Rocznik Ochrona Środowiska

Volume 23 Year 2021 ISSN 1506-218X pp. 243-262

https://doi.org/10.54740/ros.2021.016 open access

Received: 20 January 2021 Accepted: 20 May 2021 Published: 06 December 2021

Processing and Performance of Blended Biodiesel Produced from Microalgae *Pediastrum Boryanum*

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Abstract: In this present study, biodiesel was synthesized as per ASTM method by using algae as a raw material, which in the environment is considered as being a harmful waste and of a nature that blooms in ponds, lakes and reservoirs. In order to improve fuel quality, the transesterification process was carried out in this study so as to remove fatty acids and thereafter, analyze several fuel parameters of the biodiesel were determined. The calorific value of the biodiesel and its specific gravity was 42660 kJ/kg and 0.803 g/cm^3 respectively. The viscosity of the sample was found to be 1.99. The cetane number of diesel fuel ranged from 40 to 55 and for the biodiesel it was found to be 47. The flashpoint and firepoint of the sample was recorded as 80°C and 94°C respectively. The conclusion is that it is worthy to mention that this process does not require high-end technology; hence, it could be used in the energy generation process in remote areas and as an alternative resource, as well.

Keywords: biodiesel, diesel, algae, esterification, transesterification, residue

1. Introduction

Responding to dire warnings of the consequences of global climate change, researchers worldwide have searched all over for renewable fuels that could be considered as being economically viable, technologically feasible, and environmentally sustainable (Adenle et al. 2013). Bearing that in mind, during the last few years, the scientific community has had as an aim the reduction of greenhouse gas emissions, through a combination of improved energy efficiency, technology change and the use of renewable energy sources that could come from several different sources, such as: the sun, waste, water, wind and wood.

Currently, renewable energy is achieving ever more popularity due to several causes amongst which we could include an increase in the crude prices, which are going up day by day, and the phenomenon known as global warming, caused (amongst other reasons) by the burning of fossil fuels (Amin et al. 2016). Therefore, crude fossil petroleum could be substituted by algae biomass with the intention of getting an eco-sustainable biodiesel production in the upcoming future. In view of the constant diminishing supply, crude oil will continue to have a rise in cost. Analyzing from such a perspective enables the production of fuels from alternate sources to be quite more feasible. Continued climatic changes are also being furthermore increased by the constant use of fossil fuels, due to the release of environmentally potential noxious gases such as CO_2. With the dwindling reserves of fossil fuels, it is now more important than ever to search for transportation fuels that could serve as alternatives to crude oil-based fuels such as gasoline and diesel fuel. Biodiesel is a transportation fuel that has grown immensely in popularity over the past decade. Furthermore, there are many sources for biodiesel feedstock, which include canola, castor, soy, palm and sunflower. Recently, scientists and academics from all over the globe speak frequently in relation to the ever-growing controversy about the use of potential food sources for the production of fuel. Looking from such a perspective, researchers have turned their attention from some of these popular feedstock and are currently investigating the use of alternative, non-food related feedstock such as the oil that comes from algae's (Grace et al. 2010).

Biodiesel is produced from microalgae that are the largest autotrophic microorganisms that could be produced in lesser amount of water than crops and besides that a better biofuel could be produced, because it does not require land, alongside it also converts more than 60% of its body weight in lipids (Christi 2007). Researchers have estimated that microalgae produce 15-300 times more oil than crops (Christi 2007). Fossil fuels while burning emits CO, NO_x, SO_x, hydrocarbon and particulates which creates a significant amount of air pollution, when compared with CNG and biodiesel fuels (Yun et al. 2016, Liu et al. 2015). Around the world presently 934 million tons of diesel is consumed per year as a source of energy in various sectors (Kulkarni & Dalai 2006).

Nowadays, biodiesel is also used in diesel engines and as a consequence the demand of biodiesel has increased considerably (Ramkumar & Kirubakaran 2016). Biodiesel is composed of mono alkyl esters of long chain fatty acids and it is derived from vegetable oil (Zareh et al. 2017) or algae. Biodiesel is more beneficial when compared to conventional diesel. It decreases the carbon dioxide and pollutants emission from diesel engines, at the same time without needing a significant modification of the same utilized engine. Also, biodiesel has a high cetane number, therefore its performance is better in a diesel engine while compared to a normal diesel fuel. Vegetable oil is produced from seeds and plants like palm, soybean, rapeseed, sunflower etc. (Fu et al. 2016, Focke et al. 2012, Berman et al. 2011, Ghosh et al. 2016). These raw materials are very costly (Jain & Sharma 2010) due to their demand in day to day consumption by human beings both for cooking and for running diesel engines. Also, large scale production of this edible oil would promote deforestation (Leung et al. 2010).

