

Original Research Article

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Studies on Fresh Water Microalgae Harvesting Systems for Bio Fuel

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ABSTRACT

Microalgae are emerging as a promising source of renewable biomass for the production of biofuels and valuable chemicals. However, energy efficient cultivation and harvesting technologies are necessary to improve for making it popular and economically viable. The identified strain *Scenedesmus sp* is grown in FRP race way pond with capacity of 2500 l, developed for large scale cultivation of microalgae. Due to their small size and low concentration in the culture medium, cost-efficient harvesting of microalgae is a major challenge. In this study, various methods of harvesting were assessed viz. chemical flocculation, electrolysis, sedimentation and physical filtration methods are being evaluated. The efficiency of different harvesting processes were evaluated and economically assessed. The harvesting efficiency with ferric chloride showed harvesting efficiency 89.4 percent whereas with alum it was 88.2 percent. The use of alum for harvesting was found to be cost effective as compared to other chemical at large scale. Electro-chemical flocculation experiments were conducted in different volume size with constant voltage conditions and the minimum energy consumption was 1.18 kWh/kg. The capacity of harvesting volume has effects on energy consumption as the capacity increases the total energy consumption reduces. The lab scale study of harvesting of microalgae showed that auto flocculation using fine air bubbles followed by filtration showed more promising as compared to chemical flocculation method with a prolonged time as a constraint.

Keywords

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Introduction

The importance of microalgae and their valuable products has significantly increased in the fields of human health, food, feed and biofuels. The recovery of microalgae biomass from solution is a major challenge, largely due to the small biomass concentration relative to the volume of liquid and low biomass to liquid ratio (0.3 to 5.0 g/L) (Li, *et*

al., 2008 and Wang, *et al.*, 2008). The technology used for the recovery of microalgae biomass is considered to have a major influence on the economy of microalgae production (Danquah *et al.*, 2009 and Brennan and Owende, 2010). As yet, none of the commonly available technologies has proved economical at scale. The main harvesting techniques are centrifugation; filtration; flocculation; sedimentation; and

electrophoresis (Schenk, *et al.*, 2008 and Grima, *et al.*, 2003). Centrifugal process of harvesting of algal is the fastest and most reliable method of biomass recovery for a wide range of species but high energy intensive.

Filtration is common practice, but it depends on the size of the microalgae being harvested. The low recovery rate and long processing times makes filtration process unattractive at large scale. Likewise, flocculation is also uneconomical and most effective commercial flocculants are aluminum sulphate and some specific organic cationic polyelectrolyte flocculants (Uduman *et al.*, 2010) Gravity sedimentation is time consuming and requires large land areas for settling ponds and tanks. Electro coagulation and electro flotation makes the electrochemical oxidation of metal electrode to destabilize algae suspensions causing the cells to float. Foam flotation is a process for removing surface active chemicals from water and dewatering dilute solid liquid mixtures (Lehmonen *et al.*, 2019). Considering the limitations of different harvesting systems and importance study is initiated to evaluate the different harvesting process to develop cost effective harvesting system.

Micro algae harvesting studies

The recovery of microalgae is considered to have the most influential effect on the economy of microalgae production system (Monteiro *et al.*, 2012). The selection of harvesting technology is depends on type of cell, density & size, downstream processing and the end product (Borowitzka, 2013). The harvesting techniques which have been developed since past four decades are categorized into two i.e. i) Primarily bulk harvesting of the algae to increase the concentration by 2–7% in total suspended solids (TSS). This is achieved with the use of

flocculation, floatation or sedimentation process. ii) The secondary process followed for dewatering step of microalgae, which produces biomass up to 15–25% TSS, this is achieved with filtration or centrifugation which is energy intensive processes as compared to primary process (Olaizola, 2000 and Uduman *et al.*, 2010).

Sedimentation

Solid liquid partitioning by sedimentation is one of the simplest ways to harvest microalgae.

