

Performance and emission characteristics of biodiesel produced from fish oil after extracting omega 3 fatty acid

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Abstract. The dynamic working nature of modern industries demand huge energy requirement to sustain their operation. Till date, fossil fuels are the primary energy sources and their extinct being a serious threat to many industries including automotive sectors. Biodiesel fuels are limelight to many industries due to their inherent carbon neutral and eco-friendly characteristics. Waste oils (fish oil) is a potential biomass feedstock which offers excellent technological benefits over petroleum and other vegetable oils. The biodiesel (i.e. residue from fish oil after extracting omega-3 fatty acid) production is done with two-stage transesterification process. Biodiesel at different proportions (B10, B20, B30 B100 indicate 10%, 20%, 30% and 100% of biodiesel) are blended with neat diesel fuel to know the practicality of fuel properties, performance and emission characteristics. The performance and emission characteristics are tested at different loading (from no-load to full load) conditions of single cylinder compression ignition engine. The B10 designated fuel resulted in close proximity values of conventional diesel in terms of fuel properties, performance and emission characteristics.

1. Introduction

Exponential increase in energy demand in the past few decades are be due to rapid urbanization and industrialization. Urbanization of developing countries practically rely on energy (i.e. renewable and non-renewable) sources [1]. The fossil fuels are the primary source of fulfilling such energy requirements [2]. Industries and transport sectors are dependent primarily by fossil fuels. The exhaustion of fossil fuels in the next few decades could increase costs and associated impact on global warming and green-house gas emissions are the primary reasons require extensive research on alternate fuels for future [3, 4].

Biodiesel seen to be the potential alternate to diesel fuel that compensate for high energy demand.



In addition, use of biodiesel do not seek major modification to the existing diesel engine. Biodiesel production from renewable energy sources (oils derived from plant and animal fat) possess excellent features such as biodegradability, nontoxic, carbon neutral and ecofriendly [5]. In recent years, edible (soybean, sunflower, coconut, palm, pine and so on) and non-edible (muhua, karanja, jatropha, rubber seeds, algae etc.) oils are used as a potential source for the production of biodiesel [6]. India has world's second largest population and the fulfillment of huge energy demand with edible and non-edible oils has been criticized due to its low sustainability, shortfall of agriculture land, conflict with food and fiber production [7]. The feedstock (raw material) price is a key factor which accounts approximately 70-95% of total biodiesel production cost [8]. Edible and non-edible oils grown particularly for biodiesel production is treated uneconomical due to their high raw material cost [9]. Fish oil (i.e. residue after extraction of omega-3 fatty acids) is used as a source for biodiesel production is treated sustainable due to their minimal processing steps. The biodiesel (i.e. 10%, 20%, 30%, 100% designated as B10, B20, B30, and B100) are blended with diesel fuel are tested (i.e. fuel properties, performance and emission characteristics) for their practical usefulness. The performance such as break thermal efficiency (BTE), break specific fuel consumption (BSFC) and emission characteristics namely carbon monoxide (CO) and hydrocarbon emission were tested at different loading conditions (from no-load to full load) in a single cylinder compression ignition engine.

2. Materials and Methods

The fish oil was extracted from fish wastes utilizing indigenously developed oil extraction machine. The fish oil is transformed to biodiesel viz. the two-step transesterification process. Two stage transesterification process was conducted using the magnetic stirrer with hot plate maintaining constant speed and temperature. The chemicals such as sulphuric acid, sodium hydroxide and methanol with different grades were used during the transesterification process.

2.1 Biodiesel production from fish oil after recovery of omega-3 fatty acid

During the first step, the free fatty acid (FFA) level of fish oil was reduced by esterification process. The process uses one litre of fish oil, methanol (oil-to-molar ratio of 1:6) and 2% sulphuric acid solutions. The solutions are subjected to an esterification treatment by maintaining the mixture to a fixed temperature of 60 °C for 2-hour duration, with constant stirring on hot plate. Two distinct layers (i.e. acid esterified oil separated with residue) are formed upon cooling the solution. The oil was water washed to remove the pigments (present if any) and the remaining water in oil was removed subjected to heating process. Thereby the sulphuric acid-catalysed esterification treatment process reduces the free fatty acid level of the fish oil.

