Performance Analysis of Cotton Seed Biodiesel in Diesel Vehicle on Chassis Dynamometer

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Abstract. There is a need to identify alternative fuels suitable for running diesel engine as a replacement of diesel to address the problems like depletion of fossil fuel reserves and environmental pollution. The fuels derived from bio-resources found to be good alternatives for conventional petro-fuels in solving such issues. The impact of cotton seed oil biodiesel blend on vehicle performance with four stroke four cylinder diesel engine was investigated. Emission test was performed on six cylinder engine vehicle using 100% diesel of petroleum origin (fossil diesel), and B10, B20, B30 of cottonseed oil methyl ester. Analysis was carried out on major performance parameters P_b, T_b, bsfc & emissions such as NOx, CO, CO_2, O_2 and HC. It is observed that Blends of biodiesel B10, B20 & B30 reduced brake torque by 5%, 7% & 12%, also reduced brake power by 6%, 8% & 11% and increased in fuel consumption by 4%, 8% & 20% respectively. However, the emissions of the CI engine running on three biodiesel blends were reduced, CO by up to 16%, CO_2 by 17% and HC by 12% & increase NOx by 14% & O_2 by 18% as compared to diesel fuel. It is concluded that blend of 20% cotton seed biodiesel can be used in an unmodified diesel engine.

Keywords: Biodiesel · Blends · Performance and emission · Transesterification

1 Introduction

The issue of extinction of fossil fuel reserves due to higher rate of usage in daily life became a focal attention of most of the people in the world who are very much dependent on fossil fuels to meet their daily energy needs. Air pollution thereby health problems and global warming issues which are caused by continuous burning of fossil fuels is another issue attracting the attention of the engineers and scientists. The harmful emissions from the vehicles of the transportation sector, which are contributing much of the environmental pollution, must be controlled [1]. The available reserves of fossil fuels in the world are observed to be unsustainable and declining day by day. For solving these problems, it became a priority issue for automotive industries and researchers to explore the ways of replacing or minimizing the usage of fossil fuels by identifying the fuels which are ecofriendly, economical, sustainable and renewable [2]. Biodiesels which are derived from bio origin (vegetable oils, fat) are observed to be better

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alternative fuels, which can be used in CI engines without much modification to the engine. Biodiesels can be better replacement alternative fuels for conventional petroleum fossil fuels and reduce the dependency on fossil fuels. Biodiesels are nonpolluting, biodegradable, nonpoisonous, renewable and can be used in CI engines at any proportion by blending with conventional diesel [3]. Biodiesel is a mono-alkyl ester which is produced from long chain fatty acids present in animal fats and vegetable oils. Any type of vegetable oils like cotton, sunflower, jatropha etc. can be used for biodiesel production [4]. The problems of using vegetable oil as fuel in CI engines can be reduced by blending with diesel and engine life can be extended [5, 6]. The viscosity of the biodiesel is almost close to petro diesel. There is a inbuilt oxygen in biodiesels which is about 10–11% by weight. So the combustion of biodiesel in CI engine is better than conventional diesel which is hydrocarbon based [7].The methods like transesterification, blending, emulsification can be used for reducing the viscosity of vegetable oils [8]. Conversion of triglycerides to biodiesel is normally done by transesterification process which is a well-established procedure. In this process, mono alkyl ester is produced by allowing the reaction between light alcohol and triglycerides of vegetable oils in the presence of suitable catalyst. Potassium and Sodium hydroxides are found to be better catalysts for this purpose [9, 10]. But alkali catalysts are very much sensitive to free fatty acids and water, which is a limitation of this process [11]. Transesterification is generally carried out at 60 °C which is closer to the boiling point temperature of methanol. Alcohol to oil molar ratio of 5:1 is normally recommended [12].

2 Methodology

2.1 Materials

Table 1 shows the list of materials for biodiesel production.

Table 1. Materials used for biodiesel production.

