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Effect of Compression Ratio on Emission of CI Engine using Neat Karanja Oil and Karanja Oil Methyl ester Blends

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ABSTRACT

The standard design parameters of a compression ignition engine fail to give specified performance with strait vegetable oil (SVO) from different origins. This study is performed to find the effect of compression ratio on emission characteristics such as carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), nitrogen oxides (NO_x) and smoke opacity with all the tested fuels in a single cylinder, four stroke VCR engine fueled with neat Karanja oil blends (10 and 20%) with diesel (on volume basis) and Karanja oil methyl ester (KOME) blends (20, 40 and 60%) and compare the results with diesel. Experiments haves been conducted at compression ratios of 16:1, 17:1, 18:1. At higher CR, minimum value of CO is recorded as being 0.04 for 20% blend of KOME (B20), while maximum CO_2 is4.45%. Lowest HC and NO_x emission recorded are 22 ppm and 552 ppm respectively for 40% blend of KOME (B40). Emissions are marginally higher for K10 and K20 than for diesel. Overall observation shows that B40 has the lowest emissions among other blends of KOME at higher compression ratios.

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1. INTRODUCTION

Depleting petroleum reserves and increasing cost of the petroleum products demands an intensive search for new alternative fuels. The scarcity of known petroleum reserves will make renewable energy sources more attractive. Straight vegetable oils are proved to be very good substitute for the existing conventional fuels. The main advantages of vegetable oils for diesel engine as fuel are renewability, availability, lower sulfur and aromatic content, and biodegradability in nature. Tests for engine operation and exhaust emission like carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide ($NO_{x)}$ and oxygen (O_2) have been carried out by different researchers with different types of SVOs. All blends have shown higher HC emission after about 75%load. Soapnut oil 10% and soapnut oil 20% showed lower CO emission at full load. NO_x emission for all blends was lower and soapnut oil 40% blend achieved 35% reduction in NO_x emission [1]. The combustion of fat and vegetable oil derived fuels in CI engines was experimented. It was found that emissions of particulate matter can be reduced remarkably through use of biodiesel in engine, but NO_x emissions increase dramatically for both neat and blended fuels in both two and four stroke diesel engines. The experiments were conducted to evaluate and compare the use of a variety of vegetable oils of various origin as supplement to conventional diesel fuel at blend ratios 10/90 and 20/80 in a direct injection diesel engine [2]. They found that NO_x was reduced with use of vegetable oil in the diesel engine [3]. Various experiments were conducted to study the effect of reducing Jatropha oil viscosity by increasing the fuel temperature and thereby eliminating its adverse effect on combustion and emission characteristics of the engine. While operating the engine on preheated Jatropha oil, performance and emission parameters was found very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, performance and emissions were observed to be marginally inferior [4]. Combustion

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characteristics of crude rice bran oil blend with diesel oil, 20vol.%as a fuel in a stationary small duty direct injection compression ignition engine was analyzed. Blend fuel has lower smoke intensity and higher NO_x emission than diesel [5]. The feasibility of using oil from turpentine obtained from the resin of pine tree has been studied. The emission and performance characteristics of a direct injection diesel engine were studied in dual fuel mode. The results showed that except for volumetric efficiency, all other performance and emission parameters were better than diesel fuel within 75% load. The toxic gases like CO and UBHC were slightly higher than diesel. NO_x was found to be equal to that of diesel except at full load [6]. Experiments of waste plastic oil as a fuel in a single cylinder, four stroke, direct injection, diesel engine were carried out. The influence of injection timing on the performance, emission and combustion characteristics was investigated using waste plastic oil as a fuel. The results showed decreased oxides of nitrogen, carbon monoxide and unburned hydrocarbon, while the brake thermal efficiency, carbon dioxide and smoke increased under all the test conditions [7]. Rubber seed oil was experimented in a compression ignition engine and it has been reported that this oil blend fueled engine has higher carbon deposits inside combustion chamber than diesel-fueled engine [8]. The performance and exhaust emission of Mahua oil blends in a four stroke diesel engine has been investigated and compared with diesel fuel. It was found that smoke density is higher for Mahua oil blends compared to diesel at lower loads. Smoke density increased with proportion of Mahua oil in diesel [9]. In the theoretical study for comparison of three vegetable oils for diesel alternative, linseed oil was shown to have the highest NO_x emission, while cotton seed oil and peanut oil have lower NO_x emission than diesel [10]. The emission characteristics of a single cylinder diesel engine operated with preheated rubber seed oil (RSO) and rubber seed oil without preheating were studied and the results were compared with those of diesel fuel. NO_x emission for neat RSO operation is 6.9 and 10.69 g/kWh with diesel at full load. Smoke emission for neat RSO operation is much higher than that of diesel fuel [11]. For the application of neat RSO in the electric power generation, dual fuel mode operation in diesel engines using RSO and coir-pith producer gas was introduced by [12]. They found higher CO emission under all load conditions.