Although vegetable oil is used as a biodiesel (Arain et al. 2009, Evangelista et al. 2012, Silva et al. 2011), it has certain restrictions when introduced on the direct injection of engine types. It has a high viscosity, lower ignition point and also is less efficient while utilized in diesel engines. These types of problems could be solved, when biodiesel is produced from micro-algae. Microalgae could be described as being a readily available source of feedstock, coupled with the advantage of not competing with food or other oilseed crops used for arable lands. Furthermore, they thrive in contaminated water, freshwater, saltwater and sludge. As a matter or a fact, microalgae adapts well in different habitats not at all suitable for energy oil crops such as lakes, ponds, sea, and even on wastelands. Apart from that, micro-algal oil also contains quite high percentages of monounsaturated and saturated FAs that are very important from the standpoint of diesel fuel quality. This is because these problems with FAs could significantly reduce polymerization of fuel during combustion. Therefore, from the standpoint of all these considerations, *Nannochloropsis*, members of the marine green algae are considered as being remarkable candidates for biodiesel production and biomass productivity.

The last few years witnessed a weaker global growth rate which was below the average of 0.6 million barrels per day (b/d) from fossil fuels, reaching the lowest level since the mid-nineties of last century. Furthermore, energy derived from petroleum is expected to continue growing at a very slow pace. This will be due to the ever-increasing prices and gradual reduction of world governmental subsidies (B.P. statistical Review of World Energy 2012). On the other hand, the projected global supply of feedstock biofuels is expected to grow around 30% by 2030. Apparently, one major candidate representing the renewable feedstock that has the potential to replace petroleum diesel in large amounts of places without incurring in the problem of affecting food supply chain, as well as other crop products is certainly the micro algal oil (B.P. statistical Review of World Energy 2012, Demirbas & Demirbas 2011, Pienkos & Darzins 2009, Ehimen et al. 2010, Vicente et al. 2010, Shirvani et al. 2011). Most of the productive oil crops, such as canola oil, castor oil, palm oil and rapeseed do not reach the standards of microalgae in relation to being a potential provider of the global energy security so badly needed.

However, since emerging nation´s economy depends mainly on agricultural activities, the utilization of national resources for energy production is an extremely important issue. Diesel engines have been widely used as a power of engineering machinery, automobile and shipping equipment for its excellent drivability and thermal efficiency. Diesel fuels could be used in heavy trucks, city transport buses, locomotives, electric generators, farm equipments, underground mine equipments etc. (Sekhar et al. 2018).

One of the most attractive advantages is related to the fact that the cost associated with harvesting and transportation is quite low when compared to that of other oil crops. Residual biomass post extraction offers different methods for improving sources of economics by utilizing it as a type of fertilizer or for producing other types of high energy products (Ahmad et al. 2011). Microalgal biodiesel is considered a sustainably advantageous fuel due to the fact of being a carbon neutral fuel, in view of the photosynthetic fixation of atmospheric carbon dioxide. Microalgal growth actively utilizes 1.85 kg of CO_2 for every 1 kg of dry biomass produced and the obtained biodiesel has properties, such as density, viscosity, flashpoint, cold flow and heating value similar to those of petrodiesel. Very few, if not none of the other potential sources of biodiesel are a true candidate to replacing petrodiesel utilization as microalgae, in view of the fact due to the environmental impacts that occur as a result of use of those other feedstocks as mentioned in scientific literature (Ahmad et al. 2011).

The algae growth agitates the ecology of the water reservoir or local ponds and if removed then large amount of waste encroaches the land. This waste could be converted into significant resource. Moreover not much attention has been paid on solving the problem of algal proliferation and eutrophication occurring in lakes and ponds or other surface water bodies, which are very rich in nutrients. Researchers around the world are working on diverse types of proper waste management techniques but very few have emphasized on how to redeem such a valuable waste.

Alongside, there has been a postulation that oil content in microalgae contributed to the present day crude oil deposits that were formed some millions of years ago (Leung et al. 2010, Wang et al. 2011). Approximately, 650 billion barrels of crude oil energy equivalent is released by different types of microorganisms on a yearly basis (Wackett 2008). Analyzing from such a perspective, microalgae definitely is a promising sustainable source of energy for the nearby future.