No.	List of materials
1	Methanol
2	KOH
3	Cotton seed
4	Crude cotton seed oil
5	Distilled water

Crude cotton seed oil was extracted from expeller, Addis modjo edible oil complex company (i.e. screw pressed cottonseed oil) by mechanical pressing. Methanol and potassium hydroxide were obtained from an Agent of Yeshadam Chemicals trading plc in Addis Ababa. The laboratory facility available at Chemistry department of ASTU was used for chemical reaction process and blending process. Chassis dynamometer test rig available at automotive laboratory, ASTU and the facilities available at Maj General Mulugeta Buli technical college were used for conducting performance test.

Diesel fuel was purchased from fuel station, Adama. Here, it worth to note that measurements were taken at two different place because measuring instruments like chassis dynamometer and exhaust gas analyzer could not be found at a place.

2.2 Biodiesel Production

The following Fig. 1 shows the working flow for biodiesel production.

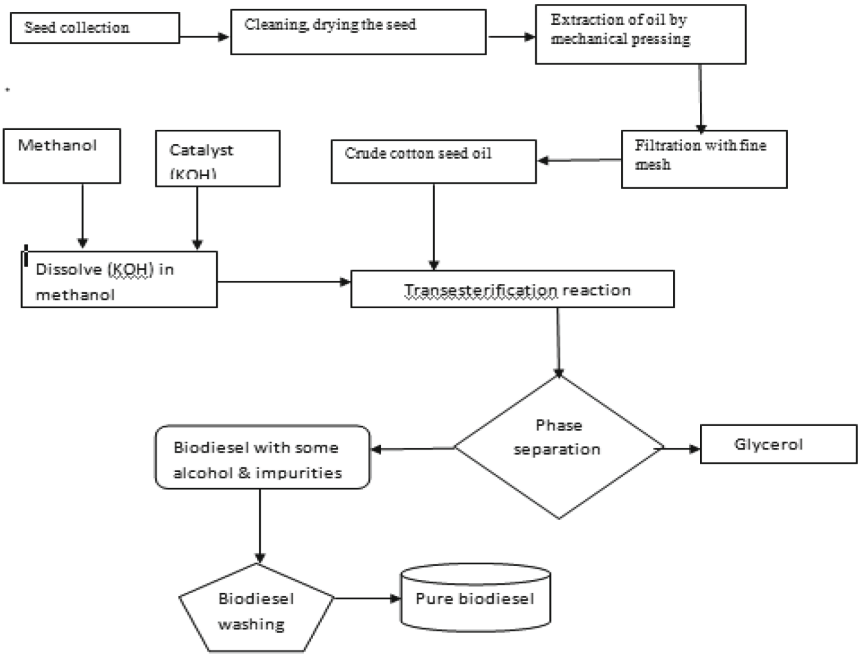

Fig. 1. Flow chart for biodiesel production

2.2.1 Transesterification of Cotton Seed Oil

The chemical reaction involves the reaction of triglycerides of cotton seed oil with methanol in the help of alkali catalyst KOH, producing ester and glycerol. In this process 5 g of potassium hydroxide was dissolved in 100 ml of methanol. The mixing ratio was taken as (the catalyst and alcohol quantity are 1% and 20% of oil respectively). Which is full dissolved for each sample of 500 ml of crude cotton seed oil.

1. Crude cotton seed oil (500 ml) was measured and poured in a flask per each sample.
2. For each sample, 100 ml of methanol and 5 gms of KOH were taken (see Fig. 2).

Fig. 2. Measuring the crude oil sample, measuring KOH and dissolving in methanol

3. Dissolve KOH completely in methanol.
4. Crude cotton seed oil is to be heated to 65 °C (see Fig. 3)

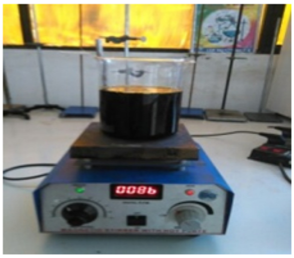

Fig. 3. Heating the crude oil

5. Methanol and KOH mixture is to be added to the heated oil.
6. Heat the dissolved mixture for 1 h at fixed temp of 65 °C, heating and stirring takes place at the same time continuously, and measure the temperature of the reactant for every 10 min with the help of thermometer. After one hour, switch off the heating mantel to stop the reaction process.

The products were kept for 24 h in separating funnel after transesterification process. There was a formation of two phases with different densities (Fig. 4).