In the second step, the solutions composed of reduced free fatty acid oil, methanol (20%), sodium hydroxide (0.4% wt./volume) base catalyst is then subjected to undergo transesterification process. During transesterification process, the prepared solution is maintained to a temperature of 60 °C for 1-hour duration with a constant stirring subjected to a speed of 1500 rpm. Upon cooling the mixture, the solution is separated with the formation of two-layer (i.e. top layer is biodiesel/methyl ester and the bottom layer appeared with glycerin). The biodiesel obtained is then washed with distilled water followed by separating the solution with the help of a funnel. The traces of water (present if any) in the biodiesel is then removed after subjected to a temperature maintained at 90 °C.

2.2 Testing the fuel properties of diesel and biodiesel blends

The fuels such as B10 (10% Biodiesel + 90% Diesel), B20 (20% Biodiesel + 80% Diesel), B30 (30% Biodiesel + 70% Diesel) and B100(100% Biodiesel + 0% Diesel) and D100 are tested to know the fuel properties. The properties of biodiesel blends and diesel fuel are tested to know their basic properties such as kinematic viscosity, density, flash point, fire point and heating values. Table 1 show the results of fuel properties of diesel and biodiesel blends.

Table 1. Fuel properties of biodiesel blends and diesel oil

Properties	Units	B10	B20	B30	B100	Diesel oil
Viscosity at 40 °C	cSt	4.21	4.33	4.48	5.2	4.1
Density	kg/m ³	803	807	811	832	800
Flash point	°C	62	76	92	167	55
Calorific Value	MJ/kg	43.2	42.8	40.3	36.3	44.8
Cloud Point	°C	-4.7	-3.2	-1.5	6	-7

3. Results and Discussion

This section discussed the results of fuel properties, performance and emission characteristics of diesel and biodiesel blends.

3.1 Fuel properties

3.1.1 Effect of kinematic viscosity. Viscosity of a fuel is tested to know the resistance offered by a fuel to flow. Viscosity is an important fuel property (in an engine the viscosity decreases with the increase in temperature) which affects the fuel injection system and spray atomization process [10-12]. Table 1 show the biodiesel viscosity found to be comparatively higher than that obtained for diesel might due to their large molecular structure and mass [12]. Furthermore, kinematic viscosity increases with the increase in methyl ester in the prepared biodiesel blended fuel. It was observed that the biodiesel up to 30% in diesel fuel showed approximately closer kinematic viscosity compared to diesel fuel (refer Table 1). Higher viscosity of biodiesel (i.e. B100 of 5.2 cSt) leads to improper atomization as a result of higher deposition of carbon and heavy gum on the different parts (piston, piston ring, fuel injector and cylinder wall) of an engine [13].

3.1.2 Effect of Density. The performance of an engine is generally affected by the density of a fuel. In general, biodiesel fuels are denser due to their higher molecular weight. Table 1 show the density of biodiesel and diesel fuels. The density of biodiesel blends (B10, B20 and B30) showed closer values to that obtained for diesel fuel. Higher density fuel is generally not recommended as they influence directly on the performance of fuel injection timing, spray pattern and amount [14]. In other words, the fuel droplet size tends to increase with increase in density as they affect both on the performance and emission characteristics of an engine [15, 16]. It was observed that B10, B20 and B30 biodiesel blends showed close density (803- 811 kg/m³) values when compared with neat diesel fuel (800 kg/m³).

3.1.3 Effect of Flash point. The temperature at which the fuel starts to burn when it comes in contact with a flame or spark referred as flash point [17]. Although the engine performance is not directly affected by flash point but the desired high flash point temperature could definitely support for safe handling, transport and storage. Biodiesel showed higher flash point (62-167 °C) compared to that of conventional diesel fuel (55 °C) (refer Table 1).

3.1.4 Effect of Heating value. Heating or calorific value of a fuel is an important fuel property which determines the energy content of the fuel. High calorific value of a fuel generally enhances the engine combustion characteristics and thermal efficiency [18]. Table 1 showed the diesel fuel (D100) possess higher calorific or heating value compared to biodiesel blends might be due to the presence of long carbon chain [19]. The heating value decreases with increase in biodiesel fuel in the prepared blends. The B10 and B20 fuels showed close values of heating or calorific value compared to that of conventional diesel fuel.

