

Experimental Investigation of Effect of Composition of Biodiesel on Performance and Emission of a Compression Ignition Engine

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ABSTRACT: Biodiesel is mono-alkyl esters of fatty acids. The composition of biodiesel affects the engine performance and emission characteristics. In this study biodiesel was produced from sunflower oil and coconut oil. Biodiesel from coconut oil is highly saturated whereas biodiesel from sunflower oil is highly unsaturated. The engine performance and emission study has been carried out in CI engine using these biodiesels to investigate the effect of composition (degree of saturation or unsaturation and carbon chain length) of biodiesel on performance and emission characteristics. Significant variations in performance and emission characteristics were found with sunflower biodiesel and coconut biodiesel due to difference in the methyl ester composition of biodiesels.

KEYWORDS: Biodiesel, Composition, Fatty acid chain, Saturated content, Unsaturated content

I. INTRODUCTION

The limited reserve of fossil fuels and increasing environmental pollution demands the development and use of alternative fuels in internal combustion engines. Thus the attention of researchers has shifted from petroleum based fuel to biofuels. The biggest difference between biofuel and petroleum fuel is the oxygen content present in biofuel. [1]. Biodiesel is defined as the monoalkyl esters of long chain fatty acids. The sources of biodiesel are primarily categorized into four main groups; (a) edible and non-edible vegetable oils, (b) Animal fats, (c) Waste or recycled cooking oil and (d) Algae [1, 2]. The engine performance and emission varies in accordance with sources of biodiesel. This is due to difference in fatty acid methyl/ethyl ester composition of biodiesel or due to difference in fatty acid composition of feed stock of biodiesel. Fatty acid composition, such as the type and percentage will subsequently determine the fuel properties of biodiesel obtained. Fatty acids are of two types: saturated and unsaturated. Fatty acids without carbon-carbon double bonds are known as saturated, whereas those that contain double bonds are known as unsaturated fatty acids. Two properties that greatly influence the overall behaviour and suitability of fatty acid methyl ester as a diesel blend stock are: (1) the size distribution of the fatty acid chains and (2) the degree of unsaturation within these fatty acid chains. [2].

Sunflower plant even though native to North America, it grows in many areas of the US, Italy, Egypt, Afghanistan, India, China, Russia and throughout Europe. It comes under the category of edible oil. The unsaturated fatty acid percentage of sunflower oil is around 90 – 92% [3, 4]. Coconut tree is found abundantly in Philippine and Thailand and is a good source to produce biodiesel. Coconut oil comes under the category of edible oil. . The saturated fatty acid percentage of coconut oil is around 94 – 95% [1, 3].

Srivastava P K and Madhumita Verma [5] studied the effect of methyl ester of karanja oil, which contains about 68 - 70% unsaturated fatty acid, and its blends on engine performance and emission and found that maximum BTE is 5.72% less for karanja biodiesel compared to petro-diesel. 45.28% increase in BSFC at peak load is found with biodiesel. 13.25% increase in EGT is obtained with biodiesel at peak load. HC emission at maximum load was found to be 41.1% less for petro-diesel compared to biodiesel. CO emission at maximum load is 16.6% higher for biodiesel and about 12% increase in NO_x emission was obtained with biodiesel.

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Sukumar Puhan et al. [6] studied the effect of injection pressure on performance, emission and combustion characteristics of methyl ester derived from linseed oil, which contains about 85 - 90% unsaturated fatty acid. BTE is found to be less and specific fuel consumption is found to be higher for linseed biodiesel compared to petro-diesel at standard injection pressure of 200 bar. The CO and HC emissions for linseed biodiesel were lower than that of diesel fuel. Higher CO₂ and NO_x emission was obtained with biodiesel compared to petro-diesel.

Mohd Hafizil Mat Yasin et al. [7] studied the effects of EGR on a Mitsubishi direct injection diesel engine fueled with biodiesel produced from palm oil which contains about 51 – 55% unsaturated fatty acids. Engine power is less by an average of 3.9%, and torque is less by an average of 2.8% for biodiesel compared to petro-diesel without EGR. BSFC is increased by an average of 14% for biodiesel compared to petro-diesel. NO_x emission was higher and CO₂, CO and HC emission was lower for biodiesel compared to petro-diesel.

