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Castor Seed from Melkasa Agricultural Research Centre, East Showa, Ethiopia and it's biodiesel performance in Four Stroke Diesel Engine

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ABSTRACT: This study focused in investigating the fuel properties of Castor oil Methyl Ester (CME) and its blend with diesel fuel in running a diesel engine. Engine tests have been carried out with the aim of obtaining comparative measures of torque, power, and specific fuel consumption. Castor oil was extracted by using a mechanical pressing machine and trans-esterification was made by methyl alcohol and potassium hydroxide as a catalyst. So that its viscosity and density were reduced and by increasing its volatility. By following the procedures given in American Society for Testing and Materials (ASTM) book the fuel characteristics were identified whether it fulfil the requirements needed to be used as a fuel in internal combustion engines or not. From the characterization result, it was proved that trans-esterified castor oil was found to be a promising alternative fuel for compression ignition (diesel) engines. But the viscosity of CME was still higher and the energy content was a little bit less as compared to petro diesel. To solve these problems CME was blended with petro diesel in some proportion (B5, B10, B20, B40, B80). The torque, power and brake specific fuel consumption performances of CME and its blends with petro diesel were tested in a four stroke diesel engine. The analyzed results were compared with that of petro diesel and found to be very nearly similar, making CME a suiTable alternative fuel for petro diesel.

Keywords: Castor oil Methyl Ester, Characterization; Diesel engine; Performance evaluation; Trans-esterification

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1. Introduction

Renewable fuels are essential for environmental and economic sustainability as compared to fossil fuel usage which accumulates carbon dioxide in the environment (Musharraf *et al*. 2012). Biodiesel, as renewable fuel, has attracted major interest worldwide in recent years (Demirbas 2003).

Biodiesel is produced from vegeTable and tree oils, animal fats, or used cooking oils and fats, that can be used as a substitute for, or an additive to, conventional diesel fuel. Biodiesel has a higher Cetane Number with other characteristics similar to diesel fuel, thus it can be used in diesel engines without any modifications. Biodiesel, due to its biodegradable nature, and essentially no sulphur and aromatic contents, offers promise to reduce particulate and toxic emissions, and is considered to be an attractive transportation fuel for use in environmentally sensitive applications such as urban buses in heavily polluted cities, national parks and forests, marine areas, and underground mining equipment. It is also reported that adding small amounts

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of biodiesel to conventional diesel can improve fuel lubricity, extend engine life, and increase fuel efficiency (Charles & Peterson 1986).

The large increase in number of automobiles in recent years has resulted in great demand for petroleum products. With crude oil reserves estimated to last in the future, there has been an active search for alternate fuels. The depletion of crude oil would cause a major impact on the transportation sector. Of the various alternate fuels under consideration, biodiesel, derived from vegetable oils or animal fat, is the most promising alternative fuel to petro diesel (Knothe & Steidley 2005).

2. Materials and Methods

2.1. Oil source

Castor seeds were obtained as an oil source from Melkasa Agricultural Research Centre East Showa, Ethiopia. The method used to extract the oil was mechanical pressing of the castor seed by a human operated hydraulic pressing machine which was developed by the Bako Agricultural Research Mechanization, Ethiopia.

The following experimental procedures were also done to compare the performance of biodiesel from castor seed and petro diesel.

2.2. Trans-esterfication

Trans-esterification of castor oil was comprised by dissolving of KOH (2grams) in methyl alcohol (100ml), heating of castor oil (100ml) to 50^{0}C, adding KOH and methyl alcohol solution (25ml) in to the heated oil, stirring of the mixture, separation of glycerol, washing with distilled water and addition of Na_2SO_4 for drying of water (Gerpen *et al*. 2004). Castor oil was Trans-esterified using the esterification system developed in the laboratory of the Wondogenet Agricultural Research Centre (Essential oil producer's laboratory), Addis Ababa, Ethiopia.

2.2. Characterization

Characterization of the fuel to be tested in this research work was done in the laboratory of Ethiopian Petroleum Enterprise (EPE) following the procedures given in the book of ASTM 1, 2, 2002. In this research the fuel properties of B100 (neat), B80, B40, B20, B10, B5 (a blend of 80%, 40%, 20%, 10%, 5% biodiesel and 20%, 60%, 80%, 90%, 95% petro diesel respectively) and petro diesel (B0) were studied.