3.1.5 Effect of Cloud point. Cloud point is another important fuel property tested to know their practical usefulness of an engine operated under low temperature condition. Higher fatty acids in biofuels resulted in high cloud point compared to that of conventional diesel fuel (refer Table 1). Higher cloud point in biofuels limit their use (i.e. run the engine) under low climatic conditions [20]. B10 fuel (-4.7

°C) showed approximately closer values of cloud point compared to that obtained for a diesel fuel (-7 °C) (refer Table 1).

3.2 Engine performance characteristics of diesel and biodiesel blends

The performance (BTE and BSFC) and emission (CO and HC) tests of diesel and biodiesel fuels are conducted under different loading conditions (i.e. 0.4, 4, 6, 8 and 10 kg) on a computerized single cylinder 4-stroke water cooled diesel engine. Note that the engine was operated under the constant speed of 1500 rpm. The specification of diesel engine used for testing the different fuels performance and emission characteristics are presented Table 2.

Table 2. Specification of Computerized Diesel Engine

Make	Kirloskar
Model	TV1
Number of cylinders	1
Number of strokes	4
Fuel	H S diesel
Rated power	5.2 kW at 1500 RPM
Cylinder Diameter	87.5 mm
Stroke length	110 mm
Compression ratio	17.5:1
Orifice diameter	20 mm
<u>Dynamometer arm length</u>	<u>185 mm</u>

For each loading condition, prior to record the results of performance and emission characteristics of a fuel the engine was allowed to run for about 15-20 minutes. This was done to stabilize the engine to record the accurate values. The load was varied from 0.4 to 10 kg and recorded the BTE and BSFC for different fuels (biodiesel and diesel). For all the loading conditions the engine is set to operate under the constant speed of 1500 rpm. Figure 1 shows the computerized diesel engine test rig used for the present work.



Figure 1. Computerized diesel engine test rig

3.2.1 Brake specific fuel consumption (BSFC). BSFC is a measure of fuel efficiency of the engine which develops the shaft power. Figure 2 show the variation of BSFC with different loads. It was clear that the BSFC of all the biodiesel fuels are higher than that of diesel fuel (refer Figure 2). In addition, BSFC increases with the increased percent of engine loads. This occurs due to the fuel properties of biodiesel namely high density and viscosity with low heating value [21]. The BSFC of B10 designated bio fuel resulted in close values with conventional diesel fuel.

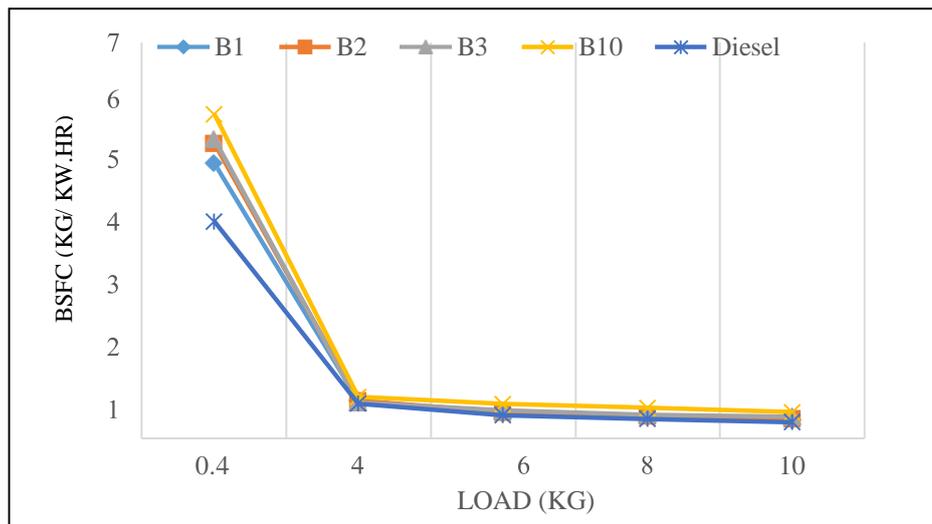


Figure 2. BSFC vs. Load

3.2.2 Brake Thermal Efficiency (BTE). BTE refers to the ratio of brake power to the heat energy supplied with considerable friction losses. Figure 3 show the BTE (%) of biodiesel and diesel fuel at different loading conditions. BTE decreases with the increase in biodiesel fuel in diesel fuel for all the engine load testing conditions. It was observed also that the BTE increases with the increase in engine load (refer Figure 3). BTE of biodiesel fuel (B10) showed closer values (27.98%) compared to that obtained for diesel fuel (31.18%) at 10 kg engine load.