H. Raheman and S.V. Ghadge [8] investigated the performance of compression ignition engine with biodiesel produced from mahua oil, which contains about 64 – 66% unsaturated fatty acid. An average increase of 41.1% in BSFC is found with biodiesel compared to petro-diesel. At full load conditions the mean BTE of biodiesel was about 10.1% lower than that of petro-diesel. The mean EGT of biodiesel is 16% higher than that of petro-diesel. An average reduction 12% in CO emission was found with biodiesel. NO_x emission was 13.6% higher at maximum load for biodiesel compared to petro-diesel.

The various studies [4-9] showed that the performance of petro-diesel is superior to that of biodiesel. But the performance of biodiesel from different feed stocks is found to be different. This is mainly due to difference in fatty acid composition of oil or fatty acid methyl ester composition of biodiesel [2]. CO and HC emissions were found to be lower and CO₂ and NO_x emission were found to be higher for most of biodiesel compared to petro-diesel. But operation with karanja biodiesel resulted higher CO and HC emission than petro-diesel [5]. The relative variation in emission is due to difference in composition of biodiesel.

OBJECTIVES OF THE STUDY

Difference in composition of biodiesels from different feed stocks leads to different fuel properties and hence engine performance. Objectives of this experimental work are production of biodiesel from sunflower oil and coconut oil and to evaluate their properties and conduct an experiment to evaluate engine performance and emission using these biodiesels and compare test result with petro-diesel. The effect of composition of biodiesel on engine performance and emission will be analysed based on experimental results

II. METHODOLOGY

BIODIESEL PRODUCTION

Biodiesel from sunflower oil and coconut oil were produced by alkali catalysed transesterification reaction. In the process the oil was taken in a container and heated up to 60 °C. Methanol (25% volume of oil) and potassium hydroxide (1% weight of oil) mixture were prepared using ultrasonic vibrator and added to heated oil. The final mixture was stirred continuously for one hour keeping the temperature around 55 to 60 °C. The mixture was then poured in to a separation funnel. A separation time of 24 hours was allotted for glycerine and methyl ester to separate. After separation period, the lower layer contained glycerol and impurities, whereas the upper layer contained the methyl ester of vegetable oil. The methyl ester was separated from glycerol. It was washed with distilled water to remove the entrained impurities and glycerine. The opaque lower layer containing water and impurities was removed. Water wash was done 4 to 5 times to ensure complete purity of biodiesel.

PROPERTY TESTING

The properties of biodiesels such as viscosity, density, flash point, iodine value and acid value were determined. Viscosity was measured using Brookfield Viscometer. Hydrometer was used for density measurement. Acid value and Iodine values were calculated using titration method. Calorific value and cetane number were calculated from methyl ester composition of biodiesel [3, 10, 12, 13]. The property values were tabulated in Table 1.

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Table 1: Properties of petro-diesel, sunflower biodiesel and coconut biodiesel

Property	Petro-diesel	Sunflower Biodiesel	Coconut biodiesel	ASTM D6751 Limit	EN 14214 Limit
Kinematic Viscosity at 40°C (cSt)	2.35	5.19	4.06	1.9 - 6	3.5 - 5
Density at 15°C (kg/m ³)	820	880	870	-	860 - 900
Flash Point (°C)	50	182	118	130 min	120 min
Cetane Number	50	46.6	59	47 min	51 min
Calorific Value (kJ/kg)	42500	39500	38280	-	-
Iodine Value (cg I ₂ /g)	-	108	19	-	120 max
Acid Value (mg KOH/g)	0.1	0.39	0.28	0.50 max	0.50 max

The methyl ester composition of sunflower biodiesel(SFBD) [3] and coconut biodiesel(CBD) [10] were listed in Table 2.