Operational definitions

- *Kinematic viscosity*: is the most important physical characteristic to decide whether it is possible to test the fuel on an engine or not.
- *Copper Corrosion test*: a test that used to assess the relative degree of corrosiveness of petroleum products due to active sulphur compounds.
- *Water and sediment content of petroleum test*: this test is a measure of cleanliness of the fuel.
- *The flash point temperature*: is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions.
- *ASTM Colour*: is a means of confirming that the correct oil or fuel is being used for its intended use and that no contamination or degradation of quality has occurred.
- *The acid number*: used as a guide in the quality control of lubricating oil formulations. It is also sometimes used as a measure of lubricating degradation in service. Acid numbers higher than 0.80 have been associated with fuel system deposits and reduce life of fuel pumps and filters.
- *Ash Content*: Knowledge of the amount of ash forming materials present in a product can provide information as to whether the product is suiTable for use in a given application or not.

2.3. Performance Testing

At this stage, the performance of the fuel was determined in the performance testing setup.

The blends which fulfil the ASTM standards for biodiesel in the characterization stage and the base fuel (petro diesel) which was used as a performance comparator for the blends were tested. The blends that pass the ASTM standards were B5, B10, B20 and B40. Torque, Power and Specific Fuel Consumption (SFC) of each blend was compared with that of petro diesel.

The following were the test procedures followed.

- The engine was warmed up to its operating temperature before starting the test.
- Using the RPM adjuster the fuel rack was set (60%) to a speed of 3500 rpm.
- Then the load was gradually increased by the load adjuster and torque, speed and fuel flow rate are registered at equal intervals of load variation.
- The engine performance characteristics (torque, speed and fuel flow rate) were monitored within the speed range of 1200rpm and 3500rpm.

Following the above procedure, 1st the base fuel (B0) performance was done and then follows the blend fuels (B5, B10, B20 and B40). The brake power P_b in watts delivered by the engine and absorbed by the dynamometer is calculated from the brake torque and angular speed. The fuel consumption was measured as a flow rate, mass flow per unit time. A more useful parameter was the specific fuel consumption (SFC) the fuel flow rate per unit power output. It measures how efficiently an engine was using the fuel supplied to produce work (ASTM International 2002).

Table 1
Test engine specifications

Fuel system	Diesel with distributer pump
Bore × stroke	76.50 mm × 86.40 mm
Cylinders	4, Inline
Displacement	1588 cc
Compression ratio	23:1
Injection plunger travel when engine piston is at TDC	1 mm

3. Results and Discussion

The machine extracts about 37.5% (v/w ratio) of oil from the sample seed (around 150 ml of oil from 400 grams of seed). If the residue from mechanical pressing was again continued to chemical extraction method, more oil had been expected from the sample; but this method was not applied to the residue after mechanical pressing. Usually, from castor up to 55% oil is expected if fully extracted. The biodiesel was synthesized using batch wise trans-esterification process. After washing two times with warm water (500°c), the clear solution of biodiesel was measured. The biodiesel production yield was found to be 98 % v/w.

3.1. Characterization

Characterization was done to know the properties of the biodiesel produced whether it satisfies the ASTM standards for biodiesel prior to testing its performance in the existing diesel engines without doing any modification. The characterization results of the biodiesel produced from castor seed are shown in the Table 2.

The specific gravity and kinematic viscosity of the blends got higher as the percentage of biodiesel increases. It was also possible to see that the kinematic viscosity of B80 and B100 are out of the standard given by ASTM to use directly on CI engines. Hence, B80 and B100 are out of specifications and their performance on CI engines cannot be measured. This is because as the viscosity is higher, it will clog fuel filters; it will not be sprayed properly by the injector nozzles; and hence, poor atomization and poor spray pattern will affect combustion. Moreover, the poor combustion of the fuel will produce large amount of carbon deposit that will be a cause for valve face and valve seat burn, piston ring stuck and contamination of lubricating oil.

In the distillation characterization process, the initial boiling point (IBP), the final boiling point (FBP), and the boiling temperatures corresponding to 10% increments of the volume of fuel distilled was recorded. Finally each recorded temperatures were corrected to 760mmHg pressure.

Copper Corrosion test was done to assess the relative degree of corrosiveness of petroleum products due to active sulphur compounds. Results are rated by comparing the stains on a copper strip to a color-match scale from 1-4. The ASTM D6751 limit for copper corrosion is number 3. All of the biodiesel passed ASTM specifications with 1a. The water and sediment level of all the samples tested in this research was found to be below 0.025 % volume which is in the limit set by ASTM standards.

