

Evaluation of Chemical and Physical Properties of Biodiesel Produced from Used Edible Vegetable Oil

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The dependence on petroleum as the primary source of energy has led to increased demand for the product. This is despite its high cost and degradation effects on the environment. This study examines the suitability of using biodiesel derived from used edible oils as an alternative for diesel fuel. Biodiesel was produced by reacting used edible oils and methanol in the presence of Potassium-hydroxide as a catalyst. Chemical and physical properties of the biodiesel were characterized by carrying out the properties: density, viscosity, calorific value, sulphur content, copper strip corrosion, cloud point, Cetane index and effects of preheating the oil on engine performance was studied. Comparative engine performance tests were then conducted on a Ford 86 BHP-6 cylinder, water-cooled turbo charged diesel engine in terms of thermal efficiency and brake specific fuel consumption. The results (density (879 kg/m³), viscosity (4.35 mm²/s), calorific value (38.52 MJ/kg), sulphur content (0.02 mass %), copper strip corrosion (1A), cloud point (12), Cetane number (45.35)) were found to be comparable to those of diesel. Engine performance tests showed biodiesel performance in terms of thermal efficiency to be comparable with that of petroleum derived diesel fuel. The brake specific fuel consumption of the biodiesel was however 12% higher than that of diesel fuel. Preheating of biodiesel to 35°C reduced this difference to 7.8% and increased the thermal efficiency from 30.04% to 31.34%.

Key words: Biodiesel, used edible oils, preheat, trans-esterification, density, viscosity, calorific value, sulphur content, copper strip corrosion, cloud point, Cetane number and effects of preheating of the oil on engine performance

Introduction

Over the years, the diesel engine has been a subject of research, with initial emphasis on devices and procedures that minimize fuel consumption (Emslie *et al.*, 2002). Current research focus is on production of alternative fuels with reduced negative effects on the environment. Vegetable oils are considered as most promising substitute for the highly priced and diminishing fossil fuels (Munavu and Odhiambo, 1984). However, using raw vegetable oils can cause engine problems such as gumming up of engine parts by polymerised oil, carbon build-up, lubricating

oil contamination, corrosion of engine parts and solid deposits in the engine (Holfman *et al.*, 1981; Romano, 1982; Pullan, 1981). Most of these problems are a consequence of the high viscosity of the vegetable oils but they can be minimized by converting the oil to biodiesel through transesterification (Rajesh *et al.*, 2009).

Trans-esterification refers to a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid alkyl esters (i.e., biodiesel) and glycerol (Zang *et al.*, 2003). This process makes the properties of the vegetable oils and animal fats comparable to those of diesel fuel. The primary advantages of biodiesel are that: it is renewable, non-toxic and biodegradable (Gerpen *et al.*, 2004). Because of similarity in properties, biodiesel can partially or entirely be used as a substitute for diesel fuel in compression ignition engines (Pasqualino, 2006). It has also been shown that Engine efficiency of biodiesel is comparable to that of diesel fuel (Kalligeros *et al.*, 2003).

The economic feasibility of biodiesel produced from edible oils depends on the price of crude oil. Furthermore, biodiesel production costs can be reduced by using less expensive feedstock containing fatty acids such as inedible oils, animal fats, and used cooking oil and by products of the refining vegetables oils Veljkovic *et al.*, (2006). Although used edible oil has been studied as potential feedstock for biodiesel production, the presence of free fatty acids (FFA) presents some technological challenges. The high temperatures of a particular cooking processes and the water from the foods accelerate the hydrolysis of triglycerides and increase the FFA content in the oil (Xiaohu, 2009). Mittelbach *et al.*, (1992) found that heating oil for long duration of time led to an increase of FFA content of up to 10%, and this could have detrimental effects in transesterification. Dorado *et al.*, (2002) showed that no esters would be formed during transesterification, if the FFA content is larger than 3%, and that the higher the acidity level the lower the conversion ratio or reaction efficiency. They further noted that excess as well as less catalyst, and the presence of water in the oil during transesterification, may lead to soap formation. Previous studies have shown that acid catalysts are too slow (Canakci and Van Gerpen, 1999). For alkaline catalysed process, the oil should not contain more than 1% FFA as soap will be formed that will lead to reduction in conversion rate (Mittelbach *et al.*, 1992).