Fig. 4. Two layers of oil formed.

In the two layers, glycerin exists in the lower layer and biodiesel, soap and alcohol exist in the upper layer. Soap may be formed due to side reactions. Glycerin is to be removed from the bottom of the funnel. The glycerin can be used to make soap (see Fig. 5).

Fig. 5. Biodiesel (left side), and glycerin and fatty acid (right side).

7. The ester is to be washed with warm water (at 55 °C) for removing the alcohol and catalyst (Fig. 6).
8. Repeat washing process six times until water is mostly clears (Fig. 7).

Fig. 6. Soap and impurities during washing process.

Fig. 7. Final washing step, water becomes clear and Biodiesel after washing process.

The biodiesel was dried by heating at a temperature of 100 °C for one hour using hot plate (Fig. 8).

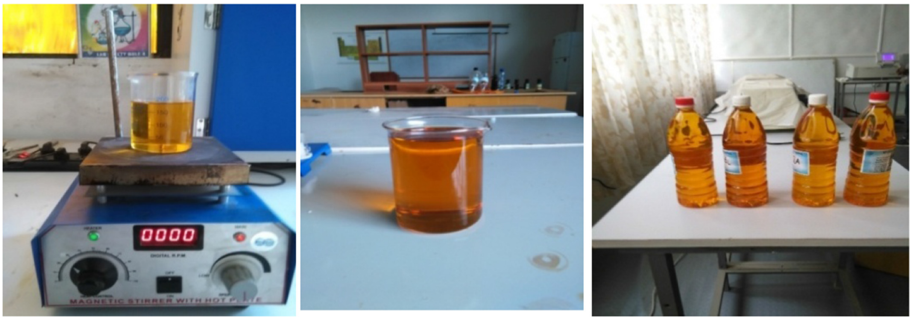

Fig. 8. Heating, drying the biodiesel and collected biodiesel.

2.2.2 Characterization of Cotton Seed Biodiesel

Characterization is the process of determining physicochemical properties of petroleum products and non-petroleum products like biodiesel blends. Before testing the performance & emission of blend fuels it's very important to check physicochemical properties. The properties of the fuel include flash point, kinematic viscosity, cloud point, density, acid number, distillation range.

Fuel blends prepared for characterization are B 10, B 20, B 30 and B 100. To prepare B 10 blend fuel, 50 ml of cotton seed biodiesel mixed with 450 ml of diesel fuel to produce B 20, 100 ml of biodiesel & 400 ml diesel fuel mixed & for B 30 150 ml of biodiesel blend with 350 ml of diesel fuel. Properties of biodiesel was measured in ASTU, (UV spectroscopy & PH) in chemistry department) & other physical properties mentioned below are measured in Ethiopian petroleum supply enterprise (quality control laboratory).

2.2.3 Experimental Facilities for the Test

The experimental measurement of gaseous emissions was carried out on Maj. General Mulugetabuli technical college using a FGA- 4100 emission analyzer and on the Mercedes Benz truck vehicle at selected five engine speed (500, 1000, 1500, 2000, 2500 rpm). The performance measurements were carried out in the work shop of ASTU. The test was performed on 3 L Toyota vehicle using Sunroad–a-matic XII chassis dynamometer. On both cases the fuels used were diesel (no 2). This is used as a reference fuel and a blend of B10, B20, and B30. Baseline data was collected by running the engine with pure diesel. Then engine was run with blends of biodiesel and the data obtained was compared with the data of the pure diesel. After comparison better blend was identified.

Table 2 shows the vehicle specification for exhaust gas measurement, and Table 3 shows the vehicle specification for performance measurement.

Table 2. Vehicle specification for exhaust gas measurement

No.	Descriptions	Font size and style
1	Vehicle model	Mercedes Benz truck
2	Strokes	4
3	Cylinders	6
4	Transmission	Manual
5	Fuel	Diesel
6	Chassis	WDB 380013-15-339123
7	Engine number	3621880102
8	Cooling system	Water cooled

Table 3. Vehicle specification for performance measurement

No.	Description	Specifications
1	Engine	Toyota 3L-4122571
2	Strokes	4
3	Cylinders	4
4	Transmission	Manual
5	Fuel	Diesel
6	Chassis	LN 106-0136567

Figure 9 shows the chassis dynamometer and vehicle for performance test.