Cetane number index (CNI) of petro diesel was calculated using corrected mid boiling point value from ASTM D86 and density at 15^{0}C, from ASTM D 976 by using the following relation.

$$CNI = 454.74 - 1641.461D + 774.74D^2 - 0.554B + 97.803(\text{Log}B)^2 \quad \textbf{(1)}$$

Where, D = Density at 15 ^{0}C, g/ml, B = Corrected mid boiling point ^{0}C,

The cetane index values for the blends B5, B10, and B20 were within the standards; B40 was little bit less than the standard whereas the others were very much below the standard set. As the Cetane number of the fuel is getting lower, its auto-ignition quality will be poorer resulting in longer ignition delay period which makes the engine susceptible to diesel knocks.

The flash point temperature is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material.

Flash point is used in shipping and safety regulations to define flammable and combustible materials. One should consult the particular regulation involved for precise definitions of these classifications. The U.S. Department of Transportation (DOT) and U.S. Department of Labor have established that liquids with a flash point under 37.8°C (100°F) are flammable.

The test methods should be used to measure and describe the properties of materials, products, or assemblies in response to heat and an ignition source under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of these test methods may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use (John 1998).

From the result indicated in Table 2, it is observed that biodiesel has a higher flash point – the temperature at which a fuel will catch fire – because biodiesel has a high number of FAMEs which are generally not volatile.

Table 2
Characterization results of Castor bean oil biodiesel

S.N	Property	Tests ASTM	Limit 6751-07b	Test Result						
				B0	B5	B10	B20	B40	B80	B100
1.	Density@15⁰c,g/ml	D1298	Report	0.8526	0.8565	0.8581	0.8670	0.8837	0.9170	0.9345
	Density@20⁰c,g/ml	D1298	Report	0.8482	0.8527	0.8547	0.8636	0.8804	0.9137	0.9312
2.	Distillation% V	D86	-	-	-	-	-	-	-	-
	IBP⁰C		-	172	164	163	162	166	<123	<113
	10%,recovered		-	204	200	201	218	217	246	296
	40%recovered		-	267	267	273.5	285.5	300	315	322.5
	50%recovered		-	281.5	282.5	290.5	304	316	321.5	326.5
	90%recovered		Max360⁰C	351	352	355	354	341.5	327.5	336.5
	95%recovered			367.5	366.5	364	363	341.5	330.5	366.5
	FBP		Max 390	380.5	370.5	368.5	365	341.5	330.5	366.5
3.	Flash point (⁰C)	D93	100 Min	68	68	69	69	69	86	152
4.	Copper strip corrosion 3hrs@100⁰C	D130	Max 3	1a	1a	1a	1a	1a	1a	1a
5.	Cloud point, ⁰C	D2500	Report	-1	0	0	0	+2	0	<-12
6.	Kinematic viscosity@40⁰C,mm²/s	D445	1.9_ 6	3.04	3.1	3. 37	3.97	5.64	12.36	18.34
7.	Cetane Index	D976	Min 47.0	49.44	48.4	49.15	49.52	45.3	37.7	34.6
8.	ASTM color	D1500	Max 3	2	2	2	2	2	1.5	<0.5
9.	Water and segment,%V	D2709	Max 0.03	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
10	Total acidity, mgKOH/g	D974	Max 0.5	0.0076	0.0156	0.0259	0.0384	0.0656	0.1015	0.1215
11	Ash content, mass%	D482	Max 0.01	0.0065	0.0073	0.0078	0.0169	0.041	0.0704	0.0728
12	Higher Heating value ,MJ/Kg	__	Report	45.33	45.053	44.776	44.222	43.114	40.898	39.79

Table 2
Saponification and iodine values

Sample fuel	SN (mg of KOH /gm of oil)	IV (g of Iodine / 100 g of oil)
B100	202.71	88.72

Thus, biodiesel is safer to handle at higher temperatures than diesel.

The ASTM Color Scale is widely utilized for the grading of petroleum products such as lubricating oil, heating oil and diesel fuel oil. Mineral oils are constantly checked for colour during processing in order to establish when they have been refined to the required grade. Colour is also used as a means of confirming that the correct oil or fuel is being used for its intended use and that no contamination or degradation of quality has occurred. The ASTM color results of the fuels in this research are well within the standards.

