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Recent Development in the Production of Third Generation Biodiesel from Microalgae

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Abstract

Increasing global energy demand at a rate faster than the population growth has led the researcher to look for alternative fuel. Amongst the options, biodiesel is an environmentally sustainable substitute of diesel fuel being renewable, biodegradable and have similar properties of fossil diesel. Among the biodiesel sources, microalgae is a potential third generation biodiesel feedstock which can be produced throughout the year and its oil yield is higher than any other crops. This paper reviews recent development in microalgae biodiesel in terms of its oil extraction technics, challenges of oil extraction, production of biodiesel from microalgae oil and its fuel properties. Finally, the paper discusses the performance and combustion analysis of diesel engine fuelled with microalgae biodiesel. This paper provides a clear understanding of the potential use of microalgae biodiesel as an alternative source to fossil diesel for diesel engines.

Keywords: Microalgae oil; Biodiesel Production; Characterization; Performance; Emission.

1. Introduction

Over many decades, the primary source of global energy demand has been fossil fuels - coal, petroleum, and natural gas. Their depletion on the one side and adverse climate effects on the other have seen continuous exploration for several alternative fuels such as diesel, biodiesel, methane, ethanol, etc. [1-3]. In recent decades, biodiesel has been considered as a promising alternative fuel that meets all the criteria and has potential to be an alternative to fossil fuel and to reduce harmful emission from internal combustion engines [4]. Fig. 1 shows the potential of biodiesel as a diesel fuel substitute [1]. Biodiesel is produced from vegetable oil, animal fat and biomass

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through transesterification process in the presence of a catalyst. The common biodiesel feedstocks are: peanut oil, soybean oil, sunflower oil, corn oil, rice bran oil, palm oil, coconut oil, olive oil, rapeseed oil, jatropha, karanja, cotton seed oil, calophyllum, rubber seed oil, desert date, Jojoba, neem oil, moringa and croton [5]. Biodiesel can be classified according to their source. Biodiesel that is produced from edible oil is known as first generation biodiesel, and that comes from non-edible oil sources are termed as second generation biodiesel. Third generation biodiesel is produced from microalgal biomass.

Nevertheless, the expansion of biodiesel production around the world has raised a major concern regarding the sustainability of several first generation (1G) biodiesel (biodiesel from edible oil source) [6]. The displacement of food-crops, effects on the environment and climate change by the first generation biodiesel has led to discovering the potential of second generation and third generation biodiesel [7]. Although currently a small fraction of first and second generation biodiesel is used, third generation biodiesel could be the potential as an alternative fuel and can play important role to the nation's energy infrastructure. Thus, recent development in third generation biodiesel (microalgae biodiesel) is reviewed in this paper, in terms of microalgae oil extraction techniques, challenges of oil extraction, production of biodiesel from microalgae oil, fuel properties of microalgae biodiesel and its performance and combustion behaviour in diesel engines.

2. Why microalgae?

Microalgae are the third generation (3G) biodiesel which has very distinctive yield compared to other biomass. 3G biofuel can be blended with most of the fuels such as diesel, petrol, and jet fuel and aviation gasoline. Microalgae is a renewable feedstock, eco-friend and contains higher energy. List of spices with the lipid contents that can be used to produce 3G biodiesel is given in Table 1 [8]. It has been reported that microalgae will have more potential to produce more energy per hectare of land use compared to that of conventional crops. The major benefits of using microalgae-derived biodiesel are; it can be produced throughout the year. As a result, oil yield is higher than any other crops; it can be cultivated in the undeveloped land that's why it doesn't have any environmental impacts; it has potential to be grown rapidly, and oil contents are 20-50% dry weight if biomass; and cultivation of microalgae does not need any pesticide application.