In order to have an optimal yield, these algae need to have carbon dioxide (CO_2) in large quantities in the basins or bioreactors where they grow. Algae can grow practically anywhere where there is enough sunshine. Different types of algae contain carbohydrates, lipids, nucleic acids, and proteins in varying proportions. While the amount yield in relation to percentages significantly vary according to the type of algae, there are some that are comprised up to 40% of their overall mass by fatty acids (Sheehan at al. 1998). The yield of algal oil is a most significant distinguishing characteristic and hence its biodiesel yield. Scientific literature shows some estimates, where the yield (per acre) of oil from algae is above 200 times the yield from plant/vegetable oils of great performance (Campbell 2008, Sheehan at al. 1998). Therefore; considering the above mentioned facts in view a study has been carried out in order to utilize pond algae. It is a high lipid raw material which could be converted into biodiesel.

One could consider that a quite limiting path for the development of biodiesel production industry happens to be the lipid extraction process is based upon microalgae. As a matter or a fact, lipid extraction from microalgae is mainly performed by organic solventes. Therefore; not happening through conventional physical methods, due to several problems encountered, such as in breaking the cell wall, enabling that microalgae-based biodiesel production becomes unfeasible per example at industrial scale (Hidalgo et al. 2013).

A Simultaneous procedure of lipid extraction, as well as esterification/transesterification is a technique of great value for biodiesel production through microalgae, as it permits extracting and converting fatty acids into fatty acid methyl esters (FAME) in a single step bypassing the use of large quantities of organic solvents used in lipid extraction as described in some researches (Jin et al. 2014, Wahlen et al. 2011).

The obtained biodiesel could be tested for various parameters mentioned in the American Society of Testing Materials (ASTM) standards and further utilized in blend with diesel or directly in the vehicular purposes. Therefore, an attempt has been made to convert algae into biodiesel and performance of the diesel engine has been evaluated using biodiesel as a fuel.

2. Materials and methods

2.1. Biodiesel production

The algae samples of species (Pediastrum boryanum) were collected from the Salt Water Ponds of Extremoz, a city in the state of Rio Grande do Norte, Brazil, 21km from the state's capital, Natal. Furthermore, they were collected for biodiesel processing and production. It is one of many species of tiny plants that are called "green algae". The thumb rule is that academics, researchers and scientists could cultivate microalgal strains that adapt to the reality of their local environmental surroundings.

The biomass obtained from Pediastrum boryanum could be considered as a suitable substrate for conversion into biofuels through a procedure known as algal recycling, enabling the process to be economically sustainable (Park & Craggs 2014). Apart from the fact that it happens to be a dominant species of the region where it was collected, in comparison for example with Botryococcus braunii, another potential species of algae with many scientific literature citations.

Therefore, the use of endemic indigenous microalgal strains is highly recommended since these strains are already adapted to the local environmental conditions (Mutanda et al. 2011, Xu et al. 2006). The overall laboratory conversion pathway, with sample photographs, is presented in Figure 1.

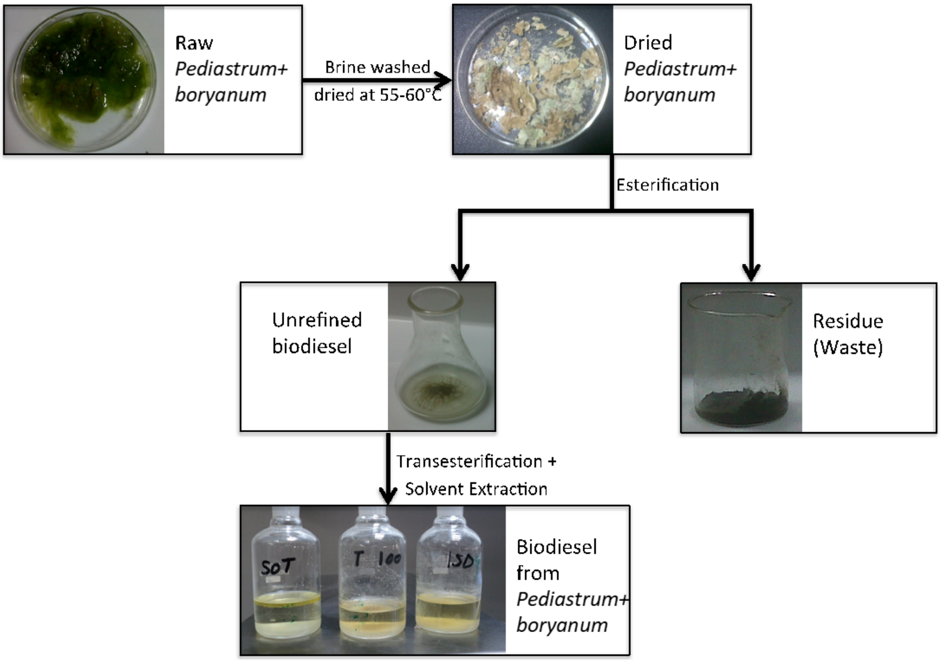


Fig. 1. Pathway of laboratory biodiesel production from *Pediastrum boryanum*

Conditions of the culturing process directly influences characteristics of growth, as well as the cellular composition of microalgae, which results in different biomass concentration and productivity, not to mention the possible variation in lipids content, carbohydrates, proteins and other components (Chojnacka & Marquez-Rocha 2004).