Used edible oils have been successfully converted to biodiesel and good results have been reported. Nye *et al.*, (1983) prepared esters of used frying oil to determine their effects on engine performance and emissions. The esters of methanol, ethanol, 1-propanol, 1-butanol and 2-ethoxyethanol were prepared using sulphuric acid and KOH as acid and base catalyst respectively. They found out that all acid-catalyzed fuels had low viscosities, but all base catalyzed fuels had high viscosities except for methanol-based fuel. In the study, the three fuels with the lowest viscosities (methyl esters prepared with base catalysts, ethyl esters prepared with acid catalyst and butyl esters prepared with acid catalyst) were tested in half hour runs in a high-speed diesel engine and in a Perkins low-speed engine and no problem was reported.

Preheating has been studied as a means of further reducing the viscosity of biodiesel. It has been shown that preheating oil prior to injection leads to increase in thermal efficiency and reduction in fuel consumption as the low viscosity will lead to improved atomisation and better combustion of the fuel in the engine (Satyanarayana and Rao, (2009); Ingle *et al.*, (2011)).

In this study, the production process and performance evaluation of biodiesel obtained from used edible oils is reported.

Materials and Methods

Oil processing

The oil used in this study was obtained from The University of Nairobi cafeteria kitchens and several fast food restaurants within Nairobi city. The used vegetable oil was processed to biodiesel in the four steps described below:

Purification. Collected used cooking oil was heated to about 100°C for about thirty minutes while stirring to reduce water content in the oil. The hot oil was sieved to remove solid particles and debris.

Titration. To determine the amount of KOH required for titration of free fatty acids, the following procedure was used. 1 gram of NaOH was dissolved in one litre of distilled water make a 0.1 % lye solution. 1 ml of dewatered used vegetable oil was mixed with 10 ml of isopropyl alcohol in a 50 ml flask. The mixture was warmed in hot water while stirring until the oil completely dissolved in alcohol. Two drops of phenolphthalein indicator was added to the oil. The lye solution was added drop wise to the resulting mixture while stirring until the solution turned and stayed pink for about 15 seconds. The number of millilitres of lye solution used for titration plus 3.5 (amount required for fresh oil) is the number of grams of NaOH required per litre of oil. Since KOH was to be used for trans-esterification, the basic lye quantity had to be adjusted to equivalent strength of KOH.

Transesterification. Potassium-methanoxide that was prepared by dissolving Potassium Hydroxide in methanol was mixed with waste vegetable oil. The mixture in the ratio of 5:1 by volume was heated to 60°C and kept stirred for 45 minutes before transfer to a settling tank to separate glycerol from the biodiesel.

Separation and Drying. After 24-hours in the settling tank, the oil formed two layers. The top layer was biodiesel while the bottom layer was glycerol. Glycerol was drained off and crude biodiesel was washed three times by agitation with warm water to remove un-reacted methanol, soap, glycerol and KOH from the oil. Finally, the oil (biodiesel) was heated to about 110°C for about thirty minutes while stirring to evaporate off residual water from the washing process.