It separates the suspended algae cells having a cell density greater than water by gravitational settling. The operating and capital costs are low, but space requirement for settling ponds and tanks are high. The ambient conditions during harvesting such as high temperature of environments deteriorate the biomass produced due to lengthy harvesting process. Conventional sedimentation systems could make slurry concentration of between 1 to 3% TSS (Collet *et al.*, 2011). When higher solid concentrations are required, sedimentation can be adopted as a pre-concentration step combined with other technologies (Gerardo *et al.*, 2015).

Coagulation–flocculation

The coagulation flocculation is the process of aggregating single cells to larger flocs, thus overcoming the hurdle of repulsion with equi-charged particles. The chemical flocculation is carried with the use of inorganic and organic chemical substances. These chemicals are aluminum sulfate, ferric chloride and ferric sulfate in case of inorganic chemicals whereas organic derived compound are polyacrylamide or polyethylene mine. The drawback of chemical flocculants is that the efficacy is influenced by the pH, micro-

organisms characteristics, water salinity, and biomass concentration. The auto flocculation can also be achieved without use of chemicals at a high pH, typically above 9, caused by the dissolved carbon dioxide (Van Den Hende *et al.*, 2014). The pH can be varied by controlling the operating conditions such as supply of air or CO₂, which could provide a cost-effective harvesting method. The bio flocculation is a process where other micro-organisms (algae, bacteria and fungi) improve the floc forming abilities of the algae in suspension. The principles of cultivation with flocculating micro-organisms may complicate the downstream process and risks of antagonistic interactions, microbial contamination etc. in the harvested biomass (Pearsall *et al.*, 2011).

Electrolytic coagulation (also called electroflocculation) is a physical chemical technique.

The electrodes used in the process releases metal cations that induce coagulation. This process may leave residual metals in the algal concentrate and would affect the quality of byproducts (Patel *et al.*, 2013). The disadvantages of electrolytic coagulation includes, cathode fouling, rise in temperature of the medium, influence of mixing, changes in pH etc. (Gerardo *et al.*, 2015).

Electro flotation is based on the same principle as electro flocculation in which the cathode is an inactive metal and induces the formation of bubbles due to electrolysis that benefits from not requiring the chemical and only requiring electricity as an input.

Centrifugation

The recovery of biomass by centrifugation involves the use of the centrifugal force to accelerate the rate of sedimentation. The separation is based on the cell size and

density difference between the biomass and the medium. The sedimentation rate is enhanced by the high-speed rotation of the centrifuge that increases the gravity field. The recovered biomass is free from flocculants or chemicals, it can be applied to all strains of microalgae, and high recovery rate and concentrates are easily, predicatively and quickly achieved. The major disadvantage is its high energy requirements.

Flotation

The flotation uses the low density of microalgae that can float upwards much more rapidly than sediment downwards. Some microalgae naturally float due to the presence of gas vesicles; they include cyanobacteria. The flotation of cell should be of hydrophobic in nature and this could be achieved with the use of surfactants or coagulants. The attachment of air bubbles to the cells depends on many factors including size, probability of collision and adhesion. This process requires generation of micron sized bubbles with the use of dispersed air, micro flotation and froth flotation. It eliminates the requirements of high energy intensive compressor for generating bubbles and foam with the more of surfactant at low pressure spurger (Hanotu *et al.*, 2012).

Filtration

Harvesting of microalgae cells using filtration systems is based on a solid/liquid separation where a semi-permeable filter acts as a barrier. This barrier contains pores smaller than the cells being retained permitting a selective passage of water, salts, and other soluble substances. The filtration may cause fouling of membrane resulting into pore blocking, and adsorption of gel flocculants such as EOM. Membrane filtration is an effective technology for the harvesting of microalgae; in absence of chemicals which

does not complicate product extraction from the biomass and culture media. Filter press can reach solid concentrations of up to 25%, though these systems are more likely to be suitable for much bigger size or cylindrical size species (Gerardo, *et al.*, 2014). Considering advantages and constrains related to these harvesting techniques, the study was carried out.