Prior to transesterification, the algae were washed with brine water to remove impurities and dried in an oven between 55 and 60°C. In relation to algae biodiesel, water content must be reduced to a bare minimum before the transesterification process. Common drying methods that are used include: drum drying, freeze drying, spray drying or sun drying.

Freeze drying becomes very expensive in large scale production but does produce the most pure results (Mutanda et al. 2011).

Algal hydrocarbon contents were measured using the following method. The wet slurry of Pediastrum boryanum was freeze-dried; 0.3 g NaOH was mixed with 28.8 ml methanol and stirred continuously for 24 minutes. The mixture of catalyst and methanol was poured to the algal oil in a conical flask and tranesterification process allowed to take place. The bio-oil was separated from the sedimentation by a flask separator. Bio-oil was washed with 5% sterile water until it became clean. Bio-oil was dried by using a dryer at temperature ranging between 55-60°C. and kept under air for 12 hrs. Harvesting contributes approximately 20-30 percent to the total cost of producing the biomass. The treated samples after washing and drying are shown in Figure 1(a) and 1(b) respectively. The dried samples were grinded in the mortar and pestle to produce a fine powdered form.

2.2. Process description of methodology used for biodiesel production

Removal of oils could be done through solvent extraction using hexane. Hexane-based solvent extraction is the standard method for lipid extraction from microalgae (Mutanda et al. 2011, Xu et al. 2006). Therefore, solvent extraction method was employed here being used for the extracting of biofuel, and the complete conversion of algae biomass to biodiesel. As per the ASTM method an equal volume of mixtures of hexane and diethyl ether were added to the powdered sample in a conical flask. Afterwards, the mixture was kept for 24 h settling and after settling, oil was separated from the residue by the filtering process.

The obtained biodiesel was of slightly below the average quality and characteristics. Therefore, in order to improve the quality and characteristics of the obtained biodiesel transesterfication process was carried out. Biodiesel could be extracted when a sample of algae reacts with methanol and NaOH is used as base catalyst. In this method methanol and NaOH have been used as a catalyst and the mixture was stirred at a speed of 1500 rpm for 3 h. Thereafter, the solution was transferred to a separator funnel and allowed to settle for 15 h till a fine layer of biodiesel was formed and the oil residue settled at the bottom of the funnel.

The biodiesel and residue were carefully separated and the weights of both were measured. The obtained biodiesel was washed with water to remove left out impurities and kept for drying for 12 h. The obtained biodiesel is pale yellow in colour, apart from having a strong alcoholic smell. The biodiesel yield was approximately 70% with the above mentioned process and described conditions.

2.3. Fuel Characterization and comparison

Biodiesel could be extracted from any type of biomass, however the extracted oil is to be verified by performing certain tests which determines the significant parameters of fuel. Initially pH value and weight of the biodiesel were measured. The calorific value of the obtained biodiesel was determined using a Bomb Calorimeter; Model Parr 6100. Thereafter, biodiesel was tested so as to verify the performance of the diesel engine. The smoke characteristics and various electrical parameters were also determined at 10% blend of biodiesel with diesel.

Biodiesel was characterized via: calorific value; density; viscosity; centane number; flash point; fire point; cloud point; pour point. To provide as basis of comparison, we obtained a series of edible oils from Blue Ville Santa Lúcia S/A and of non-edible oils from Sabão e Glicerina ltda, both located in São Paulo, Brazil. The instrument, and associated ASTM follows are given in Table 1.

Table 1. Instruments and ASTM methods used in biodiesel, diesel, and oil characterization

Fuel Quality	Instrument	Temperature (T) Range	Test Method
Density	Mettler Toledo Digital Density Meter DE 40	T < 90°C	ASTM D4052
Viscosity	ISL Viscometer Model TVB445	T < 200°C	ASTM D445
Centane Number	CID Fully automated Derived Cetane Number (DCN) Analyzer	10° < T < 35°C; recommended 15° < T < 25°C; 80% relative humidity at 35°C	ASTM D6751
Flash Point	Semi-automatic Pensky-Martens Herzog Model HFP 362	40°C < T < 360°C	ASTM D93
Fire Point	Fully-Automatic Cleveland Fire Point Analyzer	25°C < T < 400°C	ASTM D92
Cloud Point	HCP 852 Automated Pour and Cloud Point tester, 230V, 50/60 Hz	-80°C < T < 50°C	ASTM D2500
Pour Point	HCP 852 Automated Pour and Cloud Point tester, 230V, 50/60 Hz	-80°C < T < 50°C	ASTM D97
Calorific Value	Parr 6100 Bomb Calorimeter	DT > 1.5°C	ASTM D250-02