The fuel characteristics of biodiesel are approximately the same as those of fossil diesel fuel. Therefore, it may be directly used as a fuel for diesel engines without any modification of the design or equipment. The properties of biodiesel can vary depending upon processing technology and feedstock, but generally it has high cetane number, oxygen content, and very low aromatic content when compared to the conventional diesel fuel. The molecular structure of biodiesel is similar to diesel fuel, and it contains additional oxygen, which is useful to reduce CO, UHC and smoke opacity in the exhaust. In addition, biodiesel is bio-degradable, can be mixed with diesel fuel at any ratio and is sulfur-free. Although it has many advantages over diesel fuel, there are several problems that need to be addressed such as its lower heating value, higher viscosity, poor cold flow properties and oxidative stability, and sometimes its higher nitrogen oxides (NO_x) emission [2, 13-16].

Numerous investigators have reported that with the use of biodiesel as a fuel in diesel engines, a reduction in harmful exhaust emissions and equivalent engine performance with diesel fuel were attained [17-19]. Some studies have shown reductions in the emissions of CO, HC and smoke opacity, but NO_x emissions increased for biodiesel fuels. As some of the engine operating and design parameters namely load, speed, compression ratio, inlet manifold condition, injection timing, and injection pressure affects the performance and emissions of diesel engines [20, 21].

Agarwal et al. found that biodiesel-fuelled engines produce less carbon monoxide, unburned hydrocarbon, and particulate emissions compared to mineral diesel fuel, but higher NO_x emissions are observed [22]. Canakci studied and compared the combustion characteristics and emissions of petroleum diesel and biodiesel from soybean oil. He found significant reductions in PM, CO, and unburned HC, while NO_x increased with soybean biodiesel [20, 23].

The emission characteristics of variable compression ratio engine using various blends of Karanja oil and KOME at compression ratios 16:1, 17:1, 18:1 for 100% load has been performed and compared with the results of diesel fuel.

2. MATERIAL AND METHODS

2. 1. Karanja Oil Karanja belongs to the family of *Leguminaceae*. It is a medium sized glabrous tree that generally attains a height of about 8 m and a trunk diameter about 50 cm. It can grow under a wide range of agroclimatic conditions and is a common sight around coastal areas, riverbanks tidal forests and road sides. Karanja is a native to humid and subtropical environments having annual rainfall between 500-2500 mm in its natural habitat where the maximum temperature ranges from 27-38°C with a minimum of 1-16°C. The typical fatty acid composition in oil is shown in Table 1 [24].