Materials and Methods

The identified strain *Scendesmus sp* is grown in FRP race way pond developed for large scale cultivation of microalgae. The developed system has the capacity to grow the algae in 2500 litres of water media. The cultures are added in sufficient quantity i.e 5% of total volume. The nutrient was supplied in the form of urea and single super phosphate fertilizer along with the micronutrient fertilizer combination. The fertilizer concentration was maintained as per the nutrient level present in the BG-11 medium which was used for the isolation and maintenance of the microalgae culture. The algae were grown in FRP race way pond (Figure 1) for a period of 14-18 days and then harvested. The growth measurement was done by measuring the optical density of samples drawn from tank drawn at different intervals. The depth of water in FRP pond was maintained between 0.2 to 0.3 m. The circulation of culture & nutrients was maintained using paddle wheel. Fresh water algae grown in 2.5 m² pond showed a productivity of 0.94 g/L after 14 days of growth period.

Studies on Harvesting of Microalgae

Harvesting of microalgae grown in FRP pond was studied using the chemical flocculation, sedimentation and physical filtration methods. The various harvesting process and their mechanism are summarized in Table 1. These

methods are looked at vigorously because they have the potential to harvest algae with the same efficiency but varied in energy efficiency and production cost.

Chemical flocculation

The study was conducted to assess the flocculation efficiency of microalgae using different chemicals i.e. Sodium hydroxide (NaOH), Ferric Chloride (FeCl₃) and alum. The flocculation efficiency was estimated by using the following formula:

$$\text{Flocculation efficiency (\%)} = \left(1 - \frac{A}{B}\right) * 100$$

Where, A = Absorbance after flocculation

B = Absorbance before flocculation

Absorbance was measured as an optical density using UV-vis-photo spectrometer at frequency of 690 nm.

Harvesting by Electrolytic flocculation Process

The study was conducted using electrolytic process for harvesting the micro algae. This process requires the use of both physical and chemical stimuli for the effective separation of microalgae biomass. The metal ions released into the solution are metal hydroxides that contribute to the destabilization of colloid suspension and coagulate the biomass. The electrodes consisted of two flate copper metal plates with surface area of 250cm², and placed in media solution the anode and cathode were connected to the positive and negative outlet of DC power. The power is supplied by a 12 V battery during the experimentation. The current density was controlled by changing the current of the DC power supply, which was operated in the constant current mode. The electrode area was kept constant while the current was varied and the volume of the

microalgae culture was also changed to observe its flocculation and harvesting efficiency. Flocculation is achieved by the linking of the positively charged metal ion to the negatively charged microalgae cells and the movement toward the anode as a result of electrophoresis motion.

Results and Discussion

Harvesting with Sodium hydroxide

Flocculation efficiency of microalgae grown in FRP pond was studied by adding in different quantities of 0.5M NaOH solution. The efficiency was measured after 30 minute of proper mixing of chemicals. The maximum efficiency was observed to be 37.3 percent with 2.0 ml of 05M NaOH solution. The addition of NaOH increases the pH of solution up to 10.5 pH which leads to the change in the charge of algal cells and hence leading to its floc formation. The details of result are shown in Table 2.

Harvesting with Ferric chloride

The study was conducted using different concentration of ferric chloride (FeCl_3) and varying the quantity of chemicals for harvesting the algae. The study showed that with increasing concentration of FeCl_3 flocculation efficiency also increases. Microalgae culture containing no flocculent was used as control.

The flocculation efficiency of FeCl_3 sharply increased from 15.44% to 75.63% when the dosage increased from 50 ppm to 250 ppm after 30 minutes sedimentation. Therefore, the quantity of ferric chloride was also increased and conducted experiment by varying it from 0.1 to 0.25g/L. The study revealed that flocculation and harvesting efficiency increases with the quantity increases The maximum flocculation efficiency was 98.3 %

where as the harvesting efficiency was 89.4% (Table 3).

Harvesting with Alum

Alum is well known flocculant used for general purpose. It was used as flocculants in different quantities for the flocculation of micro algae. The maximum flocculation efficiency with alum was 93.6% and harvesting efficiency was 88.2% at 0.5g/L concentration of Alum (Table 3). Alum was further opted for the harvesting experiments at large scale microalgae growth conditions. Alum has also shown the comparative harvesting efficiency with ferric chloride and sodium hydroxide. Being cheaper and easily available than other flocculants, alum is the effective flocculants for further chemical harvesting experiments.