2.4. Engine tests

A single cylinder direct injection diesel engine, produced by MS Perry & Co. with specifications as detailed in Table 2, was used to compare the performance of conventional diesel with a blend of this diesel with 10 vol% biodiesel from Pediastrum boryanum. Such an engine is widely employed for agricultural purposes, as well as small and medium scale industrial applications.

Table 2. Specifications of I.C. engine used for study

Parameter	Specification
Cylinders	1
Bore x Stroke	95 x 110 mm
Cubic Capacity	0.78 liters
Compression Ratio	17.5:1
Rated output as per BS5514/ISO 3046/ISO 10001	5.9KW (8.0 HP) at 1500 rpm
Starting	Hand start with cranking angle
SFC at rated hp/1500 rpm	251 g/kWh (185 g/bhp-hr)
Lube oil consumption	0.8% of SFC max
Lube oil sump capacity	3.7 liters
Fuel tank capacity	11.5 liters
Fuel tank re-filling time period	Every 6.9 hours at rated output
Engine weight (dry) without flywheel	118 Kg
Weight of flywheel	GENSET -64 kg
Rotation while looking at flywheel	Clockwise
Power take-off	Flywheel end Optional-Gear and half speed drive or Full Speed drive

To ensure the engine was operating at steady state, it was allowed an initial warm-up period of 10 minutes at a load of 60% while running the diesel fuel. After 10 minutes, the voltage, current, exhaust temperature, RPM, fuel consumption and emissions were measured. When we obtained three sets of measurements within 1% of each other's values, each at least 2 minutes apart, we assumed that the engine was operating at steady state.

At this point, the load was increased to 100%, and the engine ran for 2 minutes. Three measurements were taken, each 60 seconds apart at this load. The load was varied as: 40%, 0%, 80%, 20%; after each load change the engine ran for 2 minutes, and three measurements were again taken 60 seconds apart. To ensure confidence in our data and methods, we then varied the load as 100%, 20%, 80%, 40%, 0%, and 60% of capacity, repeating the 2 minutes wait and three data points taken 60 seconds apart. Before beginning the bio-diesel blend run, we calculated an average and standard deviation for each data point at each load to make sure all data points were within 2 standard deviations of the mean.

Given the difficulty in producing large amounts of biodiesel in laboratory settings, we ran one set of varying loads, at 100%, 20%, 80%, 40%, 0%, and 60% of capacity, taking again 2 minutes to reach steady-state, and then three data points 60 seconds apart, for the 10% biodiesel blend.

3. Results & discussion

The goal of this work was to determine if *Pediastrum boryanum,* a locally available microalgae harvested in the state of Rio Grande do Norte, Brazil is a suitable candidate for biodiesel production, and to gauge its performance as a blended fuel in a single cylinder direct inject diesel engine. While there are many potential cultivable algal species that yield large quantities of lipids for biodiesel production, the ability to identify indigenous species that could both be cultivated and sourced from algal blooms – as a way to remediate such events – is critical to the sustainability of biodiesel production for algae.

After determining the fuel pararmeters, performance of the diesel engine was veryfied by using the algae biodiesel as a fuel. By performing such a test, the properties of the obtained biodiesel could be compared with that of conventional diesel and other edible and non-edible seed oils.

3.1. Fuel parameter tests

The generated biodiesel was tested for various fuel parameters, such as: (a) calorific value (b) density (c) viscosity (d) cetane number (e) flash point (f) fire point (g) cloud point (h) pour point.

In order to understand the characteristics of the obtained biodiesel as a fuel, the same was tested for various fuel parameters. Therefore 1.5 l of biodiesel was obtained from 2.5 kg of algae sample. The calorific value and specific gravity of the biodiesel was 42660 kJ/kg & 0.803 g/cm^3 respectively. While, the specific gravity of the normal diesel is 0.804 g/cm^3 therefore, blending of diesel and biodiesel could be easily made.

The viscosity of the sample as experimentally determined was 1.9985. High viscosity affects the flow characteristics of the oil causing improper atomization of the fuel and an incomplete combustion, therefore needing to be avoided (Bojan et al. 2011).

