

# Effects of Soybean Methyl Ester on the Performance Characteristics of Compression Ignition Engine

S. K. Fasogbon, A. A. Asere

**Abstract**—Depletion and hazardous gas emissions associated with fossil fuels have caused scientists and global attention to focus on the use of “alternative, eco-friendly substitutes for use in Compression Ignition Engines. In this work, biodiesel was produced by trans-esterification of soybean obtained from a Nigerian market using Sodium Hydroxide (NaOH) as a catalyst.” After the production, the physical properties (specific gravity to kinematic viscosity and net calorific value) of the Soybean-biodiesel produced and petrol diesel obtained from a filling station in Nigeria were determined, and these properties conform to conventional standards (ASTM). A cummins-6V-92TA DDEC diesel (Compression ignition, CI) engine was run on various biodiesel-petrol diesel blends (0/100, 10/90, 20/80, 30/70 and 40/60), the B20 (blend 20/80) was found to be the most satisfactory.

**Keywords**—Effects, Soybean, Methyl Ester, Performance, compression Ignition Engine.

## I. INTRODUCTION

BIODIESEL is produced by transesterification of oil and fat. Transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol to form esters and glycerol. A successful transesterification reaction is signified by the separation of the ester and glycerol layers after reaction time. Generally, There are three basic routes to Biodiesel production from oils and fats, namely: Base catalyzed transesterification of the oil; Direct acid catalyzed transesterification of the oil and Conversion of the oil to its fatty acids and then to biodiesel. Subject to the country where they are grown abundantly, oils from coconut, soy bean, sunflower, safflower, peanut, linseed and palm are used for the production of biodiesels. In the Philippines, research activities on the use of coconut-vegetable oils as fuel substitute have been on since 1970s. In the United States, the primary interest as biodiesel source is soy bean oil, many European countries are concerned with rape seed oil and countries with tropical climate prefer to utilize coconut oil or palm oil [1]. World production statistics on soybean show that Nigeria is the second to Zimbabwe, the leading producer of soybean in tropical Africa. Soybean is being grown in all ecological zones of Nigeria. Nigerian government is currently boosting soybean production by funding researches, subsidizing inputs, and providing Extension services to reach farmers with new innovations.

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Collaborative efforts of International Institute of Tropical Agriculture (IITA), Institute of Agriculture Research and Training (IAR&T), Institute of Agricultural Research (IAR), University of Nigeria Nsukka (UNN), and International Development Research Centre (IDRC) have led to breakthrough in soybean production package. Furthermore, Agricultural Development Projects especially in Kwara State have taught farmers better techniques in soybean production. However, in spite of these efforts, soybean is still being produced on small scale farming (1-2ha) with an average yield of 600-800 kg/ha which is far below 1800-2646 kg/ha obtained on experimental plots. It is therefore obvious that for better yield to be realized, Nigerian Government at all level will have to embark on large scale farming [2]. It has been reported that the performance of methyl ester of sunflower oil and the esters of soybean oil (methyl, ethyl and butyl) did not differ greatly from that of petrol diesel [3]-[5]. Studies by [6] and [7] indicated that while vegetable oil fuel blends had encouraging results in short term testing, problems occurred in long-term durability tests, they indicated that carbon build-up, ring sticking, and lubricating oil contamination were the causes of engine failure when vegetable oils were used in high percentages (50% or more) in blends with diesel fuel. Reference [8] reported that the atomization and injection characteristics of vegetable oils are significantly different from that of diesel fuel due to the higher viscosity of the vegetable oils. Their studies further revealed that engine performance showed lower power output when compared with pure diesel fuel; and that Injector coking and lubricating oil contamination appeared to be dominant especially for the vegetable oil-based fuels with higher viscosities. Investigation on a blend 50-50 vegetable oil and diesel fuel on the behaviour of piston ring by [9] showed premature piston ring sticking and carbon build-up. These observations eventually lead to premature engine failure. Thus, the study further revealed that in order to avert such piston ring behavior, there is need for fuel additive or a fuel blend with lower vegetable oil in composition. In the studies carried out by [10] on Amulata oil plant grown natively in India, the performance tests using the fuel blends up to 50-50 exhibited stable power output, Knock free performance, and non-carbon deposits on the functional parts of the combustion chamber. Reference [11] reported some studies in Malaysia, with palm oils as diesel fuel substitutes, the studies indicated that power outputs were nearly the same for palm oil, blends of palm oil and diesel fuel, and 100% diesel fuel. International Harvester Company reported that cottonseed oil and diesel fuel blends behaved like petroleum-based fuels in short-term performance and emissions tests. She