It grows fast and matures after 4–7 years yielding fruits, which are flat, elliptic and 7.5 cm long. Each fruit contains 1 to 2 kidney shaped brownish red kernels. The oil content of the kernel is 30–40%. A single tree yields 9–90kg of seed per tree, indicating a yield potential of 900–9000 kg seed/ha (assuming 100 trees/ha), 25% of which might be rendered as oil. In general, Indian mills extract 24–27.5% oil, and the village crushers extract 18–22% oil[25].The acid and saponification values of Karanja oil have been found to be 5.06 mg KOH/mg, 187 mg KOH/mg respectively. The unsaponifiable matter and iodine value are 2.6(w/w) percent, 86.5(mg/100mg) respectively [24].

2. 2. Oil Preparation Karanja oil after extraction from seeds using mechanical expeller is filtered by a filter,then it is blended with diesel in volume/volume basis. 10, 20% of oil is blended with 90 and 80% of diesel respectively and known as K10, K20. The mixture of Karanja oil and diesel is stirred by a mechanical stirrer fitted with electric motor. The prepared oil blends are then tested in the engine at varying compression ratios for analysis.

2. 3. Production of Karanja Methyl Ester To prepare Karanja oil methyl ester from the neat Karanja oil first the acid value of the oil is measured by titration. The acid value of the oil is found to be 6.3 mg KOH/g and is decreased by esterification method. In esterification method acid catalyzed reaction of the oil with methanol is done. Samples are taken from the products of reaction in every half an hour and acid value measured. The reaction is stopped when acid value of the oil becomes below 5 mgKOH/g. The products of reaction are then allowed to be settled in a separating funnel. After 24 hours of settling, triglyceride comes to the bottom of the funnel and untreated alcohol comes to the top. The triglyceride of Karanja oil is then collected from the bottom of the separating funnel. The triglyceride of the oil is transesterified to produce biodiesel or Karanja oil methyl ester (KOME or Biodiesel) on the same reactor. Then, reaction is carried out at 60^0C with continuous stirring. The products of the reaction is kept in the separating funnel and allowed to settle down. Glycerol is settled at the bottom of the separating funnel and collected. The top part of the funnel contains Karanja oil methyl ester. Then, it is water washed three times to remove the untreated methanol. The dissolved water particles are removed by heating the collected Karanja oil methyl ester. Biodiesel are blended with diesel fuel at 10, 20, 30, …,100% on a volume basis. Blends of 20, 40 and 60vol.% of KOME with diesel which are known as B20, B40, B60 respectively, are used for experiment.

2. 4. Experimental Setup The setup used during the course of experimental investigations is a VCR diesel engine test rig Kirlosakar make consisting of a single cylinder, 4 stroke,3.5 kW at 1500 rpm connected to eddy current dynamometer for loading. Software package "Engines of tLV" is employed for online performance and combustion analysis. The tests have been conducted at the rated speed of 1500 rpm and different compression ratios under full load condition. The exhaust emissions are measured by online AVL-444 model, multi-gas analyzer which is capable of measuring CO, HC, CO_2, and NO_x concentrations in the exhaust. Smoke opacity is measured with AVL-437 model smoke meter (measuring range 0 to 100% with resolution 0.1%).The specifications of accuracy for measurement of various parameters of multi gas analyzer are given in Table 2.

TABLE 1. Characteristics of fatty acids in Karanja oil

Fatty acid	Value %
Palmitic	3.7-7.9
Stearic	2.4-8.9
Oleic	44.5-71.3
linoleic	10.8-18.3
lignoceric	1.1-3.5
Eicosenoic	9.5-12.4
Arachidic	2.2-4.7
Behenic	4.2-5.3

TABLE 2. Measurement range and accuracy of AVL 444 gas analyzer

Measured Quality	Measuring Range	Resolution	Accuracy
CO	0…10% vol.	0.01% vol.	<0.6% vol: ±0.03% vol. >=0.6% vol: ±5% vol.
CO_2	0…20% vol.	0.1% vol.	<10% vol: ±0.5% vol. >=10% vol: ±5% vol.
HC	0…20000 ppm vol	<=2000:1 ppm vol. >2000:10 ppm vol.	<200 ppm vol: ±10 ppm vol. >=200 ppm vol: ±5% vol.
O_2	0…22% vol.	0.01% vol.	<2% vol: ±0.1% vol. >=2% vol: ±5% vol.
NO	0…5000 ppm vol.	1 ppm vol.	<500 ppm vol: ±50 ppm vol. >=500 ppm vol: ±10% vol.