The cetane number of diesel fuel as reported in literature (Bojan et al. 2011, Nabi et al. 2008) ranges from 40-55, and the obtained value for the biodiesel was 47. Cetane number of biodiesel when above 40 could be justified in terms of fuel quality that the obtained biodiesel took less time in combustion while being compared to commercial diesel fuel.

The standard value of flash point of a diesel fuel is 80°C. It is the temperature at which the fuel will continue to burn for 5 seconds after ignition in open flame. The flashpoint of the generated biodiesel was 94°C which was slightly higher when compared with the standard value of diesel. However, flashpoint values of biodiesel obtained from various sources such as neem and jatropa as reported in literature lies between 120-214 (Bojan et al. 2011, Nabi et al. 2008).

Another important parameter is cloud point which could be described as the temperature at which a dissolved solid is no longer in soluble form. In crude or heavy oil cloud point is used as a synonym of wax appearance temperature or wax precipitation temperature. The standard value of a cloud point of diesel is -5°C.

The pour point of the liquid is the lowest temperature at which it loses its fuel properties and semi-solidifies. In crude oil it occurs due to the high paraffin content. The pour point of the generated bio-diesel comes out to be -7°C which is slightly lower when compared with standard values of commercial diesel.

3.2. Comparative study of the fuel parameters

The fuel parameters of biodiesel generated from algae, edible & non-edible oil has been studied, compared and summarized in Table 3. The values depicted in Table 3 indicated that:

a. The calorific value of the algal biodiesel as determined was 42857 KJ/kg which is the highest among the non-edible and edible oils, with the exception of palm oil. However, the calorific value of the diesel and other biodiesel as reported in the scientific literature lies between 35000-40000 KJ/kg (Karmakar et al. 2012, Bojan et al. 2011, Nabi et al. 2008). Therefore, the value of the obtained gross biodiesel was higher than that reported in literature and was a good indication of the fuel value in terms of energy.
b. The specific gravity of the algal biodiesel was lesser when compared to edible, non-edible oils & diesel. The specific gravity of a substance is the ratio of the density of the substance compared to the density of the reference substance. It is a dimensionless quantity and usually water is taken as a reference substance keeping the temperature and pressure constant.
c. The viscosity of the algae biodiesel was 1.998 which was lesser than diesel and other edible and non-edible oils. The lesser the viscosity better is the pour point and its functionality in the diesel engine. The process of upgrading is done because of the high viscosity of the bio-oils. This indicated that the quality of algal biodiesel is better than those of other fuels and oils.
d. Cetane number of the algal biodiesel was 50 which could be well compared with other fuels such as diesel which has a value of 49. Also most of the biofuels or oils lies within a similar range.
e. Flashpoint of the algal biodiesel as determined is 80 which are slightly higher than the 56 value of diesel. Flashpoint of the generated biodiesel was 94 which is also more than that of diesel which was 64, however lesser than that of other biodiesel and oils. This also indicated the better quality of algal biodiesel than other biofuels and oils.

The value of the cloud and pour point of the algal biodiesel was -5°C and -7°C respectively and cloud and pour point of the diesel was -8°C and -20°C respectively. The value of cloud point and pour point as compared to biodiesel is not much appreciable. Therefore, certain tests needs to be performed for improving these factors as the fuel may tend to freeze at low temperatures. It means diesel could work nicely at lower temperatures. These results are summarized and shown in Table 3.

Table 3. Properties of biodiesel produced from pediastrum boryanum as compared to diesel used in engine tests and selected edible and non-edible oils

Property	Diesel	Algal Biodiesel	Non-edible oils					Edible oils					
			TPSO	Jatropha	Pangumia	Mahua	Neem	Corn	Palm	Cotton	Mustard	Sunflower	Rice bran
Calorific value (kJ/kg)	43200	42660	4252	42250	42334	42062	41905	41905	42857	42150	42102	41260	42125
Specific Gravity	0.804	0.803	0.828	0.816	0.821	0.815	0.829	0.820	0.826	0.838	0.823	0.825	0.828
Viscosity @40°C (cSt)	3.90	2.00	6.50	4.84	6.40	4.80	6.80	4.50	5.30	5.87	5.60	5.20	5.80
Cetane number (˚C)	49	50	51	48	50	47	50	51	48	50	47	48	47
Flashpoint (°C)	56	80	88	92	95	85	87	78	81	88	86	79	87
Firepoint (°C)	64	94	95	96	98	92	93	85	87	95	90	82	96
Cloud point (°C)	-8	-5	-6	-3	-5	-4	-6	5	8	-1	3	5	2
Pour point (°C)	-20	-7	-18	-16	-17	-14	-16	-2	-3	-7	-5	-3	-8

3.3. Mechanical & thermal parameters

After determination of the fuel characteristics, algal biodiesel was introduced in the diesel engine so as to obtain thermal and mechanical parameters. During the combustion, 10% of algal biodiesel was blended with 90% of diesel. During the experiment, the following parameters were determined:

a) Brake Specific Fuel Consumption**:** In engine test, brake specific fuel consumption is measured as mass of fuel consumed per unit time per brake horse power. If brake specific fuel consumption of one fuel is less than other fuel, it means one liter of oil produce more brake horse powers that other fuel. It is represented as BSFC.

