Review Article

Biodiesel Production from Microalgae and A Comparative Study of Bioreactors: A Scope of Replacing the Petroleum Based Fuels

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ABSTRACT

With the increasing issue of global warming, there is an urgent need for a potent substitute of fossil fuels as the usage of fuel cannot be reduced or eliminated, by any chance. The substitute should be proved to be efficient as well as economical for the consumers to enhance the rapid shifting of usage of fossil fuels to the substitute ones. There are various instances of availability of bio-fuels which can substitute fossil fuels but they don't stand to be consumer friendly with respect of cost effectiveness. For example, there have been reports of bio-fuel produced from sugarcane and various oil crops but they are too costly to substitute fossil fuels. Also, the bio fuel needs to be carbon neutral to control the alarming rate of increment in global warming. Considering the above mentioned conditions, the bio fuel from microalgae can be considered to be a potent substitute of fossil fuels in the coming future. The cost of production for the bio fuel can be reduced by using natural, freely available sources and an efficient design of low cost bio-reactor.

Keywords: Bio-fuel, fossil fuel, global warming, bio-reactor, oil crops, Microalgae.

INTRODUCTION

Petroleum derived transport-fuels causes global warming, and is also of limited availability. The scientists currently working in the green energy field, suggests that biodiesel and bioethanol can be the potent substitute for petroleum based fuels. The biodiesel and bioethanol can be produced from the agricultural crops and also from the microalgae cultures. The Biofuel and biodiesel produced by agricultural crops cannot replace the petroleum or fossil based fuel but there is a possibility of justified substitution of petroleum based fuel by the Biofuel and biodiesel obtained from microalgae cultures without adversely affecting the supply of food and other crop products. Oil palm and sugarcane are some of the productive oil crops which are not even closer to microalgae in being able to sustainably provide the necessary amounts of biodiesel. There is an immense need of carbon neutral renewable liquid fuels which can replace the petroleum derived transport fuels. This will eventually cut down the alarming rate of increase in global warming. The production of bioethanol from sugarcane and biodiesel from oil crops have already been in reports but their large scale production is not sustainable and an alternative source is in demand. The current research indicates a possibility of microalgae to be the potential and efficient alternative for the sources of biodiesel. Biodiesel from microalgae has an upper hand on the best oil producing crops by being a potential substitute of petroleum derived transport fuels without adversely impacting the supplies of food and other agricultural products. Currently bioethanol from sugarcane is the most widely used transport Biofuel and it has been demonstrated that microalgal biodiesel is the better alternative than the former.

Microalgae are the photosynthetic microbes utilizing sunlight, water and carbon dioxide to form algal biomass. The oil rich microalgae can be converted to biodiesel with the help of various technologies[1].

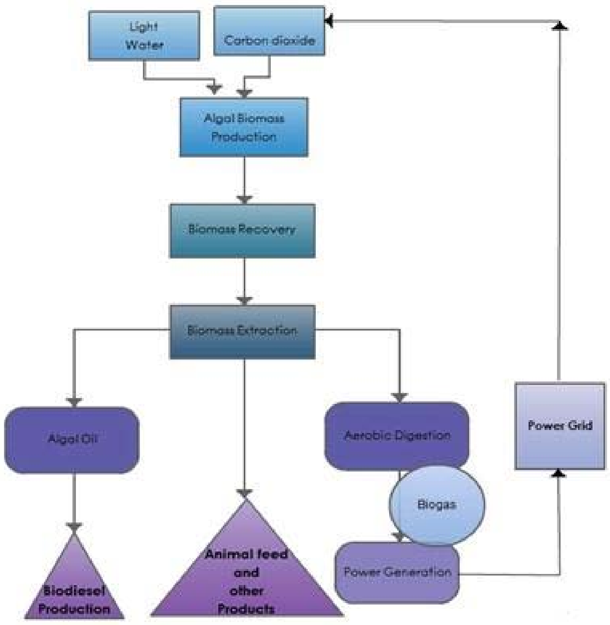

Figure 1: The flow diagram of algal Biodiesel production.

Sea water which is easily available in any coastal area, supplemented with nitrate and phosphate fertilizer, and a few other micronutrients, is commonly used for growing marine algae[2]. Microalgae are also useful in bioremediation applications and as nitrogen fixing biofertilisers[3-7].