Table 2 : Methyl ester composition of sunflower biodiesel and coconut biodiesel

FAME Name	Sunflower Biodiesel (wt %)	Coconut Biodiesel (wt %)
Methyl octanoate (C8:0)	-	8.2
Methyl decanoate (C10:0)	-	6.6
Methyl laurate (C12:0)	-	48.3
Methyl myristate (C14:0)	-	16.4
Methyl palmitate (C16:0)	4.9	9.3
Methyl palmitoleate (C16:1)	-	-
Methyl stearate (C18:0)	2.3	2.4
Methyl oleate (C18:1)	32.6	7
Methyl linoleate (C18:2)	59.4	1.7

ENGINE PERFORMANCE TEST

The performance test was conducted on a four stroke single cylinder Kirloskar diesel engine with rope type dynamometer. The load test was conducted at constant speed of 1500 rpm. The fuel flow rate was measured using a measuring burette. Exhaust gas temperature and cooling water temperature were measured using a J-type thermocouple. The readings were taken at steady state condition and steady value of cooling water temperature was taken as the indication of steady state operation of the engine at various loads. The test engine details are given in Table 3. Base line readings were taken using petro- diesel. For test with biodiesel, initially the engine was run using petro-diesel until steady state condition was reached. Then the fuel was switched to biodiesel and 5 minutes idling time was given before taking measurements to fill entire fuel line with biodiesel. Before stopping the engine, the fuel is again switched to petro-diesel.

Table 3: Test Engine details

Specification	Description
Manufacturer	Kirloskar
Number of cylinders	1
Number of strokes	4
Rated Power	5 HP
Rated Speed	1500 rpm
Bore x Stroke	80 x 110 mm
Cooling type	Water cooled
Loading type	Rope brake drum loading
Brake drum diameter	330 mm

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III. RESULTS AND DISCUSSION

Load test were conducted on engine using petro-diesel, sunflower biodiesel (SFBD) and coconut biodiesel (CBD). Brake thermal efficiency (BTE), brake specific fuel consumption (BSFC) and exhaust gas temperature (EGT) was taken as performance indicators. Hydrocarbon (HC), carbon dioxide (CO₂) and nitrogen oxides (NO_x) emission were taken as emission indicators. The biodiesel properties that influence the engine performance are cetane number, calorific value, viscosity and density and fuel properties that influence the degradation of biodiesel are acid value and iodine value [11].

EFFECT OF METHYL ESTER COMPOSITION ON BIODIESEL PROPERTIES

1. Viscosity

Viscosity of biodiesel increases with increase in carbon chain length (number of carbon atoms). SFBD is having higher number carbon atom compared to CBD. So the viscosity of SFBD is higher than that of CBD [3, 11].

2. Cetane number

Cetane number increases with degree of saturation. If the biodiesel is highly unsaturated its cetane number has a lower value compared to biodiesel which has higher saturated content. SFBD is having higher unsaturated content, about 92%. CBD contains only 8.7% unsaturated methyl ester. Due to higher unsaturated methyl ester in SFBD, its cetane number is less compared to CBD [3, 11].

3. Calorific value

Calorific of biodiesel decreases with degree of unsaturation and increases with number of carbon atom. SFBD is having higher number carbon atom compared to CBD. Since reduction in calorific value of individual methyl ester with unsaturation is not very significant, the calorific value of SFBD is higher than that of CBD [3.11].

4. Density

Density depends on the molecular weight of component. SFBD is having higher molecular weight due to higher number of carbon atom and hence higher density than CBD [3, 11].

BRAKE THERMAL EFFICIENCY

Figure 1 shows the variation of BTE with Brake mean effective pressure (BMEP) for petro-diesel, SFBD and CBD. Petro-diesel is having higher BTE than SFBD and CBD over all ranges of load. Compared to SFBD and CBD calorific value of petro-diesel is higher. Maximum value of BTE for petro-diesel 32.83% which is 12.12% higher than SFBD and 8.52% higher than CBD. CBD is having higher value of BTE than SFBD. Even though SFBD is having higher calorific value than CBD, its cetane number is lower and has higher ignition delay. Higher viscosity of SFBD leads to poor atomization which affects the combustion and leads to lower BTE.