   Brake Specific Fuel Consumption = Mass of Fuel Consumed per Unit Time / BHP

   The power developed by engine after varying load for diesel and biodiesel indicates that maximum power is higher in case of Diesel (3.982 KW) as compared to biodiesel (3.741 KW). This is due to the synergy of calorific value, oxygen content and viscosity.

b) Exhaust gas temperature: Exhaust gases are emitted as a result of the combustion of the fuel in an engine. According to the type of the fuel utilized during the combustion exhaust gas is discharged in the atmosphere. Exhaust gas temperature is a significant parameter of a catalytic converter of an internal combustion engine.

c) Carbon monoxide: Carbon monoxide is formed during the combustion process, when insufficient air (oxygen) is supplied to the fuel. Due to insufficient supply of the air, generation of heat decreases and fuel does not burn properly. Mechanical efficiency decreases and brake specific fuel increases.

d) Carbon content: Complete combustion of hydrocarbon fuel results into water and carbon dioxide. Release of carbon dioxide in the environment is quite noxious to the atmosphere. Therefore it is important to calculate the amount of carbon content in a fuel.

e) Unburnt hydrocarbon: The hydrocarbon content varies from methane to the heaviest solid hydrocarbons. It remains in the vapor phase at about 190°C. Hydrocarbons heavier than this therefore condenses and with the solid-phase soot, are filtered from the exhaust gas stream upstream of the detector. The composition of the unburned and partially oxidized hydrocarbons in the diesel exhaust is much more complex than any other fuel in spark ignition engine and extends over a larger molecular size range. Engine idling and light load operation produces significantly higher hydrocarbon emissions than full-load operation.

f) Nitrogen oxides: Nitric oxide and nitrogen dioxide are grouped together as NO_x emission. Nitric oxide is the predominant oxide of nitrogen produced in the engine cylinder. NO_x discharge of blank diesel and biodiesel B10 increase with the increase of torque. NO_x discharge increases with the increase of adding biodiesel at the same torque. When biodiesel is added into diesel, it means more of the oxygen element is added into the diesel, so NO_x discharge gradually increases. There are reports about the fact that NO_x emission increases from 1.5% to 9.5% when B100 is used instead of B20 (Bojan et al. 2011). Neat biodiesel contains about 9.5-11.5% oxygen in its molecule. This additional oxygen is responsible for higher NO_x emission. However, Nabi et al. (Nabi et al. 2008) had investigated the combustion and exhaust emissions with diesel fuel and diesel-NOME blends (5%, 10%, and 15%). He found that exhaust emissions including smoke and CO were reduced, while NO_x emission was increased with diesel blends for all the injection timing, compared with conventional diesel fuel. It was reported that NO_x emissions increases 10% in comparison to diesel when B50 blend of neem methyl ester was used (Mathiyazhagan et al. 2011).

g) Smoke number: It quantifies the emission of the smoke. It is a dimensionless quantity.

h) Oxygen content: Carbon dioxide, water vapor and heat energy are produced, when petroleum fuel burns in the presence of oxygen. Alternative fuels like biodiesel contain oxygen molecules as well as hydrogen and carbon. This promotes complete combustion. Therefore, less amount of soot, carbon monoxide and hydrocarbon are released enabling it to become a cleaner fuel.

Thermal and electrical parameters were determined and tabulated in Table 4. The tests were performed at a blend of 10% algal biodiesel with 90% diesel. The overall efficiency of the engine coupled electric generator at different load conditions were measured and summarized in Table 4.

Table 4. Thermal and electrical parameters of 10% blend of algal biodiesel with varying load condition

Load	Voltage (V)	Current (A)	Exhaust temperature (°C)	RPM	Time for fuel consumption (20 ml) in sec.
0	240	1	204	1580	138.86
20	246	44	233	1544	91.92
40	244	86	280	1495	73.37
60	234	125	343	1468	56.23
80	248	17.3	378	1440	40.20
100	232	20.8	445	1436	25.35

It was evident that the overall efficiency using biodiesel as a fuel was higher than the overall efficiency of the engine using diesel as fuel at all load conditions. This was mainly because of the oxygen content available in the biodiesel which improves the combustion process.