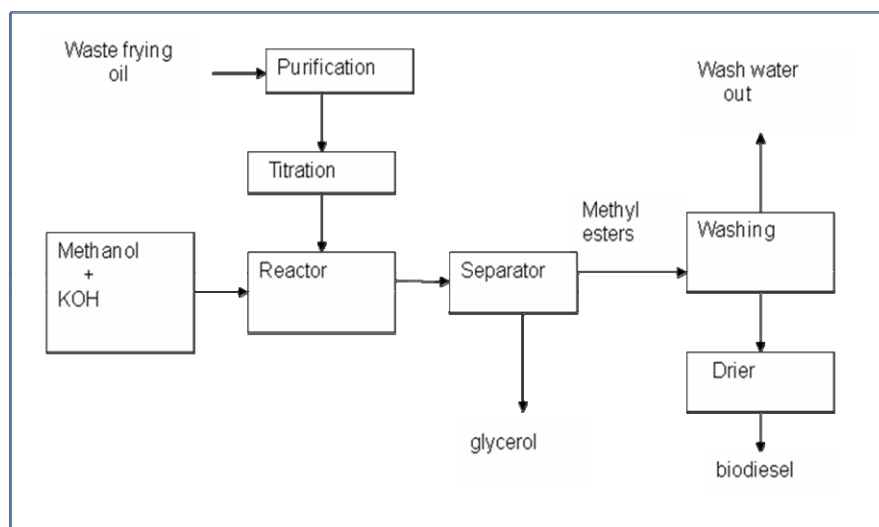


Figure 1: Process flow chart for biodiesel production from used edible oils

Fuel characterisation

Physical and chemical properties of fuel that determine suitability for use in compression ignition engines were determined. They include; Cetane index, viscosity, calorific value, Density, Cloud point, Sulphur content and copper strip corrosion test.

Engine Set- up and Test Procedure

The specifications of the engine used in the study are given in Table 1. The engine used in the study was a commercial plant that has been retrofitted for laboratory use.

Table 1: Technical details of the engine

Engine Type	Ford, 4 stroke diesel
Configuration	6-cylinder, turbo charged, open combustion chamber.
Rating	86 BHP @2250 rpm
Bore	100 mm
Stroke	115 mm
Displacement	5416 cc
Compression ratio	16:1
Cooling	Water

The load control hand wheel of the dynamometer was used to increase the load while at the same time opening the engine throttle until the desired conditions of the load and speed were obtained. A temperature control valve was adjusted to obtain an outlet temperature of between 54°C and 60°C as shown on the indicator provided. The fuel consumption was recorded on a volumetric fuel measurement system.

Results and Discussions

Fuel properties

Fuel characterisation data is shown in Table 2. ASTM D 6751 standards for biodiesel were used to ascertain the suitability of the fuel. Additionally, these properties were compared to those of diesel.

Table 2: Comparison of properties of biodiesel with respect to diesel fuel and ASTM D 6751 standards

property	Sample			ASTM D 6751	units
	Biodiesel	DIESEL	Kinast (2003)		
Property					
Density @ 25°C	879	842			kg/m ³
Cetane index	45.35	51.22	47 – 63.7	47	
Viscosity @ 40°C	4.35	1.9-6.5	4.546 – 5.62	1.9-6	<u>mm²</u>
Cloud point	12	7	-3 – 42	Report	°C
Sulphur	0.02	0.535	< 0.05	0.05	mass%
Copper corrosion	1A	1A	1A	3B	
Calorific value	38.52	43.38	39.68 – 40.04		MJ/kg

Calorific value

The calorific value is the amount of heat released during combustion; it determines the suitability of a substance for use as fuel. The heat of combustion of diesel was 43.38 MJ/kg while that of biodiesel was found to be 38.52 MJ/kg, which is a difference of 11.2 %. The density of biodiesel was higher than that of diesel fuel (879 kg/m³ and 842 kg/m³ respectively at 25°C) and, this is of special significance for diesel engines since the fuel is metered volumetrically. The high density of biodiesel partly compensates for the low energy content. Other things being equal, the fuel consumption tends to be in inverse ratio to the heat of combustion (Wright and Purday, 1950). Since injection pumps operate volumetrically, the energy content on volume basis is 36.53 MJ/L for diesel and 33.86 MJ/L for biodiesel. This results in a theoretical increase in BSFC of 7.3 %. A fuel with lower heating value will cause the engine to produce less power, therefore more fuel will be injected to make up for the power loss leading to high fuel consumption.

