

Preparation, Characterization and Engine Performance of Biodiesel Fuel Derived from Waste Cooking Oil and its Blends

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Abstract: The crude oil price hike, depletion of petroleum product reserves and global warming due to fossil fuel emissions has stimulated the researchers to explore alternative energy resources. The objective of this research was to prepare biodiesel from waste cooking oil and to study the performance characteristics in a diesel engine without any modification. In this work, biodiesel was prepared from waste cooking oil collected from a local restaurant in Multan, Pakistan. The prepared biodiesel was blended with petroleum diesel at different proportions and characterized for physicochemical properties using ASTM standard methods. A 5.5-kW water-cooled single-cylinder direct injection diesel engine was used to measure brake Specific fuel consumption (BSFC), brake thermal efficiency (BTE) and exhaust gas temperature of the engine fuelled with petroleum diesel B0, biodiesel blends B10, B15 and B20 fuels.

Keywords: Waste Cooking Oil; Biodiesel Blends; Alternate Energy; Diesel Engine; Performance Parameters

1. Introduction

The major reasons to explore for alternatives to petro diesel are high price of petroleum products, limited reserve of the fossil fuels, environmental concerns due to CO₂ emissions and growing demands of energy at faster rates throughout the world [1-3]. Biodiesel has gained a huge interest over the globe due to renewability, biodegradability and its environmental benefits [4-6].

Biodiesel is an eco-friendly and most prominent fuel resource as it emits less pollutant emissions as compared to petroleum diesel. Besides all these benefits, biodiesel increases the engines lubricity due to higher viscosity and contributes to environmental sustainability [7-8]. Dumping of waste vegetable oils is an environmental problem. These waste oils are mostly dumped into the water bodies which disturb the ecosystem by forming an oily layer on the surface of water thereby reducing the oxygen exchange. Furthermore, disposal into the sewerage systems jams the flowing pipes producing offensive smell and over flowing of sewer pipelines might cause different types of fatal diseases. Therefore, recovering and reusing waste veggie oils is the need of the time [9].

Recycling of waste veggie oil to produce biodiesel is a convenient route to manage this issue [10]. It is reported that Biodiesel contains 10–11% oxygen by weight but it contains no sulfur, no aromatic and has higher cetane number than diesel fuel [11]. Neat (unprocessed) vegetable oils cause several problems in the compression ignition engines due to its high viscosity [12].

Production of biodiesel is possible by transesterification of animal fats and vegetable oils with an alcohol in presence of a catalyst. However, the use of edible oil for biodiesel feedstock production competes with the food production. Moreover, the price of vegetable oil and edible plant installation is more than petroleum diesel. The waste cooking oil being cost effective and easily available is a good candidate to be used as a feedstock to produce biodiesel as biodiesel feedstock reduces the cost of biodiesel production [11, 13].

Biodiesel is an environmental friendly alternative fuel for diesel engines without major modifications. It can be obtained from vegetable oils and animal fats through transesterification process. It reduces green house emissions as compared to conventional diesel

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[14-15]. It is addressed by many researchers that biodiesel and its blends are suitable to be used as fuel or as additives to diesel [16-20]. Recently considerable research work has been carried out to understand biodiesel production technology as well as performance characteristic of biodiesel-fuelled engines[21-22].

The Aim of this research was to prepare biodiesel and its blends with petroleum diesel in different proportions by using waste cooking oil, a cheap resource in Pakistan and to assess its suitability to be used in a diesel engine as an alternative fuel. Transesterification process was used to prepare biodiesel. In present work, pure diesel BO, biodiesel blends B10, B15 and B20 were studied for physicochemical properties and engine performance characteristics like BSFC, BTE and EGT. The results were compared to the diesel fuel.

2. Materials and Methods

2.1 Engine Setup

A 5.5-kW single cylinder water cooled direct injection diesel engine has been examined in this study. The details of the engine specifications are given in **Table-1**. The engine was coupled to a hydraulic dynamometer for the measurement of the torque. A laser sensor was used to measure the engine speed. A calibrated load cell was attached with the dynamometer. An electronic weighing scale was used to measure fuel flow rate. The performance parameters were measured as per ISO-3046 standard [24]. Exhaust gas temperature was directly measured by using thermocouples. Before every measurement is taken, the engine was run first at the rated speed of 1500rpm to attain the steady speed. The output signal was collected by a data acquisition board and sent to PC for post processing.