claimed that the experimental fuels performed reasonably well when the standards of judgment were power, fuel consumption and emissions. However, the company reported that the engine durability was an issue during extended use of the fuel blends because of carbon deposits and fueling system problems [12]. Other research at International Harvest Company where three blends of sunflower oil and diesel fuel were tested on compression ignition engine indicated premature engine failure due to carbon buildup [3], [13] and [14]. In general, the results of most studies pointed out that most vegetable oil methyl esters are suitable as diesel substitutes, but more long term studies are necessary for commercial utilization to become practical. As a result of immense environmental benefits and significant measure of energy sustainability offered by biodiesel, coupled with global considerable progress in the field of biodiesel and its applications, this work is aimed at investigating the effect of soybean based biodiesel on the performance of C.I. engine.

## II. MATERIALS AND METHODS

### A. Material Preparations and Biodiesel Production

Soybean oil was purchased at Odo-Ogbe Market, in Ile-Ife, Nigeria, while the petrol diesel (Cetane rating 60) was obtained from Adeyanju Total filling station at Lagere, Ile-Ife, Nigeria. The transesterification of the oil was carried out at the Department of Chemistry, Faculty of Science, Obafemi Awolowo University, Ile-Ife, Nigeria. 40ml of the Soybean oil was first measured out, using measuring cylinder and poured into the mixer, the methanol (120ml) was measured in graduated cylinder and poured into a conical flask; the lid was also put on quickly. Sodium Hydroxide (NaOH) was quickly measured out on scale with the empty container and added to the methanol in the conical flask immediately, the mixture was agitated, for the dissolution of NaOH. The Soybean Oil was pre-heated to 50°C; the resulting methyl oxide and oil were mixed together and put on the hot plate at 800rpm of the stirrer speed for 1.5hrs. Biodiesel was separated from glycerin by decantation and placed in a container. Quality test was performed by adding enough water to the biodiesel (200ml) to make 400mL and the container was shaken for 10 seconds and allowed to rest, a good quality biodiesel separated from water in 30minutes or less was formed (two layers-clear, light-yellow biodiesel and milky water). 50 % water was added (500mL) and heated for 12 hours, and water was removed. New water was added and run again for twelve hours; process was repeated. Biodiesel was siphoned off; run through fine mesh (cheese-cloth) and quality test was repeated. Now good biodiesel separated from water in no more than 15 minutes.

### B. Properties Determination and Experimental Tests on the Engine

In order to compare efficiently the numerical values of the physical properties of the soya bean biodiesel and that of petrol obtained from experimental rig, three numbers of replications/experimental data were taken for each property.

The data were now subjected to standard formula to determine their standard deviations (s)

$$s = \sqrt{\left( \frac{n \sum_{i=1}^n x_i^2 - \left( \sum_{i=1}^n x_i \right)^2}{n(n-1)} \right)}$$

#### 1. Determination of Viscosity

The room temperature was measured by the thermometer and the reading was recorded, the Cannon MV-2020 Rotary Viscometer ( $\pm 1.0\%$  Accuracy and  $\pm 0.2\%$  Repeatability) was clamped to a provided stand, and the spindle was lowered into the cup, making sure the spindle did not touch the cup, the Soybean biodiesel was then poured into the cup until it got to a certain level indicated on the spindle, the viscometer was then turned on and after being set to correct scale, reading was taken to get the yield value of viscosity, after some time of rotation, the reading fell and the reading was constant over sometime, the value is known as terminal viscosity (4.05cs at ambient temperature of 25°C ).

#### 2. Determination of Specific Gravity

The temperature of the room was measured and recorded, the dry pycnometer was then weighed on the weighing balance and the weight was recorded, the pycnometer was filled with water and then weighed on the weighing balance, the weight of the pycnometer and distilled water was also recorded, the water was then poured away and the pycnometer was dried, the biodiesel was poured into the pycnometer and the weight was taken as well (calculation gives 0.88 g/cm<sup>3</sup>).

