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Evaluation of methyl ester of microalgae oil as fuel in a diesel engine

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HIGHLIGHTS

- The manuscript presents availability of methyl ester of microalgae oil as fuel.
- Fuel properties of diesel fuel, microalgae biodiesel and its blends were determined.
- The engine performance tests were carried out.
- Microalgae biodiesel was identified as a promising alternative fuel.

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ABSTRACT

Biodiesel can be obtained from various resources. However, the usage of vegetable oils as biodiesel source may impact global food market. Therefore, scientists focus on searching new biodiesel sources which are non-edible and easy to obtain. Microalgae have gained much attention recently due to their high growing rates and high oil contents. The objective of this study is to identify availability of microalgae biodiesel in diesel engines as alternative fuel. Microalgae biodiesel was blended with diesel fuel with the volumetric ratio of 5%, 10%, 20% and 50%. Fuel properties of blends and pure microalgae biodiesel were found out and the performance characteristics and exhaust emissions of the engine fueled with blends were analyzed. The results showed that, although microalgae biodiesel caused a slight reduction in torque and brake power values, the emission values of the engine using microalgae biodiesel were improved.

1. Introduction

Due to their higher thermal efficiency and durability, compression ignition engines are more useful than spark ignition engines in field of heavy transportation and agriculture sectors. However, rapid increase in transportation fuel demand, environmental concerns and depletion of fossil fuels forces scientists to develop vegetable oil-based derivatives that approximate the properties and performance of petroleum-based diesel fuel. Vegetable oils can be directly used in diesel engines as they have a high cetane number and calorific value, which are very similar to those of diesel. However, the brake thermal efficiency of vegetable oils is inferior to that of diesel. This leads to problems of high smoke, HC and CO emissions, however transesterification of vegetable oils results in better performance and reduced emissions. Biodiesel has a more favorable combustion emission profile, such as low emissions of carbon monoxide, particulate matter and unburned hydrocarbons. Due to its relatively high flash point and good lubrication properties, biodiesel became popular as a new alternative energy source [1–6]. Combustion of biodiesel alone provides over a 90% reduction in total unburned hydrocarbons (HC), and a 75–90% reduction in polycyclic aromatic hydrocarbons (PAHs). Biodiesel further provides significant reductions in particulates and carbon monoxide than petroleum diesel fuel. Biodiesel provides a slight increase or decrease in nitrogen oxides depending on engine family and testing procedures [7]. Recent investigations have indicated that the use of biodiesel can decrease 90% of air toxicity and 95% of cancers compared to common diesel source [8]. Currently, vegetable oils, waste cooking oils and animal fats are generally used as biodiesel feed stock; however, the limited supply of these feed stocks limits the further expansion of biodiesel production and the price of these feedstocks accounts for 60–75 of the total cost of biodiesel [9]. In addition to, the usage of vegetable oils as biodiesel feedstock has generated a lot of controversy, mainly due to its impact on global food markets and on food security. Currently, about 84% the world biodiesel production is met by rapeseed oil. The remaining portion is from sunflower oil (13%), palm oil (1%) and soybean oil and others (2%). Thus, instead of arable land being utilized to grow food, it is being used to grow fuel, in other words; by converting edible oils into biodiesel, food resources are actually being converted into automotive fuels [10,11]. The use of edible vegetable oils might cause starvation especially in the developing countries [12]. These problems have raised doubts about the potential of biodiesel to

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replace fossil fuels and sustainability of its production [13,14]. To reduce the dependency on edible oil, alternative biofuel sources, such as non-food feedstocks, have been developed to produce biodiesel since it is necessary to find new feedstock suitable for biodiesel production, which does not drain on the edible vegetable oil supply [15,16]. Recently, non-edible vegetable oils have been considered as prospective feedstocks for biodiesel production. This is mainly attributed to their ability to overcome the problems of food versus fuel crisis related to edible oils [17].

Microalgae are microscopic photosynthetic organisms that are found in both marine and freshwater environments [18]. Microalgae are considered as a second generation feedstock for production of biofuels since they have ability to synthesize high amount of lipids [19,20]. In addition to, biodiesel could be produced from various species of microalgae [21]. Two biggest advantages of microalgae are their fast growing ability and their high oil contents. Microalgae which can grow faster than terrestrial crops have doubling times down to 3.5 h during their exponential growth phase. Oil content in microalgae can exceed 80% by weight of dry biomass; however, oil levels of 20–50% are quite common [22]. Microalgae require much less land area than other biodiesel feed stocks of agricultural origin, up to 49 or 132 times less when compared to rapeseed or soybean crops [23].