The acid number is used as a guide in the quality control of lubricating oil formulations. It is also sometimes used as a measure of lubricating degradation in service. Acid numbers higher than 0.80 have been associated with fuel system deposits and reduce life of fuel pumps and filters. Acid number determination is an important test to assess the quality of a particular biodiesel. It can indicate the degree of hydrolysis of the methyl ester, a particularly important aspect when considering storage and transportation as large quantities of free fatty acids can cause corrosion in tanks (ASTM International 2002). The acidity of the biodiesel produced in this research is in the limit set by ASTM. Hence, it will not create any corrosion on the fuel system components.

Knowledge of the amount of ash forming materials present in a product can provide information as to whether the product is suiTable for use in a given application or not. Ash can result from oil or water soluble metallic compounds or from solids such as dirt and rust. For biodiesel, this test is an important indicator of the quantity of residual metals in the fuel that came from the catalyst used in the trans-esterification process. Producers that use a base catalyzed process may wish to run this test regularly. Many of these spent sodium or potassium salts have low melting temperatures and may cause engine damage in combustion chambers. High concentrations of metals contained in the fuel can cause injector tip plugging, combustion deposits and injection system wear. The ash content test result of the fuels in this research shows that B20, B40, B80 and B100 are above the standards.

The SN and IV of the oils is determined and the result is shown in the Table 2. The heating values are calculated by using their SN and IV obtained from simple chemical analyses using empirical relation;

$$HHV = 49.43 - 0.041(SV) - 0.015(IV) \quad (2)$$

The heating value or heat of combustion or calorific value measures the energy content in a fuel. From an operational point of view, biodiesel has about 90% of the energy content of petroleum diesel, measured on a volumetric basis. Due to this fact, on average basis the use of biodiesel reduces the fuel economy and power by about 10% in comparison with petroleum diesel. The reason for this reduction stems mainly from the oxygen content of biodiesel, ensuing better combustion process, and improved lubricity, which partly compensate for the impact of the lower energy content. Biodiesel is an oxygenated compound. Oxygenates are just pre used hydrocarbons having a structure that provides a reasonable antiknock value. Also, as they contain oxygen, fuel combustion is more efficient, reducing hydrocarbons in exhaust gases. The only disadvantage is that oxygenated fuel has less energy content. For the same efficiency and power output, more fuel has to be burned (Ali 2013; Shay 1993).

3.2. Comparison of fuel properties of Castor bean biodiesel with other oil sources.

It was found that viscosity of B10 and B20 of Castor bean oil biodiesel tested was slightly higher than B10 and B20 of Neem oil biodiesel from Pakistan see Table 3 and 4. The comparison of kinematic viscosity of blends B10 and B20 of Castor bean oil biodiesel tested was slightly less than B10 and B20 of Castor bean oil biodiesel, Pongame Oil Biodiesel and Hemp Oil Bio diesel from Pakistan, this difference may not affect their difference in atomization characteristics as shown in Table 3 and 4.

Table 3
Fuel properties of other oil sources including Castor bean oil biodiesel (COB) from Pakistan, Neem Oil Biodiesel (NOB), Pongame Oil Biodiesel (POB) and Hemp Oil Bio diesel (HOB) (Mushtaq *et al.* 2011).

Fuel Properties	Type of seed	B 100	B 20	B 10
Kinematic viscosity at 40°C	NOB	4.81	3.30	3.10
	COB	5.67	4.48	3.52
	POB	5.532	4.1849	3.7959
	HOB	3.83	5.113	4.223
Density @15°C Kg/L	NOB	0.8785	0.8476	0.8450
	COB	0.8873	0.88720	0.88111
	POB	4.086	0.5072	0.1639
	HOB	0.8195	0.8224	0.8116
Flash point °C	NOB	124	64	65
	COB	96	83	77
	POB	90	72	70
	HOB	120	91	75

Table 4
Fuel property of castor oil from Melkasa Agricultural Research Centre East Showa, Ethiopia

	Test Result		
Property	**B100**	**B20**	**B10**
Kinematic viscosity@40⁰C,mm²/s	18.34	3.97	3. 37
Density@15⁰c,g/ml	0.9345	0.8670	0.8581
Flash point (⁰C)	152	69	69

But B100 property of kinematic viscosity of Castor bean oil biodiesel tested was much higher as compared to the Castor bean oil biodiesel, Pongame Oil Biodiesel, Hemp Oil Bio diesel and Neem Oil Biodiesel from Pakistan see Table 3 and 4.

