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Investigation on Performance and Emission Behaviour of a Single Cylinder Diesel Engine Fuelled with Mixture of Cottonseed and Sunflower Biodiesel Blends along with Diesel

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Abstract
Nowadays alternative fuels are gaining more importance because of depleting crude oil resources, high rise in fuel prices, and environmental degradation due to exhaust pollutants. Transesterification process is mostly preferred for conversion of vegetable oils into useable bio diesel fuel. In the present work, performance investigation and emission examination is done on single cylinder diesel engine by usage of mixture of methyl esters of cottonseed oil and sunflower oil without doing any modifications in the engine. Here cotton seed oil methyl ester addition was kept constant as 5% by volume. For the study, both oil methyl esters were mixed and were added to diesel fuel, by volume of 10%, 15%, 20%, 25% and 30%. The effect of blends on brake specific fuel consumption and brake thermal efficiency were compared with baseline pure diesel values. Emission tests were conducted for finding the effect of blends on unburnt hydrocarbons, carbon monoxide, nitrogen oxides and smoke. A slight increase in brake thermal efficiency was found for lower blends across various loading conditions. Smoke and exhaust emission decreases on usage of higher biodiesel blends. The results indicated that 20% biodiesel blend can be replaced without any major engine modifications as it gives better performance and emission characteristics.

Keywords: Transesterification, sunflower methyl ester, cottonseed methyl ester, emission, performance.

1. Introduction

Diesel engines play a major role in commercial transportation and heavy industrial applications because of their higher fuel efficiency and higher torque output. The major problem with petroleum fuels is its depleting nature and harmful exhaust emissions [1]. Now-a-days, earth's temperature is constantly increasing because of the exhaust gas coming out from automobiles which damages the ozone layer [2]. The shortage of petroleum resources took the fuel prices to a high level. So there comes a need for developing an alternative for petroleum fuel. Constant efforts done by various researchers led to the discovery that vegetable oils can be used as a substitute since its properties were matching to diesel [5-6]. Consumption of diesel can be minimized by implementing biodiesel program expeditiously. Biodiesel extraction from various usable and non-usable oils have been found to be a promising fuel for diesel engine. The mainly used sources for biodiesel extraction are pongamia, cottonseed, sunflower, peanut and coconut [4]. A certain percent of biodiesel blend with diesel reduce the harmful exhaust emissions by a remarkable percentage. Cotton and sunflower are widely grown in Gujarat, Madhya Pradesh, Kerala, Bihar, Tamil Nadu and Punjab in India.

The positive things about biodiesel were its high energy content, higher cetane number, and cleaner emissions. The higher amount of fuel based oxygen in biodiesel lead to oxidation of exhaust emissions. The father of diesel engine tested his engine first with vegetable oil before trying it out with diesel [1]. The viscosity of vegetableoil is amajor issue as it affects the atomization of fuel in the combustion chamber. This leads to more deposits on engineand also coke the injector [7-9].

Biodiesel can be prepared from different feed-stocks. Transesterification is the process mostly used for conversion of raw vegetable oil into its methyl ester, where viscosity of oil is reduced by removing the fat content which eliminates the viscosity related problems [10-13]. Thechemical process yields methyl esters of oil (chemical name for biodiesel) and glycerine, where glycerine is used in soap industries [3].

Nomenclature

SFME	-Sunflower methyl ester
CO_2	-Caron-di-oxide
CSME	-Cottonseed methyl ester
NO	-Nitrogen oxides
D	-Diesel
O_2	-Oxygen
BTE	-Brake thermal efficiency
BSFC	-Brake specific fuel consumption
CO	-Carbon mono-oxide
HC	-Hydrocarbon
CV	-Calorific value

Experiments conductedby usage of CSME showed that the BTE of biodiesel blends are slightly lower when compared to diesel results but emissions levels were reduced by usage of blends, except NO emission which showed slight increase. A study done on vegetable oil methyl esters showed reduction in

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smoke density and increase in thermal efficiency. Only less efforts were made on usage of two biodiesel blends. A combination of these two methyl esters were selected. Since viscosity of CSME was high, its addition was kept constant as 5% and only SFME addition was varied and tests were carried out.