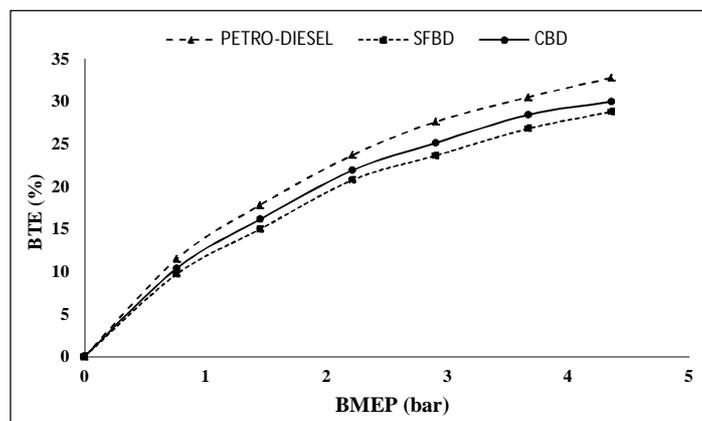


Figure 1: Variation of BTE with BMEP for petro-diesel, sunflower biodiesel and coconut biodiesel

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BRAKE SPECIFIC FUEL CONSUMPTION

The variation of BSFC with BMEP for petro-diesel, SFBD and CBD are shown in figure 2. Petro-diesel is having lower BSFC than SFBD and CBD over all ranges of load. The minimum BSFC for petro-diesel is 0.258 kg/kW-hr which is 22.48% lower than SFBD and 21.38% lower than CBD. This is due to lower energy content and higher density of biodiesels. SFBD is having higher BSFC than CBD. This is due to higher density of SFBD compared to CBD. As diesel engine fuel systems meter the fuel on volume basis, operation with high density fuel results in higher mass flow of fuel into cylinder [14].

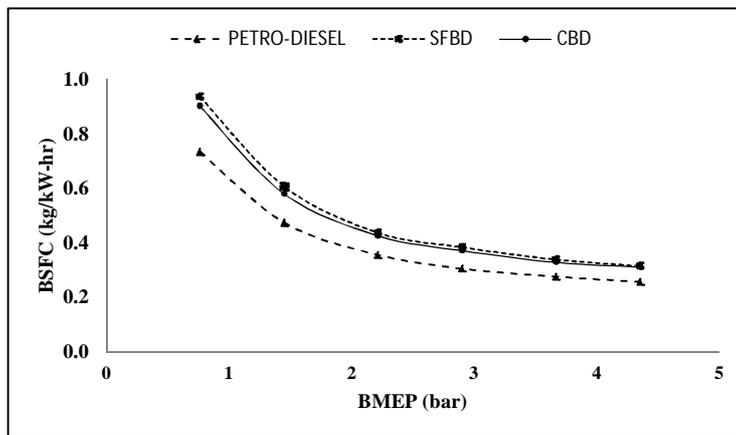


Figure 2: Variation of BSFC with BMEP for petro-diesel, sunflower biodiesel and coconut biodiesel

EXHAUST GAS TEMPERATURE

The variation of EGT with BMEP for petro-diesel, SFBD and CBD are shown in figure 3. EGT of petro-diesel is higher than EGT of CBD and lower than that of SFBD over all load ranges. The maximum EGT for petro-diesel is 331 °C which is 5.14% lower than SFBD and 2.42% higher than CBD. SFBD is having higher EGT due to complete combustion as a result to inherent oxygen present in it. Higher cetane number of CBD results in early commencement of combustion and hence the product will be slightly cooled before leaving combustion chamber. SFBD is having higher EGT compared to CBD. Due to higher ignition delay with SFBD, certain portion of the combustion is shifted to after burning stage. So the product of combustion leaves at higher temperatures.

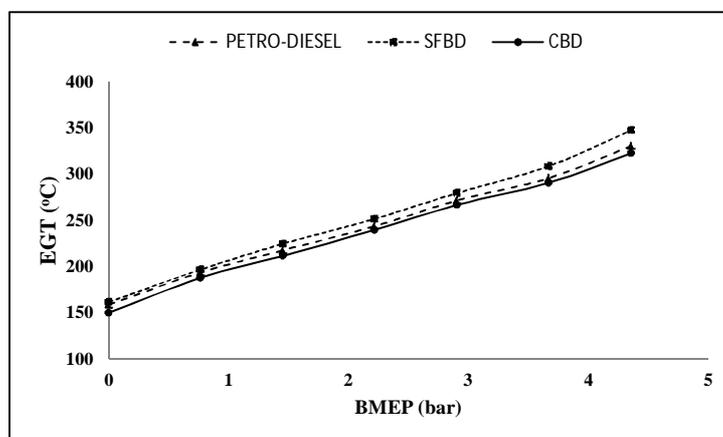


Figure 3: Variation of EGT with BMEP for petro-diesel, sunflower biodiesel and coconut biodiesel