Fig. 9. Chassis dynamometer and vehicle for performance test.

2.2.4 Emission and Performance Test Procedure in Diesel Vehicle

The Emission gases test was performed on truck vehicle running the engine with no load conditions at different engine rpm connect the emission analyzer and keep it to warm up for 15 min then displays emission gases with respect to engine rpm. The performance test was performed by driving the vehicle with chassis dynamometer (sun Road-a-Matic XII) starting from 15 km/hr upto 75 km/hr in a interval of 10 km/hr. The parameters measured are wheel power (kW), tractive force (kN) and wheel power (kW). All four gears (1^{st}, 2^{nd}, 3^{rd} and 4^{th}) were used for test. The fuel consumption was measured by recording the time for the consumption of ten grams of fuel. By measuring the fuel consumption, torque and power at different speeds, the performance of the engine was evaluated. Experiments were conducted for pure diesel, and B 10, B 20 and B 30 biodiesel blend.

3 Result and Discussion

3.1 Oil Content from Extraction

Mechanical pressing was used to extract the crude oil from cotton seed. From 40 kg of cotton seed the yield of oil was 7 L which is 17.5% (v/wt.). Oil extraction by mechanical pressing is economical and time saving method.

3.2 Production of Biodiesel

From 7L of cotton seed oil biodiesel production yield was 5L which is 71.5% by performing transesterification process. The activities like glycerin separation, washing about six times with distilled water and drying by heating up to 100 °C for 1 h were performed.

Table 4 shows the transesterification process, and Table 5 shows the characterization of blended fuels.

Table 4. Transesterification process.

Amount of cottonseed oil (ml)	Molar ratio of alcohol	Catalyst (KOH) %	Alcohol (Methanol) in (ml)	KOH in (gm)	Reaction time in (minute)	Reaction temperature in (°C)	Settling time in (hr)
500	1:5	1.0	100	5.0	60	65	24

Table 5. Characterization of blended fuels.

No.	Property	B100	B10	B20	B30	ASTM method	ASTM 6751 standard
1	Density@15 °C, (g/cm^3)	0.8911	0.8574	0.8611	0.8641	D4052	0.86–0.9
	Density@20 °C, (g/cm^3)	0.8877	0.8539	0.8576	0.8613	D4052	
2	Cloud point, °C	+4	+1	+1	+1	D2500	As report
3	Flash point, °C	178	86	89	90	D93	Min 130
4	Distillation	–	–	–	–	D86	
	IBP, °C	320.0	193.5	196.5	165.5		
	10% volume, recovered °C	331.5	229.0	233.5	240.5		–
	40% volume, recovered °C	334.5	287.5	293.5	302.5		–
	50% volume, recovered °C	335.5	299.5	306.0	315.0		–
	90% volume, recovered °C	361.0	354.0	355.0	358.0		282–362 °C
	95% volume, recovered °C	363.0	367.0	358.0	368.0		–
	FBP, °C	363.0	369.0	363.0	369.0		Max 390 °C
5	Acid value (mg of KOH/gm)	0.06	0.02	0.04	0.05	D974	0.8 mg of KOH/gm
6	Kinematic viscosity@40 °C	5.9	–	–	–	D445	1.9–6 mm^2/s
7	Cetane index	45.3	50.7	50.5	50.5	D976	Min 40 °C
8	UV spectrum (nm)	229	256	256	257		220–300
9	PH	6.85	7.00	6.99	6.99	6.85	Approx. to (neutral)

3.3 Results from Emission Test

Analyzed emissions in the present investigation are CO, NOx, O_2, CO_2 and HC. Figure 10 shows the influent of engine speed on CO emission.