#### 3. Determination of Net Calorific Value

An Oxygen Bomb Calorimeter was used to perform this test, a sample of test fuel and pure oxygen were charged to the bomb calorimeter, and the initial weight of the sample and ambient temperature were recorded. The sample was ignited; the final temperature and weight of the sample were recorded, and the heat of combustion was calculated to be 36.3MJ/kg (ambient temperature of 25°C)

#### 4. Engine Test

The fuel delivery and return lines were adapted with quick couplers for fast and clean changing of the different fuel blends. Individual two liter plastic fuel tanks were modified with a fuel filter and flexible fuel lines which could be connected to the engine quick couplers. The pre-mixed drum of blended fuel was connected to the fuel supply system of the engine (Engine Specifications: Trade name: Cummins, Model: 6V-92TA DDEC 11, Unit (Serial Number): 06VF187152, Engine Family: MDDO552FZL1, Rated: 277 hp at 2100 rpm (using D-1 fuel), Peak Torque: 880 ft-lb at 1200 rpm, Maximum No-Load rpm: 2225 rpm, Min. Idle: 600 rpm, Max. Allowable Backpressure: 3.0 in. Hg). The fuel system was purged before the return fuel was redirected to the recirculation tank. The density of the soy diesel was 0.884 g/cm<sup>3</sup> at 25°C (77°F), the diesel fuel density was 0.832 g/cm<sup>3</sup> at 25°C (77°F). These densities assisted in fuel blending. The biodiesel/diesel blends on a volume basis (at 21°C (70°F))

were (0/100, 10/90, 20/80, 30/70 and 40/60). The engine was fueled directly from each barrel, and engine parameters such as engine speed, engine pressure, muffler temperature and engine temperature were measured for each blend.

### III. RESULTS AND DISCUSSION

#### A. Physical Properties

The physical properties of the soybean based-biodiesel and petro diesel determined, compared favourably in values with ASTM standard quoted values, and the deviations noticed are particularly within the allowable by the ASTM standard (see Table I).

TABLE I  
COMPARISON BETWEEN BIODIESELS AND CONVENTIONAL DIESEL  
PHYSICAL PROPERTIES

Property	Soybean Biodiesel * ASTM Standard quoted values	Soybean Biodiesel	Petro Diesel * ASTM Standard quoted values	Petro diesel
Specific gravity g/cm <sup>3</sup>	0.88±0.01	0.88±0.006	0.83±0.01	0.83±0.006
Viscosity at 40°C (x10 <sup>-6</sup> m <sup>2</sup> s <sup>-1</sup> )	11.10±0.01	11.11±0.01	6.00±0.01	6.0±0.01
Net Heating Value (mega joule/kg)	36.30±0.01	36.30±0.01	49.67±0.01	49.67±0.006

The specific gravity of the Soybean Biodiesel produced at 0.88g/cm<sup>3</sup> is higher as against petro diesel's 0.83g/cm<sup>3</sup>. With these figures, it underscores why the Soybean biodiesel produced gelatinous substance at the bottom of the makeshift fuel tank since the petro diesel floats on top of it. Viscosity measurements show that the viscosity of the produced biodiesel is important when considering the spray characteristics of the fuel within the engine, since the change in spray can greatly alter the combustion properties of the mixture. The viscosity measured at 40°C, the viscosity of the soybean biodiesel is as twice as large as that of the petro diesel. The values 11.11 and 6.0 represent that of soybean biodiesel and petro diesel respectively. These values of course indicate that the lubricity of soybean biodiesel is higher hence confirming a more "solvent capability" of the soybean biodiesel resulting in cleansing of the engine, a good characteristic but which paradoxically explains why it clogs the fuel filter. The heat of combustion otherwise known as net heating value of Soybean biodiesel is comparatively lower than its corresponding petro diesel. From the results, a kg of Soybean biodiesel produces 36.30MJ of energy when burned and petro diesel gives off 49.6MJ of energy when burned. Generally, the soybean biodiesel has a relatively low value of net heating value, and obviously, this is a great set back. Fortunately, this set back has been subdued, in a way of higher value of viscosity and specific gravity. Hence, this explains why soya bean biodiesel has a good compatibility with petro diesel.

#### B. Engine Performance

Fig. 1 shows a direct relationship between engine pressures and blend percentage, the higher the biodiesel proportion in the blend percentage, the higher the engine pressure. The peak pressure was recorded at 100% diesel. At B20 (i.e. 20% biodiesel and 80% petro diesel) engine pressure is close to atmospheric pressure of 1.01bar making B20 a choice percentage.