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HC EMISSION

The variation of HC emission with BMEP for petro-diesel, SFBD and CBD are shown in figure 4. HC emission of petro-diesel is higher than that of SFBD above BMEP of 2.2 bar. Lower combustion chamber temperature at lower loads is the reason for higher HC emission for SFBD at lower loads. Maximum HC emission of petro-diesel, SFBD and CBD are 28, 26 and 21 ppm respectively. This is due to better combustion of biodiesel due to presence of inherent oxygen. SFBD is having higher HC emission than CBD. Higher viscosity, lower cetane number together with presence of heavier hydrocarbon in SFBD is the reason for higher HC emission with SFBD.

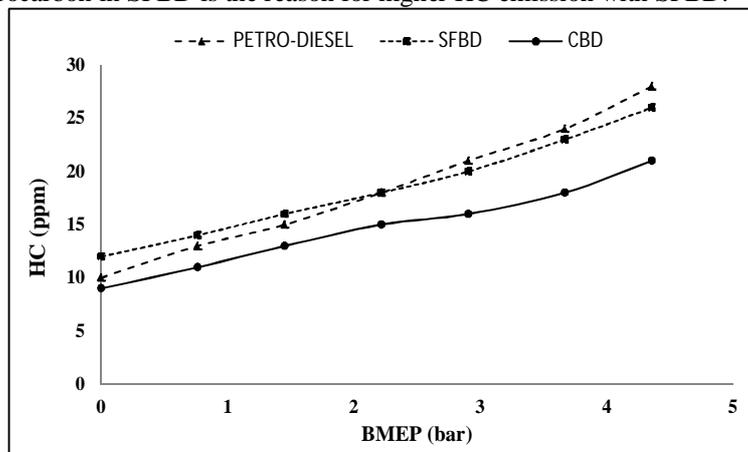


Figure 4: Variation of HC emission with BMEP for petro-diesel, sunflower biodiesel and coconut biodiesel

CO₂ EMISSION

The variation of CO₂ emission with BMEP for petro-diesel, SFBD and CBD are shown in figure 5. CO₂ emission of SFBD and CBD is higher than that of petro-diesel. This is indication of better combustion characteristics of biodiesel due to presence of inherent oxygen. Maximum CO₂ emission for petro-diesel, SFBD and CBD are 5.30, 5.80 and 5.50% respectively. SFBD exhibit more CO₂ emission than CBD over all ranges of load. Higher oxygenated nature of SFBD due to higher degree of unsaturation and long carbon chain length is the reason for higher CO₂ emission with SFBD.

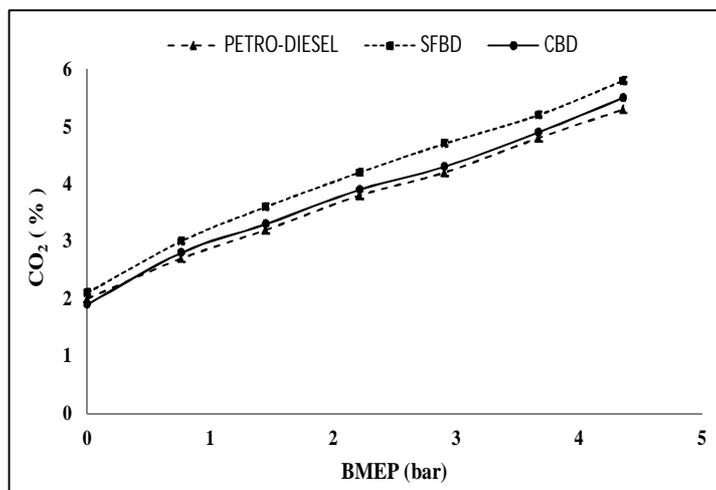


Figure 5: Variation of CO₂ emission with BMEP for petro-diesel, sunflower biodiesel and coconut biodiesel

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NO_x EMISSION

The variation of NO_x emission with BMEP for petro-diesel, SFBD and CBD are shown in figure 6. SFBD is having highest NO_x emission for all ranges of load and CBD is having lower NO_x emission. NO_x emission of petro-diesel is amidst of these two. This is due to the reason that EGT of CBD is less than that of SFBD and petro-diesel. Also due to higher cetane number of CBD the residence time for NO_x formation will be less. Maximum NO_x emission of petro-diesel, SFBD and CBD are 741, 809 and 721 ppm respectively. Higher ignition delay due to lower cetane number together with more oxygenated nature of SFBD is the reason for higher NO_x emission.

