed culture systems require relatively complex structures and therefore have substantially higher construction and operating costs [9].

B. Biomass Harvesting

Conversion of algae in ponds, bioreactors, and off-shore systems to liquid transportation fuels requires processing steps such as harvesting, dewatering, and extraction of fuel precursors [8]. Biomass harvesting may be one of the more contaminating processes in the Production of algae-based biofuels. At this stage, algal biomass from the preceding cultivation system typically carries high water content and, in most cases, is not suited for conversion to biofuel products until it has undergone some degree of dewatering and drying. There are three systemic components of the harvesting process: biomass recovery, dewatering, and drying [6].

C. Oil Extraction

The TAGs (triacylglycerols) in micro algal cells are contained in oil droplets within the cells, and the cell wall can pose a significant barrier to removal of the oil. Extraction of algal oil probably involves three steps: 1) disruption of the cell wall, 2) separation of the oil from the remaining biomass, and 3) purification or upgrading of the oil to remove impurities [2]. Solvent extraction, supercritical fluid extraction, and ultrasonic assisted extraction are the common methods used for oil extraction. The percent yield of total available oil from the biomass will depend on the efficiency of the extraction method used [6].

D. Oil and Residue Conversion to Biofuels

Finally, the extracted TAGs need to be converted into a fuel that is compatible with the existing transportation infrastructure. This means converting the oil into diesel or aviation fuel substitutes that meet all of the relevant specifications for fuel quality. Two main pathways are being considered. The first is the conversion of the TAGs into alcohol esters (i.e., biodiesel) using conventional transesterification technology. The second is to use catalytic hydroprocessing methods to generate a renewable “green” diesel product which does not contain oxygen [2].

III. PATHWAYS FOR BIOMASS HARVESTING

Harvesting and dewatering are one of the challenging areas of current biofuel technology as microalgae have small size and low density increasing the capital cost. The difficulty is in releasing the lipids from their intracellular location in the most energy efficient and economical way possible, avoiding the use of large amounts of solvent, such as hexane, and utilizing as much of the carbon in the biomass as liquid biofuel as possible, potentially with the recovery of minor high-value products[10]. Choice of harvesting technique is dependent on characteristics of microalgae, e.g. size, density, and the value of the target products [11]. Generally, microalgae harvesting is a two stage process, involving:

i. Bulk harvesting—Aimed at separation of biomass from the bulk suspension. The concentration factors for this operation are generally 100–800 times to reach 2–7% total solid matter. This will depend on the initial biomass concentration and technologies employed, including flocculation, flotation or gravity sedimentation [11].
ii. Thickening—The aim is to concentrate the slurry through techniques such as centrifugation, filtration and ultrasonic aggregation, hence, is generally a more energy intensive step than bulk harvesting [11].

A. Flocculation

Flocculation is a process, often implemented with the help of flocculating agents or flocculants (chemicals of natural or synthetic origin), that causes the coagulation of algal cells into small clumps, known as flocks, allowing for sedimentation and easy extraction from the culture medium[6]. This is the first stage in the bulk harvesting process that is intended to aggregate the micro algal cells in order to increase the effective ‘‘particle’’ size. Flocculation is a preparatory step prior to other harvesting methods such as filtration, flotation or gravity sedimentation [11].

There are two types of flocculation, auto flocculation and, chemical flocculation. Auto flocculation occurs due to precipitation of carbonate salts with algal cells whereas in chemical flocculation chemicals (organic as well as inorganic) are added to microalgae culture to induce flocculation. Auto-flocculation does not occur in all micro-algae species and can be slow and unreliable [12]. Inorganic flocculants includes Aluminium sulphate $Al_2(SO)_3$, ferric sulphate $Fe_2(SO_4)_3$, ferric chloride $FeCl_3$, Lime $Ca(OH)_2$ whereas organic flocculants includes okra mucilage, chitosan, modified cationic chitosan-polyacrylamide, Greenfloc 120, combination of starch and chitosan.

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 [13].

The shape, size and composition of flocs can be very diverse depending on micro-algal species and flocculant. An ideal flocculant should be inexpensive, nontoxic and effective in low concentrations and it should also preferably be derived from non-fossil fuel sources, be sustainable and renewable [12]

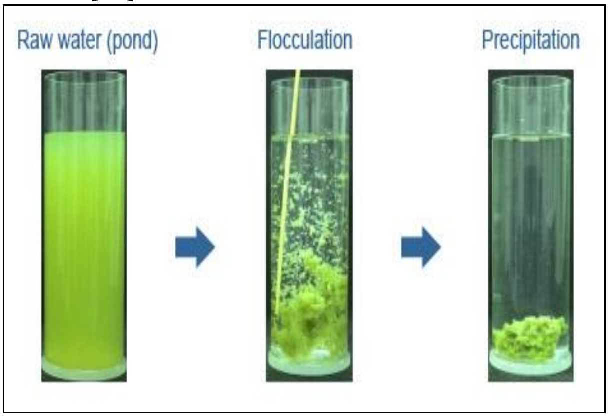

Fig. 2. Basic steps of flocculation [14]