2. Biodiesel Production

Cotton seeds that are collected from the grown cotton plant was the source of cottonseed oil and dried sunflower was the source of sunflower oil. The oil obtained was more luminous, which shown its clear. But there were some residues of oil cake even that was clear. Fig. 1 shows sequence of steps carried out for preparing biodiesel.

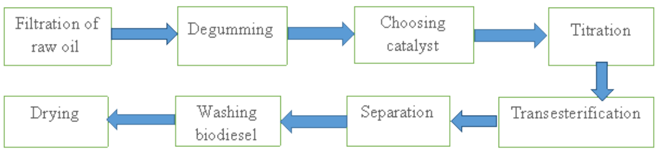
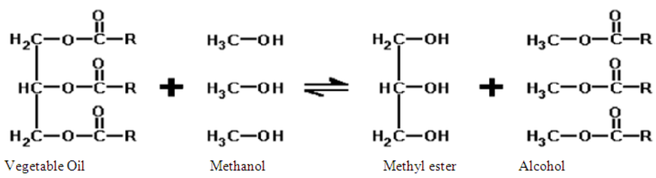


Fig. 1 Flow chart showing steps involved bio-diesel preparation

The filtration technique was carried out by bag filters made of canvas cloth and left for one day for residues to settle. The process of biodiesel preparationhas to be carried out in the existence of a catalyst [4]. The choice of catalyst is based on pH value of neat vegetable oil. The pH level of both oils were tested and since both oils have pH value of more than 7, base catalyst (sodium hydroxide) was selected. Improper catalyst selection leads to lot of soap formation, which is a by-product in trans-esterification process. Titration was carried out to determine the amount of catalyst to be used for the conversion process. In order to separate fat content from the pure oil, degumming process has been carried out. For this process, sodium hydroxide solution was prepared, where 3. 5 grams of sodium hydroxide pellets were dissolved in 100 ml of methanol.

The chemical reaction that occurs during transesterification process is given below,



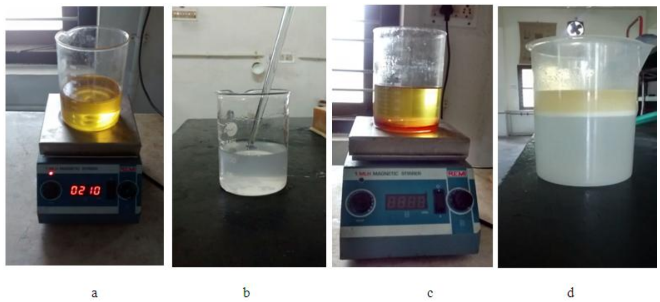


Fig. 2 Pictorial representation of biodiesel preparation a, b, c, d (from left to right) a). Heating of biodiesel in magnetic stirrer, b). Preparation of sodium hydroxide solution, c). Trans-esterification process, d). Washing biodiesel.

A 500 ml of pure cottonseed oil was taken in a round bottom flask and was heated on magnetic stirrer apparatus, which have a hot plate on the surface. The mixture was stirred at certain speed and was taken to a temperature of 70°C [1]. After that, the prepared sodium hydroxide solution was poured slowly into the heated oil in the flask and constantly stirred. The mixture in the flask has been maintained at a temperature of 65°C to 80°C for at least 3 hours with help of magnetic stirrer arrangement. The flask was taken away from the stirrer setup and kept separately for 24 hours which made the hydratable portions to accumulate, which becomes heavy and settle at the bottom of the flask, while oil being light floated on the top due to the difference in their specific gravities [1].