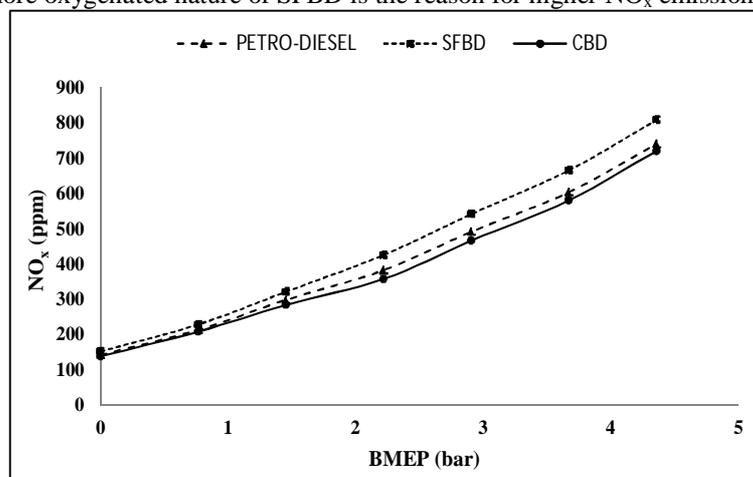


Figure 6: Variation of NO_x emission with BMEP for petro-diesel, sunflower biodiesel and coconut biodiesel

IV. CONCLUSION

In this work, biodiesel was produced from sunflower oil and coconut oil through alkali catalysed transesterification reaction and properties of biodiesel were evaluated. Performance test were conducted using petro-diesel, sunflower biodiesel and coconut biodiesel. The results of the work can be summarized as follows

- The composition of biodiesel have significant effect on fuel properties and hence engine performance and emission. Sunflower biodiesel is having larger number of carbon atom and more percentage of unsaturated components compared to coconut biodiesel. Hence sunflower biodiesel is having higher calorific value, density and viscosity compared to coconut biodiesel. Cetane number for coconut biodiesel is higher than sunflower biodiesel due to higher degree of saturation. So coconut biodiesel has better combustion characteristics than sunflower biodiesel.
- Higher brake thermal efficiency and lower brake specific fuel consumption is obtained with coconut biodiesel compared to sunflower biodiesel. This is due to higher cetane number and lower density of coconut biodiesel. The advantage of slightly high calorific value of sunflower biodiesel is offset by its higher viscosity, density and lower cetane number.
- Exhaust gas temperature is highest for sunflower biodiesel and lowest for coconut biodiesel. Presence of oxygen in the biodiesel ensures complete combustion. The lower ignition quality of sunflower biodiesel results in partial shift of combustion to after burning stage and hence temperature of combustion product leaving the combustion chamber will be higher when compared to coconut biodiesel.
- HC emission is found to be lowest for coconut biodiesel. With sunflower biodiesel, HC emission was found to be higher than petro-diesel at small values of brake mean effective pressure due to lower combustion chamber temperature. Higher viscosity, lower cetane number together with presence of heavier hydrocarbon in SFBD is the reason for higher HC emission with sunflower biodiesel compared to coconut biodiesel.
- CO₂ emission was found to be highest for sunflower biodiesel and lowest for petro-diesel. Higher oxygenated nature of sunflower biodiesel due to higher degree of unsaturation and long carbon chain length is the reason for higher CO₂ emission with sunflower biodiesel compared to coconut biodiesel.

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- NO_x emission is highest for sunflower biodiesel and lowest for coconut biodiesel. Due to higher cetane number, the residence time for NO_x formation will be less for coconut biodiesel. Higher ignition delay due to lower cetane number together with more oxygenated nature of sunflower biodiesel is the reason for higher NO_x emission.

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