Filtration of microalgae

The filtration process was studied for harvesting the microalgae using different types of fabric filters. The air bubbling used during the growth period has shown partial flocculation. The partial flocculants coupled with filtration unit using the fabric film of 400 mesh (Fig. 2) has shown filtration effective varied from 81.6 to 83.0% (Table 4). The filtered water was observed to be suitable for recycling for microalgae growth.

Harvesting by Electrolytic flocculation Process

The energy requirement for different experimental conditions was assessed (Fig. 4). The energy requirement was found to be lowest in the highest volume size while it is highest in lower volume of microalgae samples. As the volume of the harvesting solution is increased the resistance is also increased due to the presence of higher microalgal cells. Due to increased resistance

the current has been lowered down leading to the lower energy requirement at higher volume size. The coagulation process is induced by the generation of current from a copper electrode as shown in Figure 3. The microalgal recovery efficiency was

determined based upon the decrease in optical density of the microalgal suspension. The difference in harvesting efficiency was found to be slightly vary in all the three volume samples of microalgal culture (Fig. 4).

Table.1 Harvesting methods of microalgae

S.N.	Process	Mechanism followed	Influence of algal strains on process	Solid conc. (TSS),%	Energy Input level
1	Inorganic Lime	Floc -enmeshment	Minor	8-10	High
	Alum	Floc -enmeshment and destabilization	Minor	8-10	High
	Poly-electrolytes	Floc –enmeshment, destabilization and bridging	Minor	8-10	Medium
	Bio-flocculation	Spontaneous flocculation	High	1-3	Low
2	Centrifugation	Accelerated discrete settling	Minor	> 10	High
3	Cross Flow Filtration	Membrane self cleaning	Minor	2-6	High
4	Micro straining	Fabric straining	High	2-4	Medium

Table.2 Flocculation efficiency with NaOH

S.No.	Volume of 0.5 M NaOH	Initial optical density	Optical density after flocculation	Flocculation efficiency
1.	0.1 ml	0.332	0.328	1.20
2.	0.5 ml	0.332	0.302	9.04
3.	1.0 ml	0.332	0.263	20.78
4.	2.0 ml	0.332	0.208	37.35

Table.3 Flocculation efficiency of Alum & Ferric chloride

S.N.	Concentration Flocculants g/L	Optical density before experiment	Optical density after flocculation	Flocculation efficiency (%)	Harvesting efficiency (%)
A.	Ferric Chloride				
1.	0.1	0.860	0.477	44.5	63.9
2.	0.2	0.860	0.052	93.9	88.3
3.	0.25	0.860	0.015	98.3	89.4
B.	Alum				
1.	0.25	0.860	0.279	67.6	78.7
2.	0.50	0.860	0.055	93.6	88.2
3.	0.75	0.860	0.067	92.3	87.9

Table.4 Harvesting of microalgae by filtration processes

S. No.	Materials used	Optical Density		Harvesting Efficiency (%)
		Before	After	
1	Fine cloth	0.932	0.024	97.4
2	Micro nylon filter cloth	0.932	0.015	98.4
3	Non woven Fabric cloth	0.932	0.047	94.9

Table.5 Flocculation efficiency of microalgae harvesting using alum in the race way pond

Alum concentration (g/L)	Quantity (L)	Biomass Recovery (g)	Optical density		Harvesting efficiency (%)
			Before	After	
0.5	1000	390.440	0.927	0.134	85.55

Fig.1 Cultivation of microalgae in FRP raceway pond



Fig.2 Filtration of microalgae a) Before filtration, b) After filtration using nylon 400 mesh cloth c) Filtration in the race way pond using nylon 400 mesh cloth