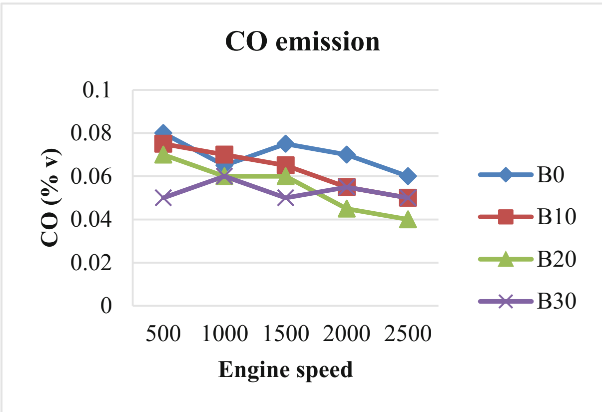

Fig. 10. Variation of CO

Figure 10 shows, CO emissions in the blends of the biodiesel is lower than that of the diesel due to the less carbon content in to the biodiesel blends. B10, B20 and B30 reduce CO emission by 7%, 13% and 16% compared with B0 fuel, respectively.

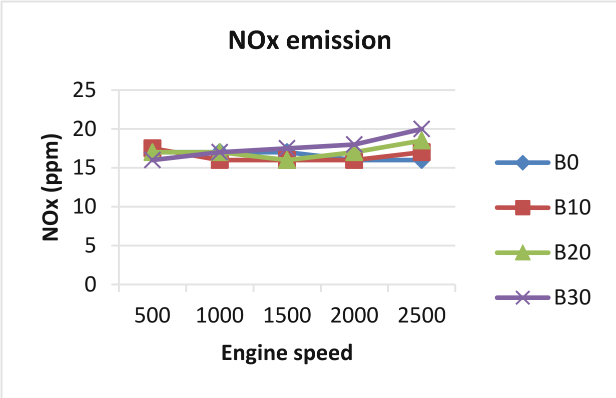

Fig. 11. NOx emission.

With increasing engine speed NOx observed to be increasing (Fig. 11). Three blend fuels increase NOx emission by 5%, 8%, 11% respectively. This can be due to higher oxygen content which lead to increased combustion temperature.

3.4 Vehicle Performance Test

The performance of diesel vehicle was tested using chassis dynamometer. The performance parameters like tractive force in (kN) and wheel power in (kW) were measured.

BrakePower(P_b) is an engine performance parameter. Brake power (Pb) is given by, $Pb = \frac{2\pi NT}{60}$ Where, T is torque in N-m and N is the speed in revolutions per minute & also we can express brake power as the following.

$$\mathrm{Pb} = \frac{Pw}{\eta t} \quad (1)$$

Where; Pb is brake power, Pw is wheel power, and ηt is gear box efficiency (Fig. 12).

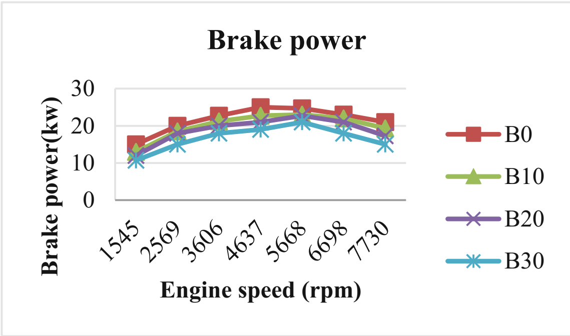

Fig. 12. Variation of brake power.

It can be seen that from the graph the biodiesel blend fuels produced lower Pb than diesel fuel. As the engine speed increasing brake power increasing until 5668 rpm and then starts to decrease. Biodiesel blend fuels B 10, B 20 and B 30 decreased Pb by 6%, 8% and 11% compared with diesel. It might be because of lower calorific value of biodiesel. Also, fuel consumption of blended fuels is more due to lower density of biodiesel.

Brake Torque (Tb) is the torque available at the 'output shaft' of the engine or at the 'Flywheel'.

$$Pb = \frac{2\pi NT}{60} \tag{2}$$

$$Tb = \frac{Pb}{\omega} = \frac{60 \times Pb}{2\pi N} \tag{3}$$

$$Tb = \frac{60 \times Pb \times 1000}{2\pi N}, \text{Pb in kW; N in rpm, and Tb in Nm.}$$