The density of Castor bean oil biodiesel of B100 Castor bean oil biodiesel tested was slightly higher than that of COB, HOB and NOB but it is much lower than POB see Table 3 and 4. Comparison of castor been oil biodiesel blends of B20 and B10 was almost equal to the density of respective blends of COB, HOB and NOB except POB which is lower see Table 3 and 4.

The flash points of B10 and B20 Castor bean oil biodiesel tested was higher than flash points COB, HOB and NOB from Pakistan but it was a little bit higher than NOB from Pakistan. Whereas the flash point of B100 Castor bean oil biodiesel tested was much higher than COB, HOB, NOB and POB studied in Pakistan see Table 3 and 4.

3.3. Performance test

After the fuel properties of the net biodiesel (B100), the petrodiesel (B0) and their blends (B5, B10, B20, B40, and B80) are studied, those blends which satisfy the ASTM standards are identified to test their performance characteristics in CI engines. The blends that satisfy the ASTM standards in this research work are B5, B10, B20 and B40. Therefore their performance characteristics (Torque, power and fuel consumption) are compared with that of the petrodiesel (B0) as follows.

3.3.1. Torque Vs Speed

From Fig. 1, torque performance with fuel blends, one can say that the trend of the parameter versus speed is almost similar to neat diesel fuel. Particularly at high engine speed ranges for all types of fuels the resistance to flow (flow losses) are very high and short opening periods of the valves. This results in reduced cylinder filling and hence reduced volumetric efficiency, engine power and engine torque. It is also clear to see that at a particular speed values the torque output decreases as the percentage of biodiesel increases in the blends. This is may be due to the lowering of the heating value of the fuels as the percentage of the biodiesel in the blends is increasing.

3.3.2. Torque Vs Power

From Fig. 2, it is possible to say that the trend of the curves is almost similar. But the power output reduces as the percentage of the biodiesel increases in the blends due to the reduction in the heating values of the blends. At lower torque values the power output is reduced due to insufficient time for charging of the cylinders (reduction in the volumetric efficiency). At higher torque values the power output is also reduced due to increased time for heat losses.

3.3.3. Torque Vs brake Specific fuel Consumption (BSFC)

The specific fuel consumption, SFC, is a measure of how efficiently the fuel supplied to the engine is used to produce power. Clearly a low value for SFC is desirable since for a given power level the lesser the fuel consumed the better it is.

Brake specific fuel consumption (BSFC) defines the amount of fuel needed by the engine to produce one kilo watt hour (1 KWh) of useful energy output. Normally, lower engine speeds produce a higher BSFC because of increased time for the heat transfer from the working fluid to the cylinder walls. Also higher engine speeds produce a high BSFC because of rising friction losses in the engine. Higher friction losses reduce brake torque, which increases BSFC.

The lower BSFC value of diesel is attributed to the lower density and weaker molecule bonds leading to a lower flash point. Consequently, petrodiesel is burnt faster than biodiesel giving higher amount of torque within the same time.