The two products formed are methyl ester of the oil and glycerine. The two products were separated and washing of biodiesel had been done to remove catalyst, unreacted alcohol, and further more glycerine from the biodiesel [3]. Washing process was carried out three times to obtain the neat biodiesel with the help of separating funnel, which uses gravity phenomenon as its principle. Only distilled water has been used for washing purpose. The final product of this process was pure biodiesel. Even though it was pure biodiesel, it had some moisture content in it which has to be removed otherwise it will lead to corrosion in the engine parts. The prepared biodiesel was heated to around 1050°C in vacuumstate for a time period of 3 hours to remove the residual moisture contained in the final biodiesel [4]

3. Experimental Setup

A naturally aspirated single cylinder agricultural diesel engine was nominated for this research. Table 1 shows the engine's key specifications.

Table 1. Specifications of chosen diesel engine

Make	Field Marshall
Type	Four stroke
Displacement	1433CC
Rated power	7. 35kW
Rated speed	1000rpm
Stroke	139mm
Bore	114mm

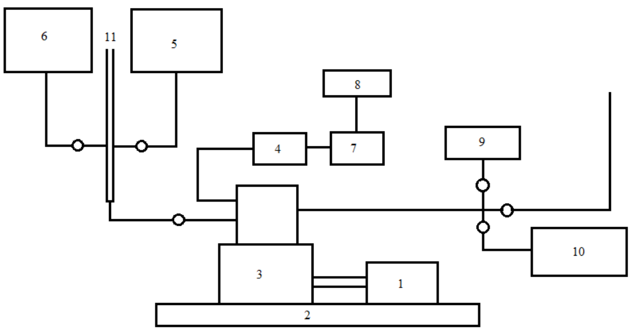


Fig. 3 Experimental setup-Skeleton diagram 1. Rope brake dynamometer, 2. Engine test bed, 3. Engine, 4. Air filter, 5. Bio-diesel tank, 6. Diesel tank, 7. Air box, 8. Manometer, 9. Smoke meter, 10. Exhaust gas analyser, 11. Burette

The taken engine was fitted with needed instrumentation which is shown in the fig. 3 and the required tests were performed. As blends were used two fuel tanks were fitted, one for pure diesel and the another one for biodiesel. Prony brake dynamometer had been used to apply different load on the engine. The exhaust gas analyser used was HORIBA make (model-MEXA-584L), which measures HC, NO in parts per million (ppm) and CO in percentage volume (% vol). AVL smoke meter was used to measure smoke density, which measures smoke in percentage volume (% vol).
Firstly, engine was cranked at no load condition and allowed to run for 20 minutes on neat diesel to attain the steady state. The performance, emission, and smoke data are noted which was used as reference value for comparing. Time for 10ml consumption of fuel was noted, which was the major data in computing performance. Testing was done on constant speed (1000 rpm) and varying load mode. Each time, load was incremented by 2. 5 kg (starting from no load to a maximum of 12. 5 kg)

4. Blend Ratios and its Properties

The prepared biodiesel was blended with neat diesel at the below mentioned percentages for testing the engine performance and emissions. The blend ratios were given in Table 2.

Table 2. Blend name and its ratios

Blend name	Blend ratio
B10	5% SFME, 5% CSME and 90% D
B15	10% SFME, 5% CSME and 85% D
B20	15% SFME, 5% CSME and 80% D
B25	20% SFME, 5% CSME and 75% D
B30	25% SFME, 5% CSME and 70% D

The blends were prepared correctly by using calibrated beakers otherwise the ratio won't be proper which affects the entire results. The cottonseed methyl ester addition was kept as constant as 5% by volume and only sunflower methyl ester addition was varied because of its higher density and calorific value.

Table 3. Properties of blends

Sl. no	Property	B10	B15	B20	B25	B30
1	Density (kg/m³)	818. 8	819. 8	821. 5	823. 2	824. 9
2	Flash point (°C)	47. 95	49. 75	51. 55	53. 35	55. 15
3	Fire point (°C)	53. 65	55. 80	57. 95	60. 10	62. 25
4	CV (MJ/kg)	44. 994	44. 747	44. 500	44. 253	44. 006
5	Kinematic viscosity (mm²/s)	3. 17	3. 277	3. 32	3. 37	3. 42

The properties such as density, viscosity, flash point, fire point and calorific value vary for each blend which is mentioned in Table 3. For higher blends, density and viscosity keep on increasing while the energy content available in the blend decreases.
Density was calculated by known technique, which is mass of liquid divided by its volume. Calorific value was calculated by bomb calorimeter apparatus. Flash point and fire point keep on increasing with higher blends as biodiesel has less firing capability when compared to neat diesel. Viscosity had been measured by redwood viscometer, where resistance to fluid flow was measured in terms of mm²/s. If viscosity and density of fuel are high, it affects the flow properties and fuel atomization in the combustion chamber, which eventually affects the performance and emission values.