Copper strip corrosion

This test measures the level of corrosion of a fuel by use of copper strips. Results obtained show that biodiesel has a corrosion level of 1A, which is the minimum on the defined scale. 1A means that the strip used was slightly tarnished and looked almost the same as a freshly polished strip after the test. ASTM D 6751 allows a maximum value of 3B. Therefore biodiesel and its blends conform to this standard.

Viscosity

Viscosity is a very important property since it directly affects combustion of the fuel in the engine. For complete combustion to take place, proper air and fuel mixing is necessary. The quality of spray on injection is attributed to the viscosity of the fuel. Apart from the effects on combustion, viscosity is associated with lubrication and durability of fuel system parts. The standard ASTM D 6751 recommends 1.9 cST and 6 cST at 40 °C as optimum operating limits for viscosity of biodiesel. The viscosity of biodiesel @40 °C was 4.35 cST, which is well within the recommended range.

Cloud point

ASTM D 6751 does not specify the limits for cloud point as it varies with local climatic conditions. Biodiesel had a cloud point of 12° C. Therefore, the fuel should not be used in areas where the local temperatures fall below 12°C as wax crystals can be formed and clog up the fuel filter, thus impeding fuel flow to the engine.

Sulphur content

The maximum Sulphur content permitted by the standard ASTM D 6751 for biodiesel is 0.05 %. The biodiesel had sulphur content of 0.02%, which is within the standard specification while that of diesel was 0.535%. Sulphur has no effect on combustion, however, on burning sulphur forms sulphur oxides that dissolve in condensed water arising from the combustion of hydrogen to form sulphuric acids. Therefore, corrosion effects are likely to be experienced in turbo blowers, silencers and exhaust pipes with increase in sulphur content (Wright and Purday, 1950).

Biodiesel performance in the engine

The thermal efficiency of B100 and diesel fuels manifested no significant difference throughout the full range of brake power as shown in Figure 3. The Brake Specific Fuel Consumption (BSFC) for B100 fuel is higher than for diesel fuel by an average of 12.7% as shown in Figure 2. This is primarily attributed to the lower calorific value of the biodiesel fuel that prompts the injection of more fuel to sustain the same output power while the high viscosity of biodiesel would tend to constrain the rate of flow. Reduction of viscosity of the biodiesel through preheating was therefore performed. It was observed that preheating biodiesel from ambient conditions to 35 °C reduced the average BSFC of the biodiesel from 12.7 to 7.8 % above that of diesel while the average thermal efficiency increased from 30.04 to 31.34%.

No significant changes in average BSFC were observed on heating to a higher temperature of 47°C. However, at full load, the BSFC was 0.26 and 0.275 kg/kWh while the thermal efficiency was 34% and 36% respectively. Satyanarayana and Rao (2009) have also reported improved performance of preheated biodiesel. They observed a reduction in fuel consumption at all loads for Pongamia Biodiesel preheated to 50 °C and an increase in thermal efficiency when compared to Pongamia Biodiesel. This was attributed to improved fuel spray characteristics, and faster evaporation of biodiesel. At full load, the efficiency of Diesel, Pongamia Biodiesel, and Pongamia Biodiesel preheated to 50 °C are 30.3%, 27.2% and 28.8% respectively. Ingle *et al.*, (2011) also showed that preheating biodiesel to 50 °C leads to an increase in thermal efficiency and a reduction in Brake Specific Energy Consumption. The changes were attributed to the reduction in viscosity that resulted in improved fuel atomization, vaporization and combustion.