B. Floatation

Flotation is a gravity separation process based on the attachment of air or gas bubbles to solid particles, which then' are carried to the liquid surface and accumulate as float which can be skimmed off. The success of flotation depends on the instability of the suspended particles. The lower the instability the higher the air particle contact [15]. Floatation is more beneficial and effective than sedimentation with regard to removing microalgae. Flotation can capture particle with a diameter of less than 500µm by collision between a bubble and a particle and the subsequent adhesion of the bubble and particle [16]. Flotation processes are classified according to the method of bubble production: dissolved air flotation, electrolytic flotation and dispersed air flotation [15].

Dissolved air flotation (DAF) is a process where small bubbles are generated, with a mean size of 40 µm and ranging from 10 to 100 µm [12]. Dissolved air flotation (DAF) is also known as forth flotation process. The production of fine air bubbles in the dissolved air flotation process is based on the higher solubility of air in water as pressure increases. This can be achieved in three ways: saturation at atmospheric pressure and flotation under vacuum, saturation under static head with flow upward resulting in bubble formation (micro floration) and saturation at pressures higher than atmospheric and then flotation under atmospheric three ways: saturation at atmospheric pressure and flotation under vacuum, saturation under static head with flow upward resulting in bubble formation (micro floration) and saturation at pressures higher than atmospheric and then flotation under atmospheric conditions [15]. Dissolved air flotation make use of flocculant and of highly pressurized air bubbles (heat or entrained air) to force the algal cells to cluster and float to the water surface where they can be removed by a skimming device. Unfortunately DAF although an efficient flotation option, is energy intensive due to the high pressure required [12].

Electrolytic flotation another type of flotation process in which gas bubbles are formed by electrolysis. Electrolytic flotation has been found to be effective at a bench scale on a range of micro-algae, but as with DAF it is energy intensive and not the ‘best choice for micro-algal recovery [12]. Flotation processes initially have high investment and operation cost, especially when fine bubbles are required. It has been determined that the cost of flotation is even more than centrifugation process when the cost of flocculants are consider.

C. Gravity Sedimentation

Gravity sedimentation is commonly applied for separating microalgae in water and waste water treatment. This process generally yields a wet, voluminous sludge, as a result of poor compaction and slow settling velocities [17]. Density and radius of algae cells and the induced sedimentation velocity influence the settling characteristic of suspended solids [11]. Enhanced micro algal harvesting by sedimentation can be achieved through lamella separators and sedimentation tanks. Flocculation is frequently used to increase the efficiency of gravity sedimentation. The success of solids removal by gravity settling depends highly on the density of micro algal particles. [18].

D. Centrifugation

Centrifugal processes rely on the generation of a centrifugal force which acts radially and accelerates the movement and separation of particles based on a density difference between the particle and the surrounding medium [19]. Most microalgae can be recovered from the liquid broth using centrifugation. Laboratory centrifugation tests were conducted on pond effluent at 500–1000xg and showed that about 80–90% microalgae can be recovered within 2–5 min [18]. Centrifugal recovery can be rapid, but it is energy intensive. Nevertheless, centrifugation is a preferred method of recovering algal cells, especially for producing extended shelf life concentrates for aquaculture. The recovery of the biomass in a sedimenting centrifuge depends on the settling characteristics of the cells, the residence time of the cell slurry in the centrifuge, and the settling depth [20]. Centrifugation can be used alone or as a second step to further remove water from concentrated algae collected with other methods [21]. Five basic types of centrifuges, namely disc stack centrifuges, perforated basket centrifuges, imperforated basket centrifuges, decanters (or scroll centrifuges) and hydro cyclones, as shown in Figure 3 are used [19].

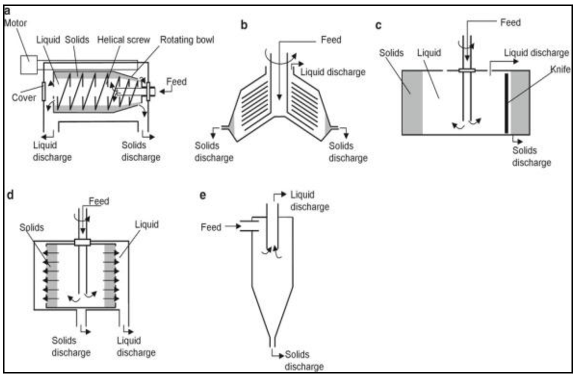

Fig. 3. Cross sectional view of a (a) decanter type centrifuge (b) Disc stacked centrifuge (c) imperforated basket centrifuge (d) perforated basket centrifuge and (e) hydro cyclone [19]

Centrifugation technologies are more energy intensive and required large initial capital investment.