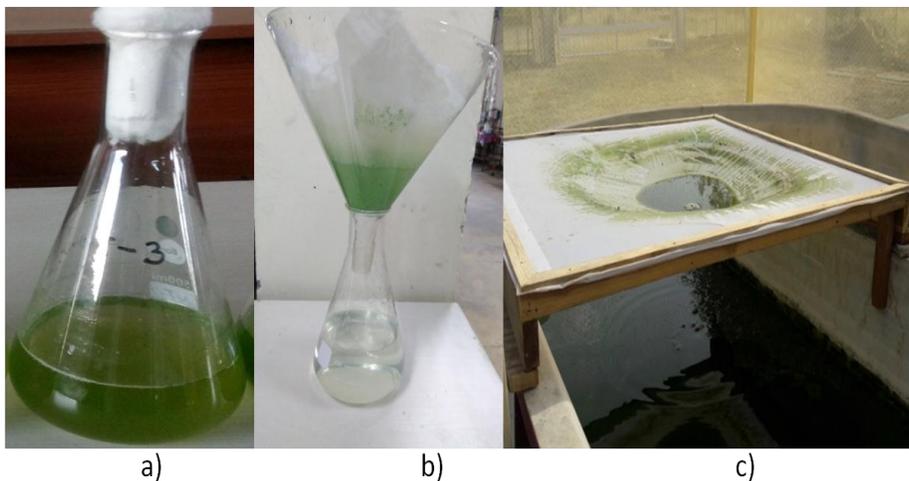
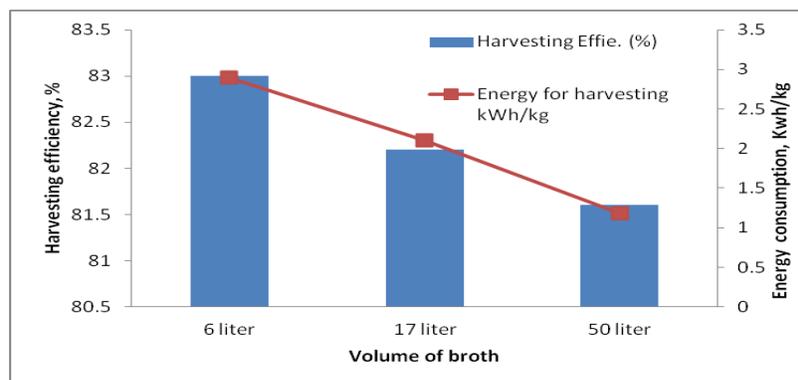


Fig.3 Electrolytic flocculation microalgae harvesting



Fig.4 Performance of electrolytic harvesting of microalgae



Harvesting of microalgae from FRP pond

The flocculation of microalgae grown FRP raceway pond was done using alum for harvesting of microalgae. The alum was added at the concentration of 0.5g/l and the harvesting efficiency of alum 85.55 percent was achieved. The productivity of 0.39 g/L achieved after growth period of 14 days is presented in Table 5.

Drying of microalgae

The slurry obtained after harvesting using flocculation and filtration process was dried to achieve moisture content of 5-10%. *Scenedesmus sp.* algae slurry was dried up to 8% moisture content in a vacuum shelf dryer at a temperature of 50–65 °C. The oven dried algae showed hygroscopic characteristic and

porous biomass structure. The open sun drying used for the slurry of microalgae had shown change in texture and color of algal biomass. A solar dryer chamber with black surface and top covered with glass plate, takes 5–6 h at temperatures 60°C to dehydrate the final algal biomass about 4–8% moisture content. The dried micro alga was analyzed for lipid content of *Scenedesmus sp.* using solvent extraction method.

In conclusion among the inorganic flocculants, ferric chloride and alum had shown the comparable flocculation efficiencies of 88.3 and 88.2 percent respectively. Alum is cost effective compared to other chemical at large scale. The initial study of harvesting of microalgae showed that auto flocculation using fine air bubbles followed by filtration showed more promising

as compared to chemical flocculation method; however it took 3 to 4 hours. The microalgae harvested using electrolytic method has shown energy consumption between 1.18 – 2.9 kWh/kg of dry microalgae biomass showing lower energy consumption at higher harvesting volumes. The lab scale electrolysis process showed contamination and hence needs further refinement in the electrolysis process for its application at large scale.

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