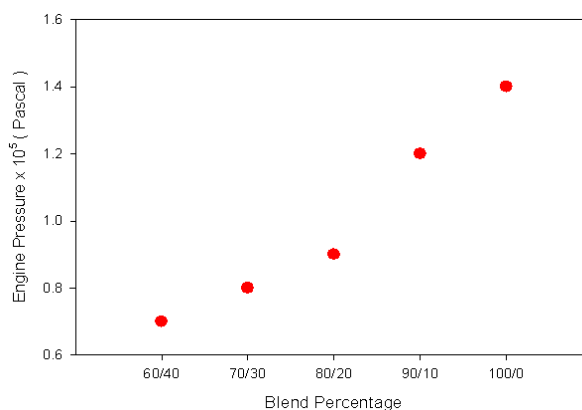


Fig. 1 Relationship between engine pressure and blend percentage

The relationship between the muffler temperature and blend percentage is a zigzag one as shown in Fig. 2. A zigzag behavior of muffler temperature was first noticed for the 60/40, 70/30 and 80/20 blend percentages. However, peak temperature was noticed at 80/20 blend and a steady decrease in the temperature was noticed from the same 80/20 blend down to 100/0 blend. The fact that the highest muffler Temperature was recorded at 80/20 blend, confirms that the best engine performance is obtainable at B20 (i.e. 20% biodiesel and 80% petrodiesel).

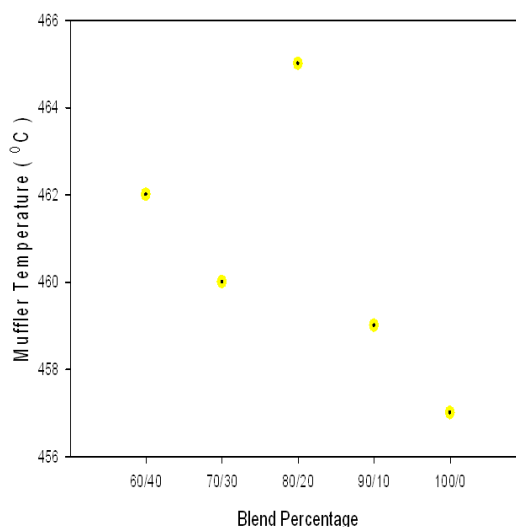


Fig. 2 Relationship between muffler temperature and blend percentage

The engine temperature increases steadily with increase in blend percentage from 60/40 blend to 80/20 blend as shown in Fig. 3. At exactly the same 80/20 blend, the engine temperature decreases unsteadily up to 100/0 blend composition. Generally speaking, it was noticed that even though the engine temperature increases as well as decreases, at certain blends as stated above, all the same, the variations in the engine temperature was almost unnoticeable. This is unconnected with the elevated temperatures of the Cummins engine such that with much varied change in blend percentage, the effect on engine temperature remain almost constant between 642°C and 662°C, the fact that the peak of the engine temperature (662°C) was noticed at B20, further establishes the fact that the optimum performance of the engine occurs at 80% Diesel/20% Biodiesel composition.

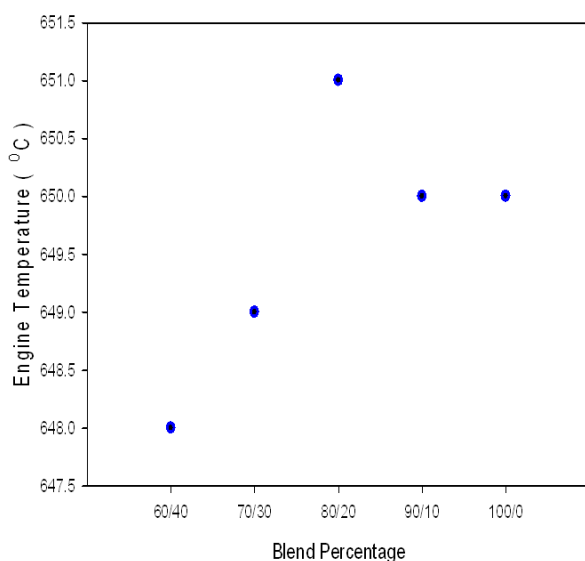


Fig. 3 Relationship between the engine temperature and blend Percentage

#### IV. CONCLUSION

The effects of soybean-based biodiesel on engine performance parameters such as engine temperature, engine pressure and muffler temperature have been investigated. The study reveals that soya bean-based biodiesel has good compatibility with petrol diesel when blended together, and that CI engine will always run on all blends of soybean-based biodiesel and petrol diesel with petrol diesel not lower than 60% in composition. All the blends seems to be satisfactory in terms of the reduced engine pressure and effective engine temperature, however, the blend 80/20 was found to be the most satisfactory, as this was the only blend during testing which gave Knock free performance, no carbon build-up syndrome, free movement of piston rings and non-contamination of lubricating oil. The physical properties of the biodiesel spanning from specific gravity, kinematic viscosity and net calorific value were also determined. It was

discovered that these properties conform to conventional standard (ASTM), as the standard deviations in the experimental values obtained, are within the allowable by the standard. In general, all the observations recorded run perfectly with the literature.

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