E. Filtration

Filtration is a method commonly used for solid liquid separation [16]. Filtration harvests micro algal biomass through filters on which the algae accumulate forming thick algae paste and allow the liquid medium to pass through [10]. Filtration process may be continuous or discontinuous. Filtration systems can be classified as microfiltration (pore size of 0.1–10 □m), macro filtration (pore size of >10 □m), ultra filtration (pore size of 0.02–2 □m), and reverse osmosis (pore size of <0.001 □m) [10]. A schematic diagram of a filtration process is shown in Fig.4. Conventional filtration may be insufficient due for biomass recovery. Filtration aided by suction or optimal pressure net energy for relatively smaller size algal cells can be relatively sluggish, tedious and time consuming especially if large volumes of micro algal suspension are to be processed [22].

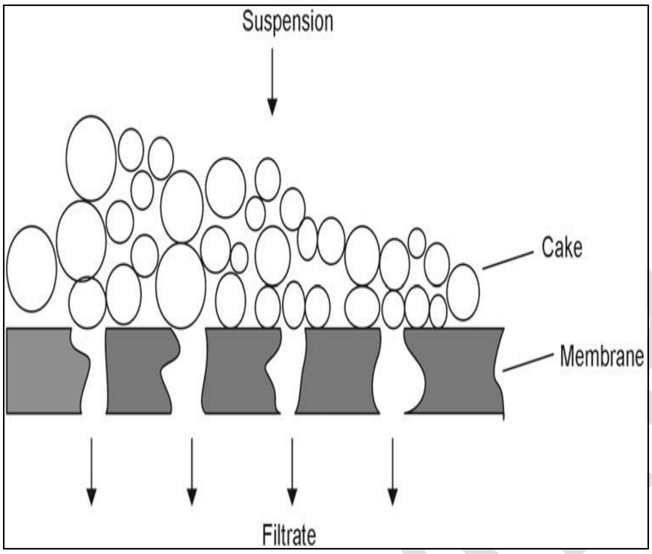

Fig. 4 Mechanism of filtration process [19]

Membrane microfiltration and ultra filtration are possible alternatives to conventional filtration for recovering algal biomass [20]. Microfiltration, or micro screening, is a basic approach to biomass recovery whereby algal cells are filtered through micro screens to be separated from the growth culture [6]. Microfiltration is suitable for fragile cells but large-scale processes for producing algal biomass do not generally use membrane filtration [20]. Ultra filtration is a possible alternative for recovery in particular of very fragile cells, but has not been generally used for microalgae and operating costs are high and maintenance costs very high [12]. One of the major problems associated with filtration is that media that are fine enough to retain the microalgae tend to bind and therefore require regular backwashes. This results in a decrease in the amount of micro algal concentrate [23]. Comparisons in terms of advantages and disadvantages of the various techniques to harvest micro-algae are given in Table 1.

Table 1
Comparison of micro algal harvesting techniques [12]

Harvesting Techniques	Advantages	Disadvantages	Dry solids output conc.' (%)
Chemical flocculation	Wide range of flocculants available, price varies although can be low cost	Removal of flocculants, chemical contamination	3–8
Flotation	Can be more rapid than sedimentation. Possibility to combine with gaseous transfer	Algal species specific. High capital and operational cost.	7
Sedimentation	Low cost, potential for use as a first stage to reduce energy input and cost of subsequent stages	Algal species specific, best suited to dense non-motile cells. Separation can be slow. Low final concentration	0.5–3
Centrifugation	Can handle most algal types with rapid efficient cell harvesting	High capital and operational costs	10-22
Filtration	Wide variety of filter and membrane types available	Highly dependent on algal species; best suited to large algal cells. Clogging or fouling an issue	2-27
Ultra filtration	Can handle delicate cells	High capital and operational costs	1.5-4

IV. CONCLUSION

The selection of particular harvesting techniques depends upon microalgae properties such algal cell size, density and the final desired product required. Centrifugation seems to be best harvesting techniques based on dry solid output concentration; yet initial investment and operation cost are high. Floatation is more beneficial and effective than sedimentation but it is algae specific species. Sedimentation and flocculation required less energy input but sedimentation process is slow moreover the recovery may be affected by chemical in flocculation process. Among the various method of harvesting, floatation is the most promising method for harvesting microalgae as higher solid concentrations can be obtained.

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