5. Results and Discussion

5. 1 Performance

Diesel engines deliver high torque and power output hence play a major role in commercial vehicle segment. The main parameters considered here are brake thermal efficiency and brake specific fuel consumption. BTE can be defined as the brake power of an engine as the function thermal input from fuel. BSFC looks at engine's fuel efficiency and is calculated by dividing fuel consumption by brake power.

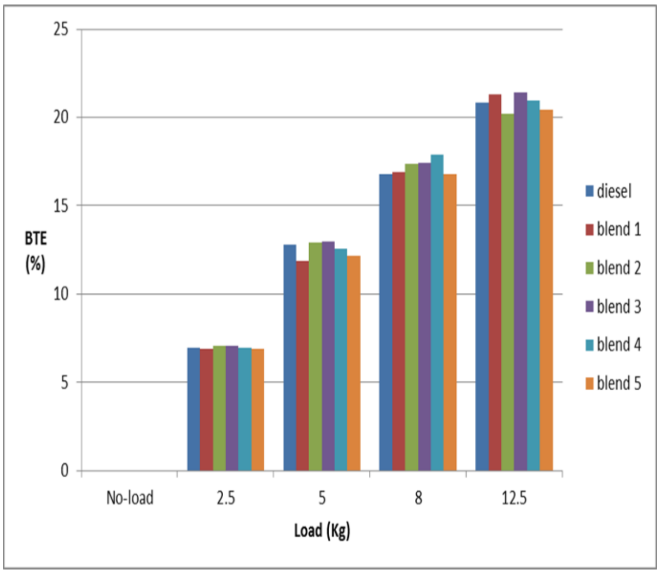


Fig. 4 : BTE vs load graph

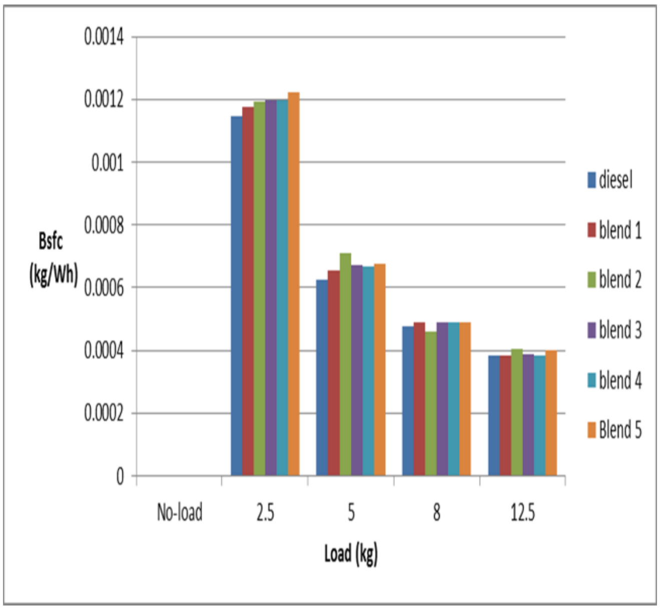


Fig. 5 : BSFC vs load graph

From fig. 4, it was observed that brake thermal efficiency of biodiesel blends shows an increasing trend when compared with diesel fuel. An increase in brake thermal efficiency was observed for blend-3 (15% SFME, 5% CSME and 80% D) in all loads because of extra oxygen available and greater cetane value. High cetane value improves ignition quality of fuel and supports for complete combustion. From fig. 5, it was detected that BSFC for blends risesmarginally than diesel owing to lesser energy content in biodiesel. BSFC of blend-3 (15% SFME, 5% CSME and 80% D) seemed comparable to diesel at higher engine load.