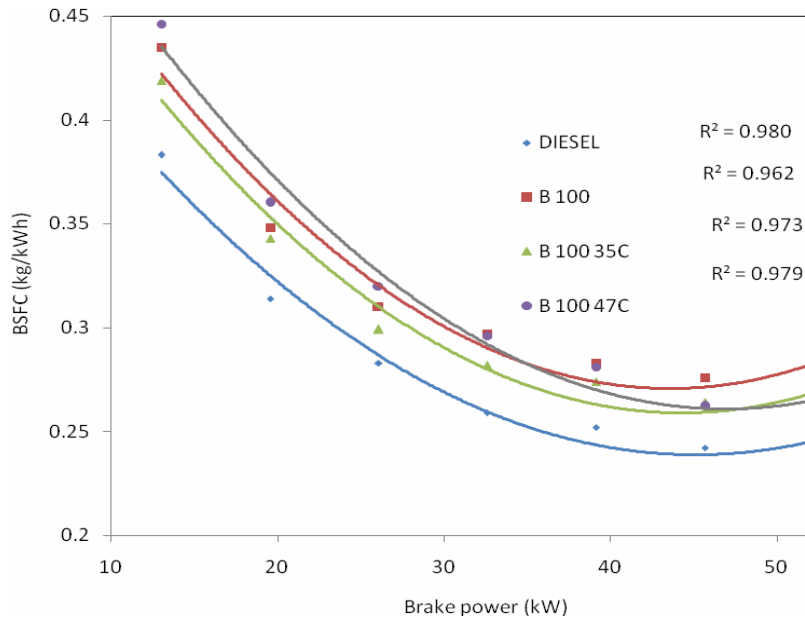


Figure 2: Variation of BSFC with Brake Power for the different fuels

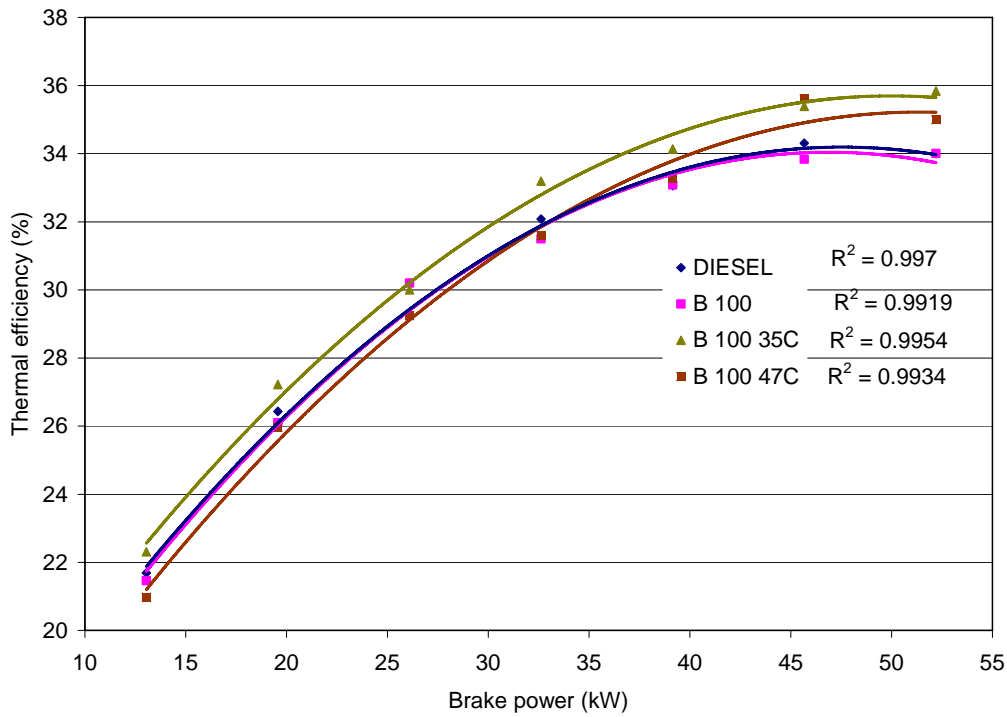


Figure 3: Variation of BTE with BP for the different fuels

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