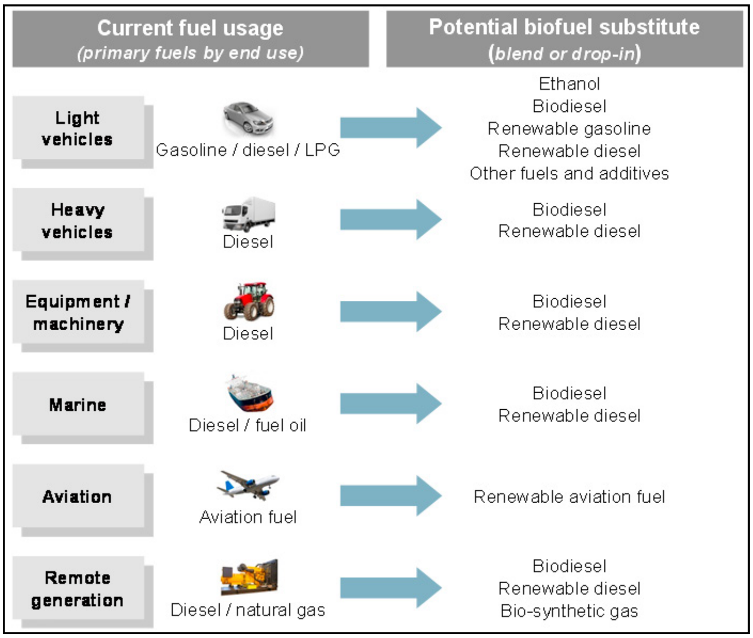


Fig. 1: Potential of biodiesel as a diesel fuel substitute

3. Extraction of microalgae oil

Oil/lipid from microalgae can be extracted in different ways. The conventional process of extracting oil is a mechanical and chemical process. The mechanical method can be further classified into oil expeller; microwave assisted extraction and ultrasonic assisted extraction process. Similarly, chemical extraction method can be categorized into accelerated solvent extraction, supercritical fluid extraction, and Soxhlet extraction process. The advantages and disadvantages of both extraction process are given in Table 2 [9]. There are some challenges in extracting oil from microalgae:

- The efficiency is lower compared to other sources
- Weak interaction of chemicals in wet biomass.
- Expensive drying cost
- Excessive chemical consumption
- The reaction of chemicals with other products.
- Separation of lipids from the liquid medium.
- Dependence on physical properties of the cells.

Table 1: List of the spices to produce 3G biodiesel

Name of microorganisms	Oil content per ton of biomass (w_t% dry mass)	Lipid content (%, w/w_{dw})
Microalgae		
*Schizochytrium*sp.	50–77	35–55
Botryococcus braunii	64	25–75
Nitzschia laevis	69.1	–
Neochloris oleoabundans	35–65	29–65
Chlorella vulgaris	63.2	5–58
Parietochloris incise	62	–
Crypthecodium cohnii	56	20–51.1
S. obiquus	35–55	11–55
Nannochloris sp.	–	20–56
Nannochloropsis oculata	50	22.7–29.7
Nitzschia sp.	45–47	16–47
Scenedesmus dimorphus	16–40	
Monodus subterraneus	39.3	16
Phaeodactylum tricornutum	20–30	18–57
Haematococcus pluvialis	25	25
Dunaliella primolecta	23	23.1
Tetraselmis sueica	15–23	8.5–23
Chlorella sorokiana	22	19–22
Monallanthus salina	>20	20–22
Dunaliella salina	14–20	6–25
Porphyridium cruentum	19.3	9–18.8

4. Biodiesel production from microalgae

The most common method that is used to convert crude oils into methyl ester is transesterification process. It is some consecutive reaction between vegetable oils and alcohol in the presence of a catalyst. Through the reactions, triglycerides are converted into monoglyceride. Details production process of microalgae biodiesel has been described by Haik et al. [10]. First, the crude oil was preheated to 60 and then added to a mixture of methanol (20% of total crude oil) and sodium hydroxide (3.5g) for 1 liter of oil. After the transesterification reaction in the reactor, the mixture was kept for 8h to settle. Then glycerine was removed, and biodiesel was washed and filtered. The flow chart of biodiesel production process is given in Fig. 2 [11]. It is crucial to check the properties of produced biodiesel before using in the engine. The key fuel properties of produced biodiesel are given in Table 2 [12].

Table 2: Advantages and disadvantages of oil extraction technics

Method	Advantages	Disadvantages
Oil expeller	1.Easy to use 2.No solvent required	1.Large amount of biomass require Slow process
Ultra-sonication assisted	1.Reduced extraction time 2.Reduced solvent consumption	1.High power consumption, difficult to scale up
Microwave assisted	1.More economical 2.Environmental friendly, 3.Reduced extraction time, 4.Reduced solvent usage 5. Improved extraction yield.	1. Filtration or centrifugation is necessary to remove the solid residue; 2. Efficiency of microwaves can be very poor when either the target compounds
Solvent extraction	1.Very simple and cheap 2.Good for small scale 3. High efficiency.	1.Extraction time is long; 2.Large volume of solvent required, toxic and highly flammable 3.Solvent recovery is energy intensive
Supercritical CO_2	1.Reduced time, 2.Low toxicity solvents, 3.Favorable mass transfer equilibrium due to intermediate diffusion/viscosity properties of the fluid, 4. Production of solvent-free extract.	1. High process cost associated with its infrastructure and operation.
Wet extraction	1.Saving in energy required for drying the biomass, 2. Reduced solvent usage.	1. The quality of lipid extracted may not be as good as lipid extracted from dried biomass.