BIODIESEL PRODUCTION

$$Triglyceride\ (Parent\ oil) + Methanol\ (alcohol) \Leftrightarrow Glycerol + Methyl\ esters\ (Bodeiesel)$$

Triglycerides are the parent oil being used in making of biodiesel. Transesterification or alcoholysis reaction in which triglycerides are reacted with methanol is carried out to produce biodiesel. Biodiesel are basically the methyl esters of fatty acid. Transesterification reaction produces biodiesel and glycerol. This is a stepwise reaction in a sequence as follows:

$$Triglyceride \xrightarrow{yields} Diglyceride \xrightarrow{yields} Monoglyceride \xrightarrow{yields} Glycerol$$

Transesterification is catalyzed by acids, alkalis and lipase enzymes[8,9]. The alkali catalyzed-transesterification reaction is 4000 times faster than the acid catalyzed reaction[10]. The reaction temperature for alkali – catalyzed reaction is kept to be 60ºC under atmospheric pressure, as boiling point of methanol is 65ºC at atmospheric pressure. With these optimum conditions, it takes 90 mins for the reaction to complete. Saponification reactions are prevented and for this oil and alcohol must be dry and minimum of free fatty acid should be there in the oil. Biodiesel is recovered by repeated washing with water to remove methanol and glycerol.

Biofuel sources

There are various sources of Biofuel, which includes many agricultural crops, oil crops, and algal species. The reported crop sources of Biofuel are namely Corn, Soybeans, Safflower, Sunflower, Rapeseed, and Oil Palm. Apart from these the micro algal source is the major and most efficient source of Biofuel, as reported by various scientists working on Biofuel production. The various microalgal strains having potential of efficient Biofuel production are *Spirulina maxima, Chlorella vulgaricus, Chlorococcum littorale, Ankistrodesmus TR-87, Botryococcus braunii, Chlorella protothecoides, Cyclotella DI-35, Dunaliella tertiolecta, Hantzschia DI-160, Nannochloris, Nannochloropsis, Nitzschia TR-114, Phaeodactylum tricornutum, Scenedesmus TR-84, Stichococcus, Tetraselmis suecica, Thalassiosira pseudonana, Crpthecodinium cohnii, Neochloris oleoabundans,* and *Schiochytrium.*

Microalgae production on a large scale, using light energy, carbon dioxide and water can be carried out in n open or closed pond and Photobioreactors.

Raceway Ponds

A raceway pond is typically of 0.3m depth with re-circulating closed loop channels. Baffles are placed in the flow channel to guide the flow. A paddlewheel is placed for mixing and circulation. The raceway channels are usually build in concrete earth and lined with white plastic, to get access of the maximum available light. In the presence of sunlight, the culture is continuously fed in front of the paddlewheel where flow begins and the broth is harvested behind the paddlewheel on completion of circulation loop. At the night time or dark period, the paddle wheel keeps operating to prevent sedimentation.

Since 19th century, the raceway ponds for mass culture of microalgae have been used. The largest raceway – based biomass production facility is owned by Earthrise Nutritionals, to produce Cyanobacterial biomass for food[11].

Photobioreactor

The Photobioreactors are used to overcome the problems faced in open pond systems. The problems being pollution and contamination risk, which prevents their usage in pharmaceutical and drug industries. Also, single species of microalgae can be cultured for prolonged duration with lower risk of contamination in Photobioreactors[12]. Photobioreactors may be of several types such as tubular, flat and column Photobioreactors. Having a better hand over the open pond production system, these closed Photobioreactors are costly[13]. Closed Photobioreactors comprises of an arrangement of straight glass or plastic tubes. The tubular arrangement can be aligned vertically, horizontally, helically or as an inclined position[14-16]. To enhance the gaseous exchange in the closed Photobioreactors, mixing and agitation are highly reccommended[17].

Flat plate Photobioreactors are the oldest forms of closed production system for microalgae and they have large surface area available for illumination[18, 19]. The transparent materials, being used to make the flat – plate Photobioreactors allow the capture of maximum solar energy available. A thin layer of dense culture passes across the flat plate, absorbing radiation in few millimeters thickness[20]. The flat – plate Photobioreactors are advantageous for mass cultures of microalgae because of lesser availability of dissolved oxygen and better photosynthetic efficiency compared to tubular Photobioreactors[21].

Tubular Photobioreactors have been shown to be reliable for engineering and operation of algal Biofuel production but there are various unsolved problems till date[22]. The length of the tube in the reactor is the limiting factor for the designing of the tubular Photobioreactor, and it depends on the potential oxygen accumulation, carbon dioxide depletion and pH variation in the system[23]. The length being the limiting factor, prevents the indefinite scaling up of tubular Photobioreactors and therefore the large scale production units are basically the integration of various units depending on the need of the industry. But, for outdoor mass cultures of microalgae, tubular Photobioreactors are more suitable because they expose a larger surface area to sunlight. The largest closed Photobioreactors are tubular. Few of them re 25 cubic meter plant at Mera Pharmaceuticals, Hawaii and 700 cubic meter plant in Klotze, Germany[24, 25]. The tubular Photobioreactors when being operated with high density culture such as to obtain high productivity irresistibly has photo limited dark central zone and a relatively better lit peripheral zone. The photo limited zone has a light intensity lower than the saturation light level. There is a continuous cycling of the fluid between the dark and light zones which is caused due to the turbulence in the tube. This is named as light – dark cycling. The frequency of light – dark cycling above certain threshold frequency can increase biomass productivity, provided the sufficient and excess external irradiation[26]. The short dark period in a rapid light – dark cycling allows the photosynthesis machinery of the cell to fully recover from the excited state produced in the previous illumination event. The estimation of frequency of light – dark cycle has not been possible yet[27, 28].