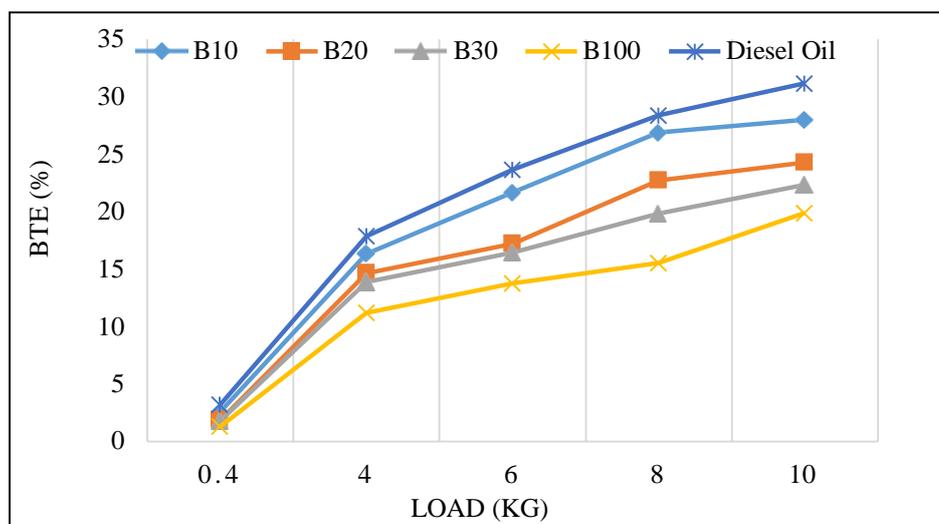


Figure 3. BTE vs. Load

3.3 Emission characteristics of biodiesel and diesel fuel.

Conventional diesel oil generally emits higher emission from the engine exhaust. Higher emission generally results in poor health (i.e. causes lung cancer, respiratory, blood circulation problems, nose irritation, sneezing, and coughing problems) [22]. Gas analyzer emission test device is used to record the CO and HC emission (refer Figure 4). Therefore, study of emission characteristics of biodiesel fuels at different engine load conditions are of industrial and environmental relevance.



Figure 4. Gas analyser

3.3.1 Carbon monoxide (CO) emission. Figure 5 show the carbon monoxide emission at different loading conditions for all biodiesel and diesel fuels. The CO emission tends to decrease with increased percent of biodiesel in diesel fuel from no-load to full load condition (0.4 to 10 kg). Note that, B100 fuel resulted in very less carbon monoxide emission might be due to their presence of excess oxygen molecules presented in the chain. At full load condition (i.e. 10 kg), B100 fuel showed 50% reduction in carbon monoxide emission compared to that that of diesel fuel.

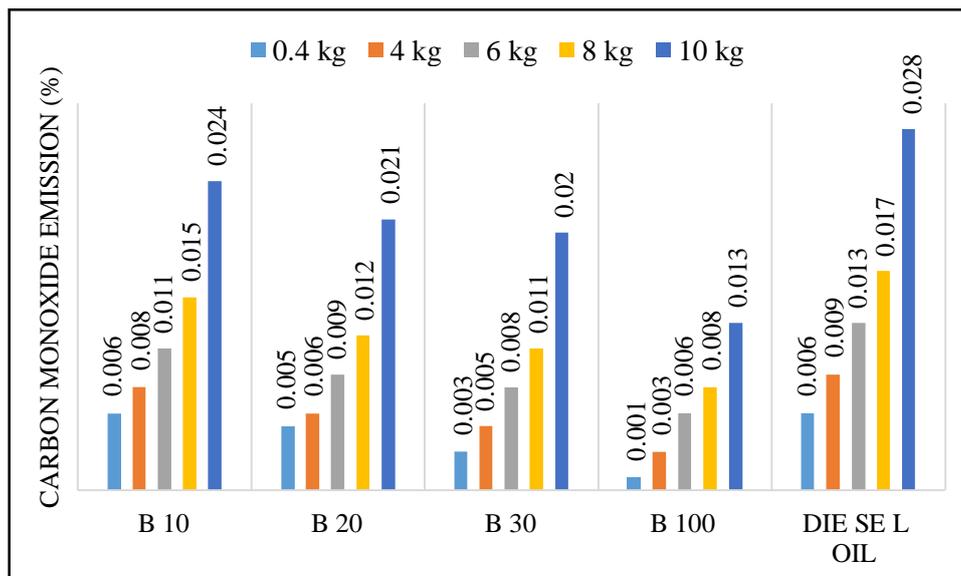


Figure 5. CO emission of biodiesel and diesel blends with different loading condition