Table-1: Test Engine Specifications

Engine	Specifications
Type	Four stroke engine
Method of Cooling	Water Cooled
Compression ratio	17.5:1
Bore x Stroke	87.5mm x 110mm
Number of Cylinders	One
Type of ignition	Compression ignition
Rated power	5.5 kW
Rated Speed	1600rpm
Initial injection	23 crank angle degrees BTDC
Injection Pressure	15-20 MPa

2.2 Samples Collection

The waste cooking oil was collected from a local restaurant (Eaton Bar BQ Restaurant) in Multan, Pakistan, which serves continental as well as fast foods. The cooking oil used was known to be the

canola oil. Three liters of the waste oil sample were collected as per standard sampling procedures. Physicochemical properties of waste cooking oil and canola oil are given in **Table-2**.

Table-2: Physicochemical properties of oil feed stocks [23].

Property	Waste Cooking Oil	Neat Canola Oil
Acid value (mg KOH/g)	2.1	< 0.5
Kinematic viscosity at 40oC (cSt)	35.3	30.2
Fatty acid composition (wt.%)		
Myristic (C14:0)	0.9	0.1
Palmitic (C16:0)	20.4	5.5
Palmitoleic (C16:1)	4.6	1.1
Stearic (C18:0)	4.8	2.2
Oleic (C18:1)	52.9	55
Linoleic(C18:2)	13.5	24
Linolenic(C18:3)	0.8	8.8
Arachidic (C20:0)	0.12	0.7
Eicosenic (C20:1)	0.84	1.4
Behenic(C22:0)	0.03	0.5
Erucic (C22:1)	0.07	0.4
Tetracosanic (C24:0)	0.04	0.3
Mean molecular wt (g/mol)	856	882

2.3 Transesterification of Waste Cooking Oil

3.70g NaOH was dissolved in 200ml Methanol in 500 ml conical flask to obtain sodium methoxide solution. The waste cooking oil was first heated at elevated temperature (110°C) to remove moisture content and then cooled to 50 °C. One kilogram of this preheated waste vegetable oil was weighed and transferred to the sodium methoxide solution. The mixture was placed on hot plate having magnetic stirrer 55 °C for about 70 minutes to complete the transesterification reaction. Now, the covering of the flask was removed to evaporate the extra methyl

alcohol for about half an hour. Then the mixture was transferred to the separating funnel and left for 24hrs in a vertical position. Two distinct liquid phases appeared inside the funnel. The top layer was crude biodiesel and the lower layer was glycerin. The Biodiesel layer was separated out and further purified by washing with de-ionized water (30 % by volume of biodiesel) and dried with Na₂SO₄ followed by filtration to obtain pure biodiesel (waste cooking oil methyl esters). After preparation of biodiesel, its blends were prepared as shown in **Table-3** for further analysis.

Table-3: Petroleum Diesel and biodiesel blends Composition

Sr. No	Description	Petroleum Diesel (Volume)	Biodiesel (Volume)
1	B0	1000ml	0ml
2	B10	900ml	100ml
3	B15	850ml	150ml
4	B20	800ml	200ml
5	B100	0ml	1000ml

2.4 Analytical Methods

Different physicochemical properties of petroleum diesel (B0) and biodiesel blends B10, B15 and B20 were performed as per American Society of Testing Materials (ASTM) standards. The Standard Methods ASTM D-1298, ASTM D-445, ASTM D-240-17, ASTM D-93, ASTM D-97, ASTM D-664, ASTM D-95 were used for the determination of Density Kg/m³, Kinematic Viscosity cSt, Calorific Value KJ/kg, Flash Point °C, Pour Point °C, Acid Value mgKOH/g and Water Contents correspondingly.

3. Results and Discussions

3.1 Fuel Properties

Different fuel properties of biodiesel (B100) obtained from waste cooking oil and its blends with petroleum diesel (B10, B15 & B20) were determined as per ASTM Standards as mentioned in section 2.4. The results are summarized in **Table-4**. It has been observed that the fuel properties of biodiesel blends are comparable to those of petroleum diesel and all the results were found within the European (EN 4214) and American (ASTM D6751) standard limits of biodiesel fuel.