5. 2 Exhaust Emission

The harmful pollutants from diesel engines are CO, HC, NO_X and particulate matter. Exhaust gas analyser (HORIBA MEXA-584L) was allowed to warm up for 300 seconds and after that leak test, HC hang up test were carried out to ensure its proper functioning. After these tests, analyser became fully functional and ready to measure the emission values. Exhaust gas analyser probe was introduced into the exhaust pipe to measure the emission data. Smoke meter measure the smoke values precisely only if the heater temperature is between 70^0C to 80^0C. Firstly, the engine was allowed to run with diesel fuel until steady state was achieved and emissions values were taken. Engine steady state was attained for each blend before taking emission values and the results were compared with baseline diesel values.

From fig. 6, it was observed that 10% increase in NO emission for each higher blend starting from blend-1 because of high oxygen content in blends, which made the combustion chamber temperature to shoot up. Nitrogen pools with oxygen to form NO, only if the combustion chamber temperature is sufficiently high. From fig. 7, it was observed that HC emission decreases by 20% by the usage of blends and at high loads HC reduction rate was high (about 45%) as blends have high oxygen content, which supports better and stable combustion.

From fig. 8, it was observed that smoke density decreases by 30% by the usage biodiesel blends.

This reduction in smoke was due to more stable and complete combustion occurrence owing to more quantity of oxygen in blends. Blend-5 shows higher reduction in smoke density. The reduction in smoke is up to certain percent of blend. At very high blends, smoke increases due to improper combustion due to higher density and viscosity reasons. From fig. 9, it was observed that carbon monoxide formation was reduced by 20% by the usage of biodiesel blends. The main reason for CO formation is due insufficient oxygen. As biodiesel have higher content of oxygen, the excess oxygen available will combine with CO and oxidize it to CO_2. At higher loads and blends, decrease in CO rate was observed higher.