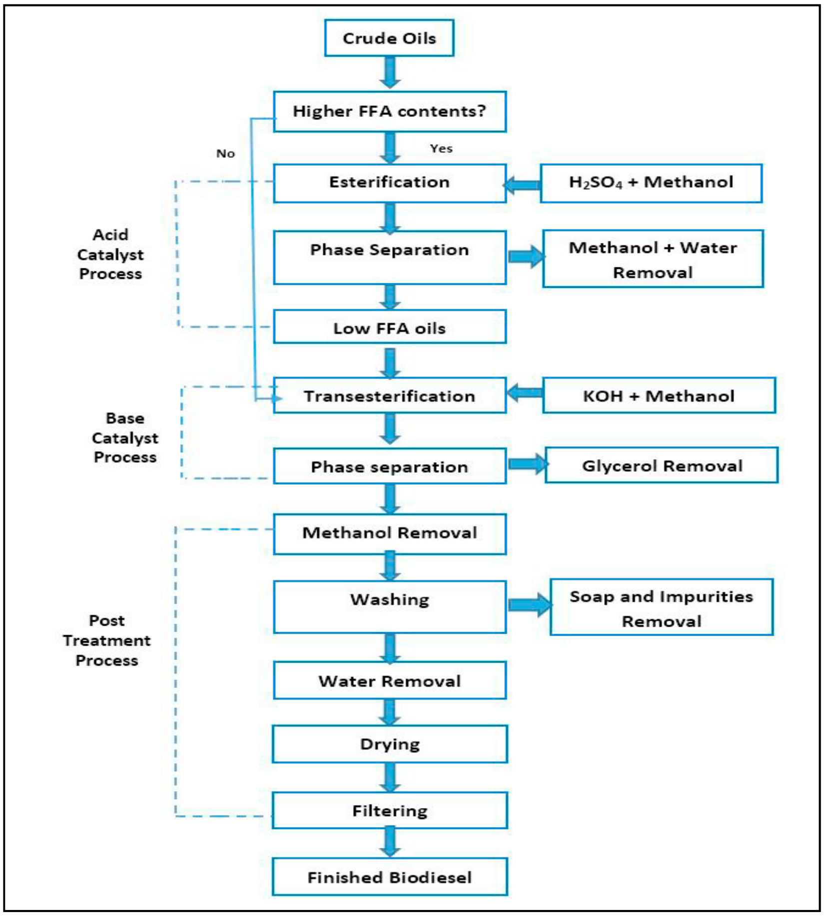


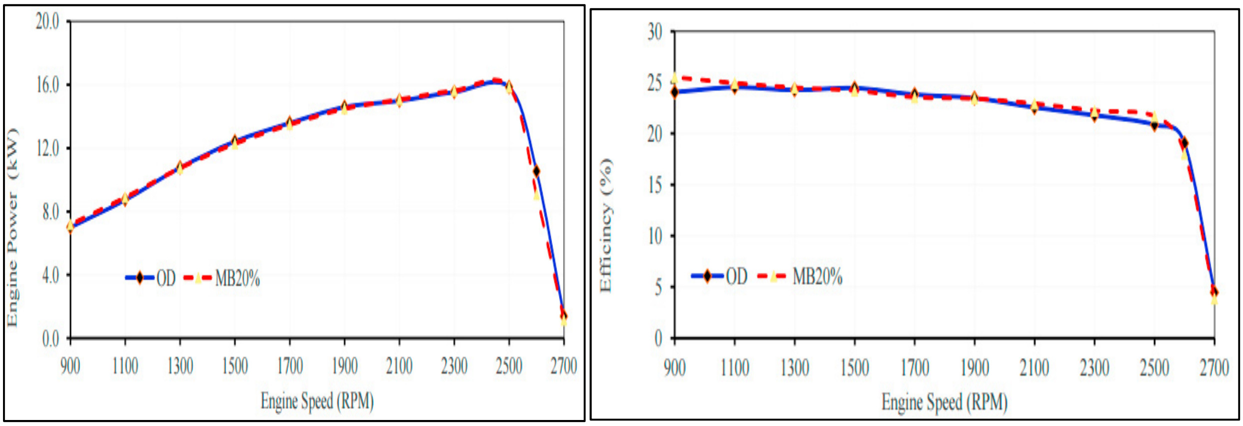
Fig. 2: The flow chart of biodiesel production process