Table-4: Fuel Properties of diesel, biodiesel and its blends

Fuel Type	Density, (Kg/m ³)	Kinematic Viscosity at 40°C, (cSt)	Heating Value (KJ/kg)	Flash Point (°C)	Pour Point (°C)	Acid Value (mgKOH/g)	Water Contents (mg/l ⁻¹)
B0 (HSD)	834	2.66	43200	58	-15	-	75
B10	838	2.99	42370	66	-12	0.18	150
B15	842	3.08	41800	71	-9	0.2	170
B20	848	3.14	41325	82	-6	0.25	188
B100	861	4.5	37840	165	6	0.38	410
ASTM D6751	-	1.9 to 6.0	-	> 120	-	<0.50	<500
EN14214	860 to 900	3.5 to 5.0	-	> 120	-	<0.50	<500

3.2 Engine Performance

3.2.1 Brake Specific Fuel Consumption

Figure-1 illustrates the variations of the brake specific fuel consumption with engine load for

petroleum diesel and biodiesel blends B10, B15 and B20. It was observed that with an increase of biodiesel proportion in the fuel blends, BSFC was found to increase. BSFC values of diesel, B10, B15

and B20 were found 271.36, 279.40, 284.22 and 292.66 g/kW h respectively at maximum load. The BSFC values of B10, B15 and B20 were 2.96%, 4.73% and 7.85% higher than those with petroleum diesel. The 10% blend shown the minimum BSFC

value among the tested fuel blends. With increase in the loading for all the fuels tested BSFC was found to decrease sharply. This may be due to fewer amounts of heat losses at higher loads.

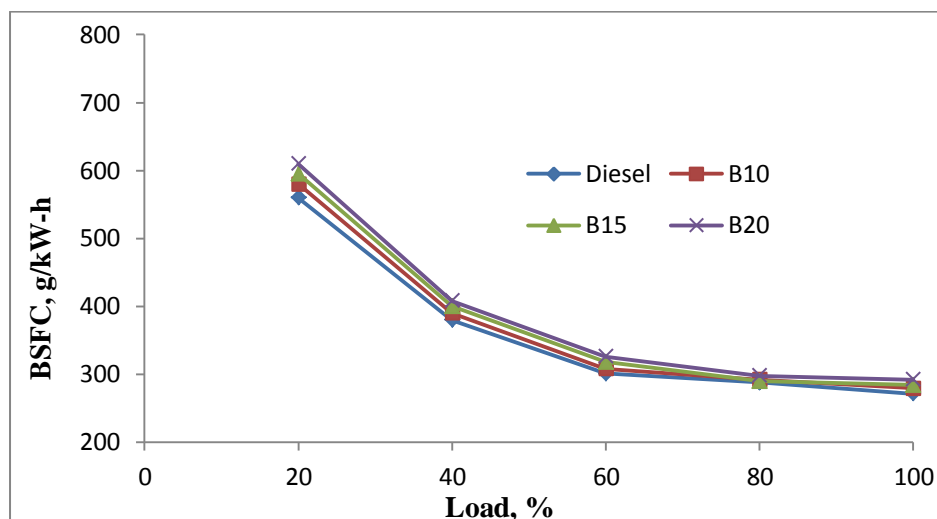


Figure-1: Variations of BSFC with engine load

3.2.2 Brake Thermal Efficiency

BTE behavior of diesel engine when operated with diesel, B10, B15 and B20 at various engine loads is plotted in Figure-2. With diesel, B10, B15 and B20, the BTE value were found to be 32.68%, 32.18%, 31.88% and 31.51% correspondingly at full load. As compared to diesel, the BTE values of fuel blends

were decreased with increasing levels of biodiesel proportions in the blends. This is due to the less heating (calorific values) of the blends. There was improvement in BTE with increase in engine load because the engine had lost its less power along with the engine load increase.