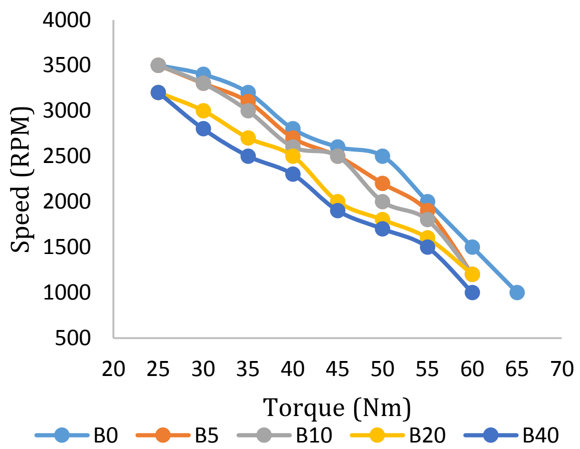

Fig. 1 Torque vs speed characteristic curves

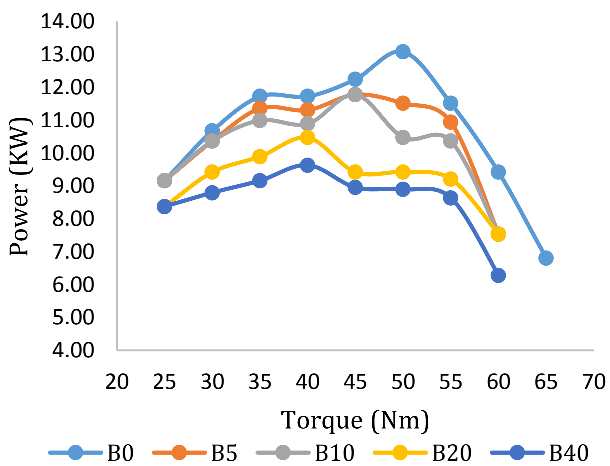

Fig. 2 Torque Vs Power characteristic curves

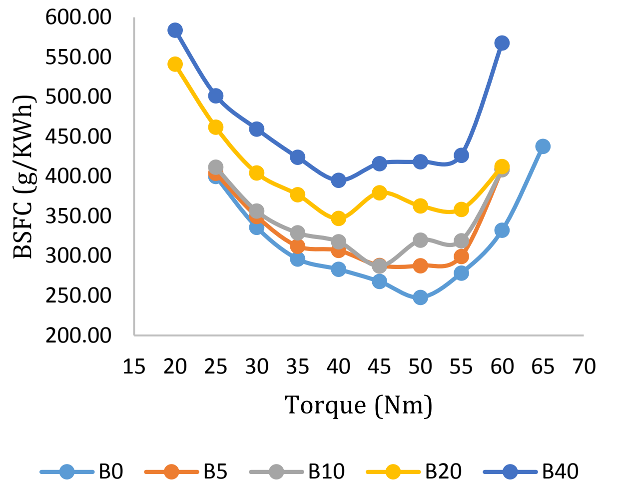

Fig. 3 Torque Vs brake specific fuel consumption characteristic curves

Further, the lower calorific value for biodiesel fuels resulted in consuming more fuel to produce some torque developed by normal diesel. This results in an increase of engine specific fuel consumption (Lapuerta *et al*. 2008).

From Fig. 3, it is possible to see that the trend of the curves for all blends is similar and comparable with that of the petro diesel. But the BSFC increases as the percentage of the biodiesel increase in the blends. This may be due to the fact that biodiesel is an oxygenated fuel. The higher fuel viscosity may also reduce the quality of fuel atomization, and could result in higher gas emission and fuel consumption. However, this increase was partially compensated by the higher density of biodiesel in the volumetric injection system, and thus, differences in volumetric consumption between diesel and biodiesel became smaller. As long as diesel fuels are delivered by volume, the final sale price of biodiesel should be proportionally lower.

4. Conclusions

The main aspiration of the research was to produce biodiesel from castor seed and compare its performance characteristics with that of petro diesel in the existing four stroke cycle diesel engine without making any modifications to it. The results from the research are illustrated as follows.

- All the tests from characterization of biodiesel demonstrated that, almost all the important properties of biodiesel (except for B100 & B80) are in very close agreement with the mineral diesel, making it a potential candidate for the application in CI engines.
- The experiment showed that castor seed has higher biodiesel yield and the characterization results witness that biodiesel from castor seed can be blended with petro diesel in order to minimize the problems that can arise from its higher viscosity

while using the neat biodiesel in unmodified diesel engines. Hence, the research shows a good bright future, that it is possible to produce an everlasting and safer fuel above the earth's surface which can potentially substitute petro diesel.

- The performance test results depict the tested blends (B5, B10, B20, and B40) perform almost similar when compared with the performance of petro diesel. The torque and power performances get reduced and fuel consumption increase as the percentage of biodiesel in the blends increase. This is because of the fact that biodiesels are oxygenated fuels and hence has less energy content compared to petro diesel. But this little reduction in performance can be compensated with lots of its advantages like its usage in unmodified engine, better lubricity, renewability, degradability, very less contribution to global warming, and its provision of great ecological advantages in terms of erosion control and wasteland recovery.
- The performance characteristics showed that diesel engine can perform satisfactorily on biodiesel blends without any engine hardware modifications.
- The performance result also showed that out of the blends, B5 is most nearer to petro diesel performances and hence it is possible to start driving diesel engine vehicles with 5% biodiesel and 95% petro diesel blend. But small generators and water pump engines (because the load imposed on them is not that much bigger) can be fuelled with B20, a 20% biodiesel and 80% petro diesel blend; which brings a great cost reduction especially for farmers (because biodiesel can be locally produced).

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