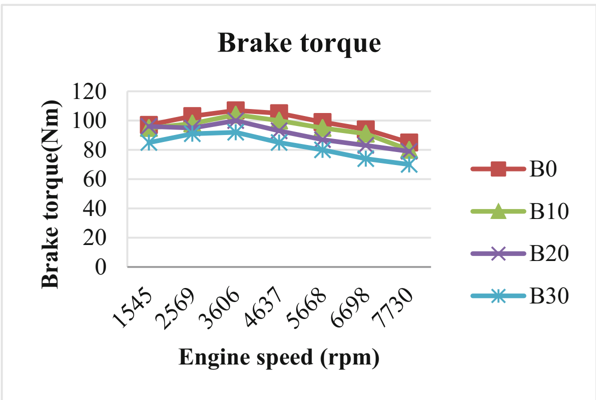

Fig. 13. Variation of brake torque.

Up to engine speed of 3606 rpm, brake torque observed to be increasing and then starts decreasing with increase in the speed for all fuels (Fig. 13). Diesel fuel produced more torque than the blends. It might be due to lower calorific value of the biodiesel. There is a reduction of 5%, 7% and 12%, respectively.

Brake specific fuel consumption (bsfc): is the amount of fuel consumed by engine in ‘kilogram per hour (kg/h)’ to develop a brake Power (Pb) of one kilowatt (kW) while running at a constant engine speed (N) in ‘rpm’. It is an engine performance parameter which mainly determines, the ‘fuel consumption’ or the ‘fuel economy’ of the engine.

$$\text{Specific fuel consumption (sfc)} = \frac{mass\,flow\,rate}{Power} \tag{4}$$

$$Brake\,specific\,fuel\,consumption\,(bsfc) = \frac{\text{mass flow rate}}{Brake\,power} \tag{5}$$

The bsfc is given by the Eq. 6.

$$\text{bsfc}\left(\frac{gm}{kwhr}\right) = \frac{mf\left(\frac{gm}{se}\right) * 3600}{Pb} \tag{6}$$

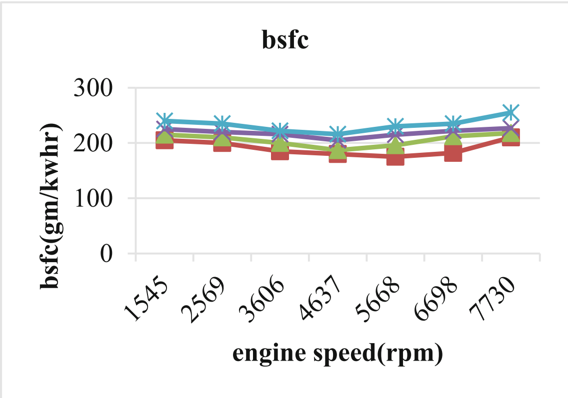

Fig. 14. bsfc with engine speed.

Figure 14 shows that diesel fuel had the lowest BSFC, but the BSFC increases as biodiesel increases in the blends. It is due to its higher viscosity, lower density may reduce fuel atomization and then due to this require large mass of fuel flow. The increased fuel consumptions for blend fuels are 4%, 8%, 20% respectively.

3.5 Engine Performance Curves for Diesel and Biodiesel Blend

Figures 15, 16, 17 and 18 shows the engine performance curve for B0, B10, B20 and B30, respectively.

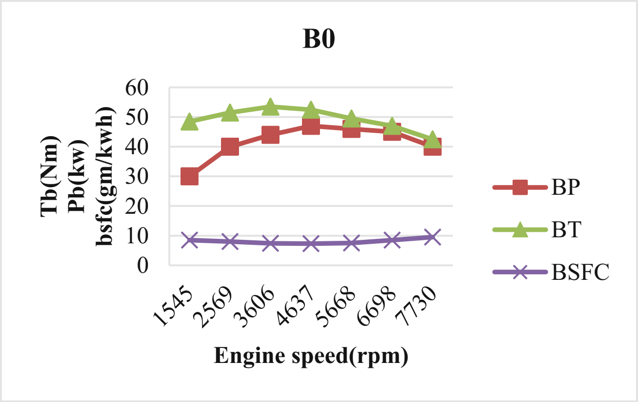

Fig. 15. Engine performance for B0.