Table 3: Properties of microalgae biodiesel

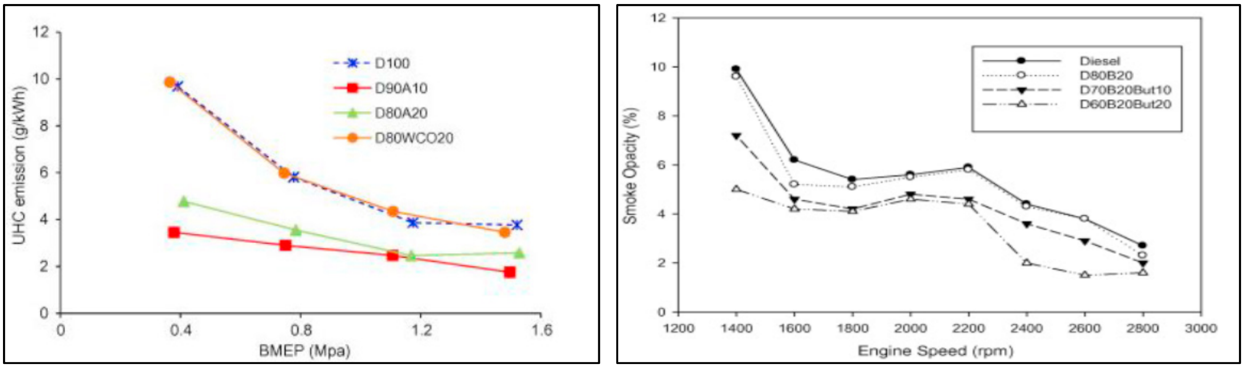
Fuel property	Unit	Microalgae biodiesel	Biodiesel Standard EN 14214	Diesel
CN	–	46.5	51	53.3
Kinematic Viscosity @40 °C	mm^2/s	5.06	3.5–5.0	2.64
Density @15 °C	kg/L	0.912	0.86–0.90	0.84
HHV	MJ/kg	39.86		–
LHV	MJ/kg	37.42		44.0
Acid value	mg KOH/g	0.14	0.5max	0.0
Flash point (closed cup)	°C	95.0	–	71.0
Flash point	°C	–	120	–
Sulphur content	mg/kg	7.5	10max	5.9
Cloud point	°C	16.1	Report	4.0
Lubricity @°60	mm	0.136	–	0.406
Copper corrosion (3 h @50°C)		1a	1 max	1a

5. Performance of microalgae biodiesel in diesel engine

Islam et al. [12] studied the combustion behavior of B10, B20, and B50 of microalgae biodiesel in a single cylinder engine at different load condition. The found that the use of microalgae biodiesel with diesel fuel in diesel engine reduces the in-cylinder pressure and output torque, by a maximum of 4.5% at full throttle. Also, increases the BSFC due to the lower calorific value which subsequently reduces the BTE by 4% at higher loads as shown in Fig. 3. Microalgae biodiesel reduces the engine emission but increases the NOx emission slightly. Haik et al. [10] studied the effect of engine speed and load on combustion of algae biodiesel in a diesel engine. They found that algae biodiesel produces lower torque than diesel fuel but higher heat release rate than diesel fuel. They suggested that power output could be improved by retarding the injection timing of algae biodiesel. Tuccar et al. [13] studied the performance and emission of butanol added diesel-microalgae biodiesel blend in a diesel engine. They found that the power and torque output of engine reduced slightly when butanol was added to the MB–diesel blends. Engine emission results indicated that the exhaust emission tests revealed that CO and NO_x emission and smoke opacity values improved with butanol addition.



(a) **(c)**



(b) **(d)**

Fig. 3: Performance of Microalgae (a) Power (b) Efficiency

6. Conclusions

Microalgae represent the third generation feedstock for biodiesel, with much higher yields than other crops. In recent year's biodiesel production from microalgae have received much attention worldwide. Finding the most efficient method and optimized conditions for the extraction of lipid are important for reducing the cost of biodiesel production from microalgae. Making biodiesel from microalgae oil is similar to the process of making biodiesel oil from any other oilseed, and thus can quite possibly use the same conversion processes to produce biodiesel. The use of biodiesel in diesel engine reduces the engine power slightly but also reduces the engine emission except the NOx emission. The engine outPUT response varies with the operation condition. Finally, more investment and more research on microalgae biodiesel are needed to find out the new approaches which could lower the production cost of biodiesel. Also, research on microalgae combustion in internal combustion engine should be done to improve the engine performance and lower the emission.

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