A lot of researches have been conducted about usage of different oils in existing diesel engines as fuel [24–32]. However, most of these oils are edible. The emphasis of the present work is to experimentally evaluate the possibilities of using biodiesel developed from one of the most important non-edible resources: microalgae. Therefore, the objective of this study was to identify availability of microalgae biodiesel in diesel engines. Fuel properties of microalgae biodiesel and its blends were determined and the performance, emission and combustion characteristics of biofuel blends were evaluated.

2. Materials and methods

2.1. Biodiesel production

Microalgae oil used in biodiesel production was purchased from Soley Biotechnology Institute. During the microalgae biodiesel production, the necessary amount of catalyst (NaOH) for the transesterification reaction (0.4% by weight of the oil) was dissolved in methanol and added to the reactor after heating the microalgae oil to 65 °C; the reaction was performed at 60–61 °C and the mixture was stirred by the help of a magnetic stirrer at about 600 rpm during 1 h. After completion of the transesterification reaction, the mixture was cooled to room temperature and then transferred to a separatory funnel and separation of the ester and glycerin phases was performed by letting them stand for 8 h in the separatory funnel. The crude ester phase was washed 3 times with hot water at 1/5 water to ester phase ratio. After washing process, the mixture was waited in seperatory funnel during 30 min and by this way water is separated from methyl ester. Since purity level has strong effects on fuel properties, in order to provide water content to be less than 0.1, drying process was conducted by heating the biodiesel to 105 °C during 1 h until bright color occurred. Finally, filtering process was done in order to ensure that the end product is of excellent quality. Two batches of transesterification reaction were conducted. Therefore, two number of fuel samples were prepared in order to see the difference from batch to batch.

2.2. Property analysis

In this study, mixtures consisting of methyl ester produced from microalgae oil and diesel fuel were used as alternative fuel. 100% diesel fuel was also used as reference. MB (microalgae biodiesel) fuel and diesel fuel were mixed at the volumetric ratios of 5%, 10%, 20% and 50%. Mixtures were prepared just before the tests. Important physical fuel properties of diesel fuel, microalgae biodiesel and the mixtures were determined. The tests were performed three times, and averages of three results were taken for both fuel samples obtained from separate batches of transesterification reaction. The maximum coefficients of variation between the results were about 0.4% and 0.7% for three experiments and for two separate fuel samples, respectively. Therefore, the differences between results obtained from three experiments were insignificant for two separate fuel samples.

2.3. Experimental set-up

In this study, experiments were conducted on a four stroke, four cylinder diesel engine. Specifications and the schematic diagram of the engine are presented in Table 1 and Fig. 1, respectively. This engine was coupled to a hydraulic dynamometer which has torque range of 0–1700 N m and speed range of 0–7500 rpm to measure engine torque. Before starting to the experiment, the engine was operated with the new fuel for sufficient time to clean out the remaining fuel from the previous experiment. Engine performance values such as torque and specific fuel consumption were read by the help of a computer program of dynamometer control unit which can take values in two second time intervals and exhaust emissions such as CO and NO_X were obtained by the help of another computer program.

3. Results and discussion

3.1. Fuel properties

The measured physical fuel properties of microalgae oil, and methyl ester of microalgae oil are compared with those of diesel fuel and given in Table 2. The measured physical properties of microalgae biodiesel like density, viscosity, pour point and heating value are comparable with those of diesel fuel. It can also be observed from the Table 2 that except its low cetane number, all other measured properties of microalgae biodiesel are within the European Biodiesel Standard (EN 14214). However, low cetane number of microalgae can be compensated by mixing it with diesel fuel, as it can be seen from the Table 2, cetane numbers of all blends meet EN 14214 Standard.

3.2. Engine performance

3.2.1. Brake power and torque output

Fig. 2 shows the variation of brake power according to different engine speed values. As it can easily be seen in Fig. 2, power of the engine was reduced with increasing percentage of microalgae biodiesel in the blends (there is an average of about 6% reduction for B100 compared to diesel fuel). The reason of this reduction can be because of incomplete combustion of the fuel due to low cetane

Table 1
Technical specifications of the test engine.

Brand	Mitsubishi canter
Model	4D34-2A
Type	Direct injection diesel with glow plug
Displacement	3907 cc
Bore	104 mm
Stroke	115 mm
Power	89 kW @ 3200 rpm
Torque	295 N m @ 1800 rpm