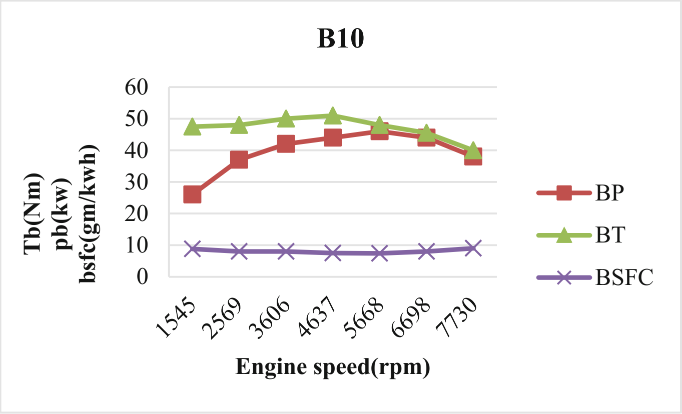

Fig. 16. Engine performance curve for B 10.

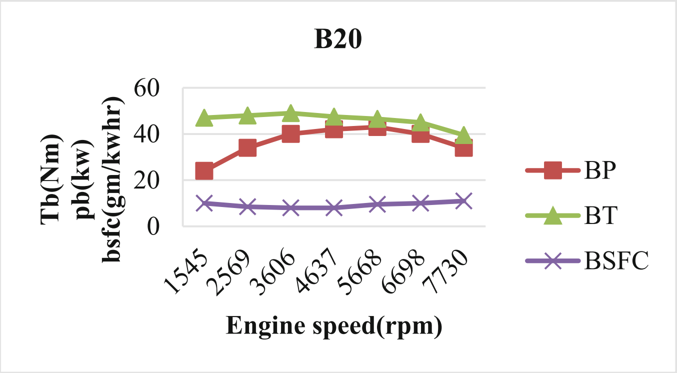

Fig. 17. Engine performance curve for B 20.

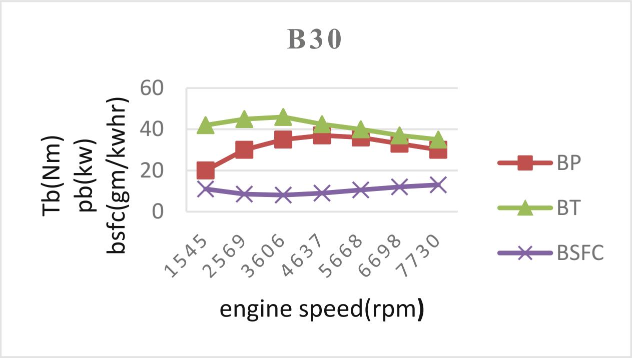

Fig. 18. Engine performance curve for B 30.

Figures 15, 16, 17 and 18 indicate that the performance of the engine with B0, B10, B20 and B30, respectively. The comparison was made by comparing the brake power, Tb and bsfc with engine speed. When the percentage of blend increases brake torque and Pb decreases and bsfc increases with the increase in engine speed. This is because of higher viscosity and lower calorific value of biodiesel.

4 Conclusions

Various experiments were conducted in this research work with the aim of testing performance and emission of cotton biodiesel in diesel vehicles. Pure biodiesel was not used because it is found that the viscosity of cotton biodiesel is higher than petro diesel. So, blends of biodiesel B10, B20 and B30 were used for testing. From the results, it is observed that performance of the engine when fueled with biodiesel blends is comparable to that when fueled with diesel. The bsfc when fueled with the biodiesel blend is observed to be higher than when fueled with petroleum diesel. The conclusions are summarized as follows.

1. Properties of cotton seed biodiesel and its blends conform to ASTM D6751 standards.
2. Torque and power performance gets reduced and fuel consumption increased as percentage of biodiesel in blends increase. It happens because of lower calorific value of the biodiesel compared to diesel.
3. The biodiesel blends producing lower emission with drop in CO, CO_2 and HC emission while NOx and O_2. Emissions are show a little increment compared to the conventional diesel. This is due to that biodiesel is a green fuel and contain less carbon molecules.
4. The results obtained in this work suggest that cotton seed biodiesel blend can be used in an unmodified diesel engine since their performance and emission characteristics were very close to that of diesel and it is environmental friendly with reduced emissions.

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