The obtained results indicated that biodiesel could be utilized in the place of diesel. Some experiments were essential to observe the performance of the vehicle at variable load starting from 0 to 100 Watts. At low load conditions, an engine works well, but as soon as the load increases, smoke capacity and exhaust temperature increases and rotation per minute (rpm) decreases.

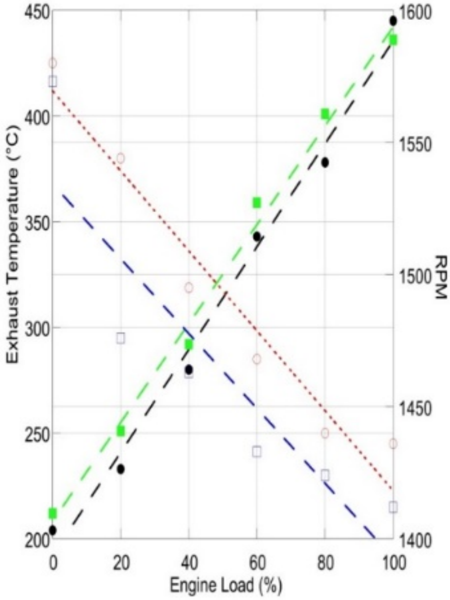
The consumption of the fuel was steady up to 60 watt but after that the consumption of fuel increased significantly. Emission rate also increased with increasing load, at full load rate, the emissions increased significantly.

The emission produced at the full load was black because of incomplete combustion, however the characteristics of the emissions at low load was promising. The emission rate of the biodiesel did not deviate much from the emissions in the case of diesel.

Also after combustion, petroleum fuel generated significant amount of ash particles when compared to biodiesel which generated a very little amount of ash. Therefore, it could be inferred that petroleum fuel operated vehicles are far more damaging in terms of pollution to the atmosphere than when compared to those of algae biodiesel.

3.4. Engine performance: blend vs. diesel

The exhaust temperature as a function of engine load for 10% biodiesel blend ranged from 204°C with no load to 445°C with 100% load, and for the diesel from 212°C to 436°C. As shown in Figure 2, the exhaust temperature and applied engine load are linearly correlated for both the biodiesel blend (at $R^2 = 0.98$) and diesel fuel ($R^2 = 0.99$).



Exhaust temperature and engine RPMs as a function of applied load; (□) Blend Temp; (□) Blend RPM; (□) Diesel Temp; (□) Diesel RPM

Fig. 2. Engine performance with 10% biodiesel blend (circles) as compared to pure diesel (squares)

The correlation between load and engine RPM is not as high ($R^2 = 0.95$ and $R^2 = 0.81$ for blend and diesel, respectively). Interestingly, though exhaust temperature appears to increase linearly with applied load, and the opposite for engine RPMs, there appears to be little difference between the blended and pure diesel.

That is, the values at each engine loading (correlating to intercept) are within 6% and 2% for temperature and RPM, and relative magnitudes of change (i.e. the slopes for each correlation) are only 4% and -8% different for temperature and RPM, respectively. In this sense, there is no penalty for using a blended biodiesel.

4. Conclusion

Algal blooms grows on the water bodies, such as water reservoir and ponds, as a consequence this stagnated water could be considered as being a harmful waste and instead could be utilized as a one of the best sources for biodiesel production. This process does not require high end technology hence being able to be used in energy generation processes in remote areas.

The calorific value of produced biodiesel could be found within the range of 5429-6438 cal/g, which indicates lower caloric value when compared to petroleum fuel. Afterwards, this oil was blended with diesel, furthermore being ignited in a single cylinder diesel engine to analyze the performance of the diesel engine. Thermal and electrical parameters were determined in this current paper and tests performed using algal biodiesel blend with diesel. The obtained results indicated that biodiesel could be comfortably utilized in the place of diesel. The power developed from an engine using biodiesel as a fuel was 6% less as compared to diesel because of the lower heating value of the biodiesel.

It is inferred that as per ASTM standards the fuel characteristics of algae biodiesel can be very qualitative when compared with diesel, biofuels and oils. One advantage of diesel, when compared to algae biodiesel is that it could work at a very low temperature; it will not freeze, however biodiesel freezes at very low temperatures. Therefore such a parameter of this type of biodiesel fuel needs to be improved in future so that this fuel could be utilized for various commercial purposes. Biodiesel has been produced from pond algae and its fuel – properties are in accordance with the ASTM standards, therefore, algae biodiesel could be used in the diesel engine.

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