3.3.2 Hydrocarbon (HC) emission. HC emissions are more common in diesel engines. The HC possess close affinity to diesel particulates which may cause lung disease. Figure 6 show the variations of HC emission tested under different loading conditions of both biodiesel and diesel fuels. Increased percent of biodiesel in the blends resulted in reduced HC emissions. Hydrocarbon emissions under full load condition (i.e. 10 kg) of B10 to B100 (19 to 7 ppm) is comparatively lesser than that obtained for diesel fuel (22 ppm).

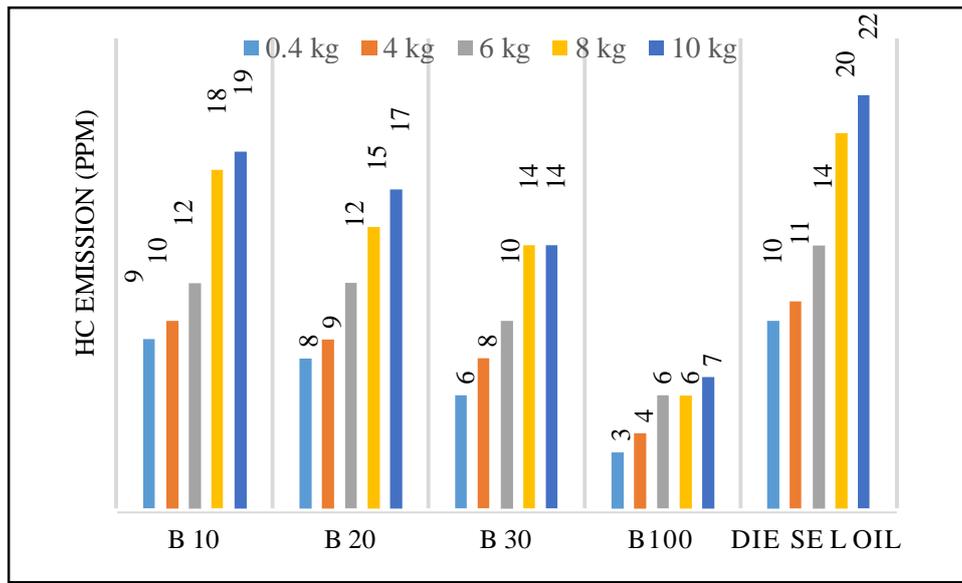


Figure 6. HC emission of biodiesel and diesel blends with different loading condition

4. Conclusions

Fish oil (residue after extraction of omega-3 fatty acids) is a sustainable fuel in terms of economical, technological and societal benefits. Two-step transesterification process is used to convert the fish oil the biodiesel. The practicality of prepared biodiesel is tested for fuel properties and compared with that of diesel fuels. In addition, the performance and emission characteristics of biodiesel blends and diesel fuels are tested subjected to 0.4 to 10 kg loading conditions. The following key points are discussed as follows,

1. Higher FFA of fish oil is reduced when it is subjected to two-step transesterification process. The kinematic viscosity and density of biodiesel blend (B20) showed close proximity values with diesel fuel under all loading conditions. Note that, higher FFA in biodiesel blends resulted in high cloud point which limit to run the engine subjected to lower climatic condition. B10 fuel closely resembles the cloud point of diesel fuel. High flash point of biodiesel favors safety handling and transport.
2. The BTE and BSFC of the biodiesel and diesel fuels are tested under different loading conditions. BTE and BSFC of all biodiesel fuels are higher compared to diesel for all the loading conditions. At 10 kg load, B10 designated biodiesel fuel resulted with close values of diesel fuel with regard to BTE and BSFC. Biodiesel resulted with low values of BTE, might be due to the poor mixture formation that could results in slow combustion.
3. The biofuels emit lesser CO and HC at all loading conditions compared to diesel fuel. Lesser emissions might be due to the oxygenated fuel (i.e. biodiesel) supports better combustion.

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