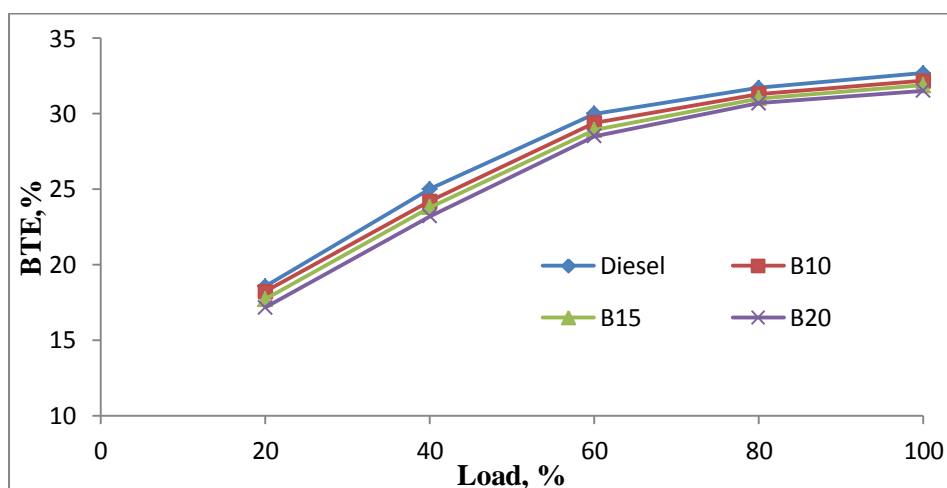


Figure-2: Variations of BTE with engine load

3.2.3 Exhaust gas temperature

Variations of EGT of a diesel engine when operated with diesel, B10, B15, B20 at various engine loads are shown in Figure-3. EGT was observed to rise with increased concentrations of biodiesel in the blends as well as with increase in engine loads. The EGT values of B10, B15 and B20 were found 306 °

C, 308 °C and 312 °C respectively at maximum load, which were 4.43%, 5.11% and 6.4% higher than that with diesel (293 °C). The increase in EGT with heavier loads is due to the fact that the engine requires high amount of fuel to create extra power to take up the additional loads.

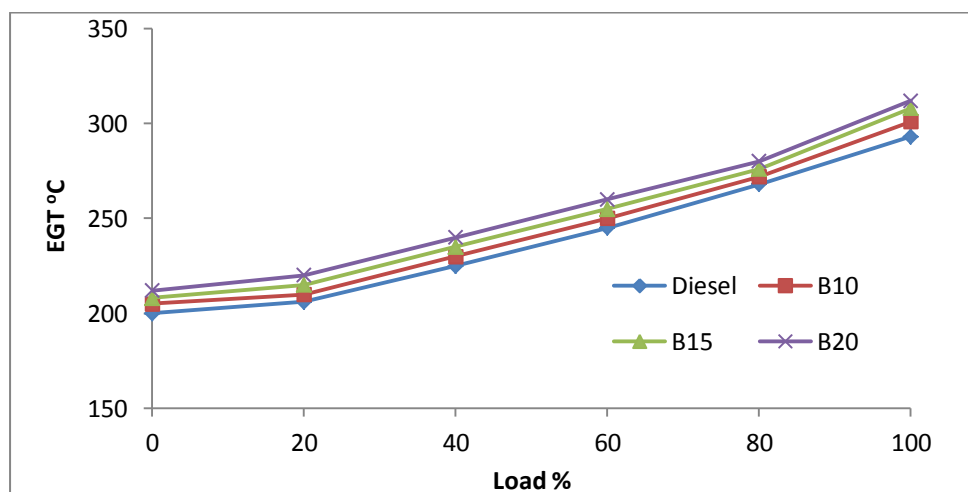


Figure-3: Variations of EGT with engine load

4. Conclusions

Based on current study following properties have been made:

1. All the fuel properties of the biodiesel blends (B10, B15 and B20) obtained from waste cooking oil were found within the specified international standard (ASTM 6751 & EN14214) limits.
2. The fuel properties of blends B10 and B15 having fewer concentration of biodiesel were comparable to those with petroleum diesel.
3. BSFC of the diesel engine when operated with B10, B15 and B20 blended fuels as compared to diesel fuel was observed to increase 2.96%, 4.73% and 7.85% respectively and EGT was found to increase 4.43%, 5.11% and 6.4% respectively. However, BTE was found to decrease by 1.52-3.58% with increase in the concentration of biodiesel in the fuel blends.
4. B10 has shown lower BSFC (279.40 g/kWh) and EGT (302 °C) as well as BTE value closer to that of petroleum diesel among all the blends of biodiesel examined.
5. On the basis of lower fuel consumption, closer fuel properties and BTE value of B10 to those of petroleum diesel, it is very much obvious that B10 biodiesel fuel blend can be used as an alternative fuel in diesel engines without any engine modification.

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