Column Photobioreactors are low cost, compact and easy to operate. These reactors provide the most efficient mixing, the best controllable growth conditions and highest volumetric mass transfer rates. They are comprised of vertical columns which is illuminated through transparent walls or internally and aerated from bottom. They stand equal to tubular Photobioreactors when compared for their performances[29, 30]. In recent years, the closed Photobioreactors seem to be replacing the open raceway ponds and this is mainly because of better process control and a higher biomass production rates in the closed reactors. Hence, the higher biomass production leads to potentially higher Biofuel and by-product production.

Hybrid Production system

The combination of distinct growth stages in open ponds and closed Photobioreactors leads to a hybrid production system. The first stage is in closed Photobioreactors to reduce contamination from other organisms and enhances continuous cell division. The next stage is of nutrient stressing for the synthesis of target lipid product. This stage is best suited for open pond systems, because of the environmental stress while transferring the culture from enclosed system to open ponds[31, 32].

Technologies for microalgal biomass production

Microalgal biomass production could be more expensive than growing crops if the production does not rely on freely and easily available sunlight. Inorganic elements namely Nitrogen, Phosphorus, Iron and Silicon must be present in the growth medium. These elements constitute the algal biomass.

Ideally, microalgal biodiesel would be carbon neutral, as all the power needed for producing and processing the algae would come from biodiesel itself and from methane produced by anaerobic digestion of biomass left behind after the oils has been extracted. It can be clearly visualized from Fig. 1. But, this process would not result in any net reduction in carbon dioxide that is accumulating as a consequence of burning of fossil fuel.

A continuous culturing of microalgal biomass during daylight is required for large – scale production. It implies that a fresh culture medium is fed at a constant rate and the equal quantity of microalgal broth is withdrawn continuously. During the night period or dark period, feeding ceases but the mixing of broth must continue to prevent settling of biomass.

In the commercial production of Biofuel, the natural conditions suitable for the growth of microalgae should be used because of their benefit of using a free natural resource as sunlight and keep the artificial conditions limited to the fact of enhancing the optimum natural growth conditions[33]. Sunlight is conditionally available and depends on the diurnal cycle and seasonal variations, thus, making itself as a limiting factor for outdoor algal production. To overcome this limiting factor, fluorescent lamps as an artificial means of irradiation can be used for the cultivation of phototropic algae. For the artificial lightning a higher energy input is required. This need of energy input will again use the fossil fuel resources which in turn increases the production cost of Biofuel and hence makes the process inefficient to match its goal of producing a price – competitive fuel. The artificial light source should be selected on considering the absorption spectra of algal accessory pigments present in different algal groups.

CONCLUSION

The Biofuel production from microalgal sources is more efficient when compared to other agricultural crop sources but when compared to fossil fuels or petroleum fuel. The large scale production of Biofuel from microalgae has higher cost of production, which is because of cost involved in Photobioreactor construction and maintenance. This high cost of production for Biofuel makes it a non qualifying candidate to substitute the existing petroleum fuel. To overcome this problem, the cost of production of Photobioreactor has to be minimized which can be achieved by using more and more natural sources of energy as sunlight and CO_2 from the power plants. The Photobioreactor needs to be effectively designed with minimum cost of manufacturing without compromising on the quality of the product. With a better and cost effective Photobioreactor, Biofuel from microalgal sources have the potential advantages to replace the petroleum fuels and reduce the alarming rate of increase in global warming and depletion of fossil fuels.

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Haymanti Saha, an inquisitive student with a passion in the field of research, has a hands-on knowledge on the Biotechnology tools and techniques, presently doing her under-graduation from Vellore Institute of Technology, Vellore. Her summer internship at Emami Ltd. has helped her gain further experience. She is well acknowledged as an enthusiast researcher in Science and Technology among her peers and professors in VIT University. She has worked with ***Mr. Alok Prakash*** under the well guidance of ***Prof. Mrudula P*** (SBST, VIT University) with utmost dedication and passion. Her area of interest is Bioprocess Engineering and Food Biotechnology.