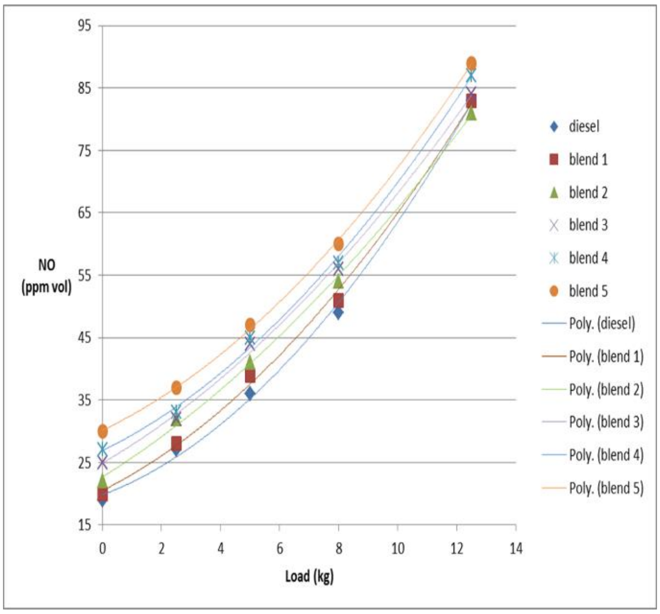


Fig. 6: Load vs NO emission

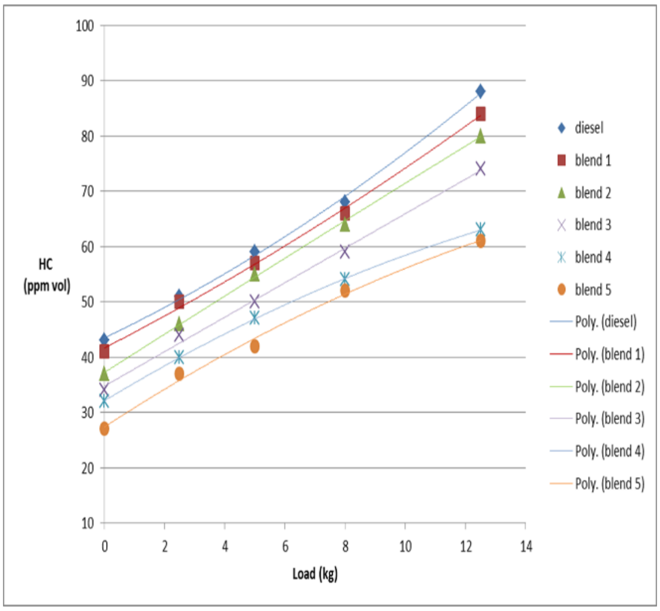


Fig. 7: Load vs HC emission

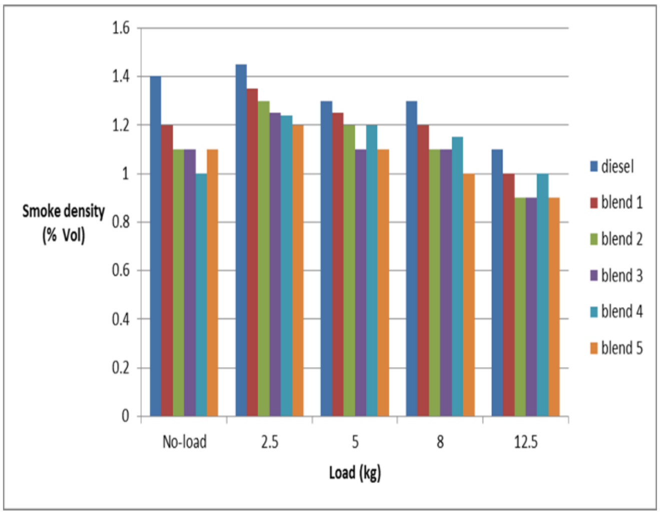


Fig. 8: Load vs Smoke density

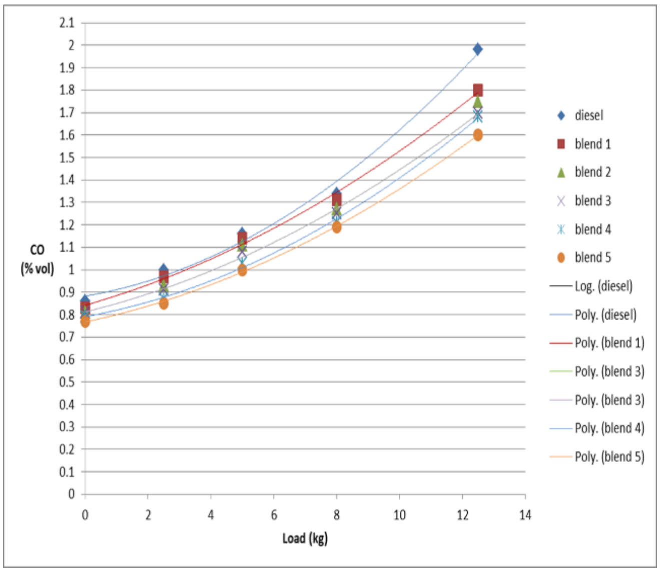


Fig. 9: Load vs CO emission

6. CONCLUSION

The experimental results obtained showed that the use of biodiesel blendsreduce the performance of engine asblends had lower calorific value. In performance wise, blend-3 (5% CSME, 15% SFME, and 80% D) showed 10% increase in brake thermal efficiency on all operated loads comparing to baseline values of diesel. The SFCincreases for blends because of their lesser energy content and increasing densities. Smoke opacity decreases by 30% for all the blends due to stable and complete combustion, as biodiesels are richer in oxygen content. The emission results showed that HC emission reduces for all the blends and particularly blend-5showed 35% reduction when compared with baseline diesel emissions due to complete combustion as blends have high oxygen content. NO emission increases by 10% for each higher blend than the previous lower blend, starting from B10. A 50% increase in NO emission was observed for B30 when compared with baseline diesel emission values. Results proved that lower blends, particularly B20(5% CSME, 15% SFME, and 80% D) can be used for obtaining better performance and emission values.

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