TABLE3. Fuel properties of diesel, Karanja oil blends and Karanja methyl ester blends.

Properties	**Diesel**	**K10**	**K20**	**B20**	**B40**	**B60**
Calorific value (Kj/Kg)	42000	41120	40240	40935	39900	38871
Density (Kg/m^3)	830	838	849	848	860	868
Viscosity at 40^{O}C (cSt)	1.38	3.23	4.35	2.41	2.84	3.34

A computerized data acquisition system is used to collect, store and analyze the data during the experiment by using various sensors.The properties of the diesel, neat Karanja oil blends and Karanja oil methyl ester blends are summarized in Table 3.

3. RESULTS AND DISCUSSIONS

3.1. Carbon Monoxide Emission

The variation of CO emission with different compression ratios for diesel and different blends of neat Karanja oil (K10 and K20) at maximum load is given in Figure 1. It shows that the CO emission decreases with increasing compression ratios. This may be due to better atomization of fuel at higher compression ratios leading to proper air fuel mixing, while presence of additional oxygen molecule in the blends improves the combustion resulting a decrease in CO emission. The CO emission using diesel, K10 and K20 for compression ratio 18 is recorded as 0.1, 0.11and 0.15% respectively.

Generally, CO emission from the engine occurs due to partial oxidation of the fuel mixture. As it is well known, the rate of CO emission is a function of unburned fuel which is affected by air-fuel ratio, fuel type, atomization rate, engine load and speed. The variation of CO emission with different compression ratios for different blends of KOME B20, B40 and B60 and diesel at maximum load is given in Figure 2. It shows that the CO emission is found to be decreasing with increase in compression ratios. The CO emission using diesel, B20, B40 and B60 for compression ratio 18 is 0.1, 0.04, 0.06 and 0.12% respectively. This may be due to better air fuel mixing at higher compression ratio leading to proper atomization of the fuel while presence of additional oxygen molecule in the blends improves the combustion resulting decrease in CO emission. B60 gives highest CO emission than other blends at CR 18. This can be attributed to higher viscosity and reduction in calorific value of the fuel with increase in blend ratio leading to decrease in peak cylinder temperature resulting an increase in CO emission.

3. 2. Carbon Dioxide Emission

Carbon dioxide emission indicates complete oxidation of the fuel. The variation of CO_2 emission with different compression ratio is shown in Figure 3. It shows that the CO_2 emission of neat Karanja oil blends is higher at all compression ratios. This may be due to the presence of oxygen in the neat Karanja oil blends, which improves the oxidation process while the increase in compression ratio increases the peak cylinder temperature with improved atomization of the fuel leading complete combustion of the fuel. The CO_2 emission using diesel, K10 and K20 for compression ratio 18 is found to be 4.8, 4.9 and 5.2%, respectively.

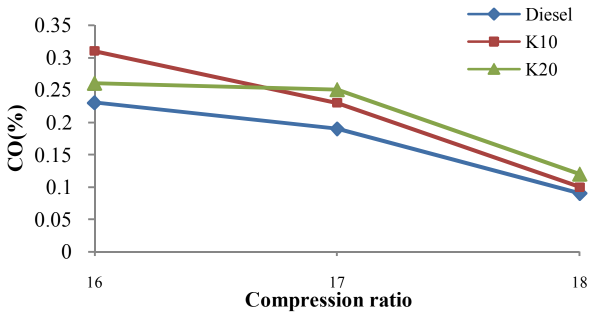

Figure 1. Variation of carbon monoxide with compression ratio for neat karanja oil blends

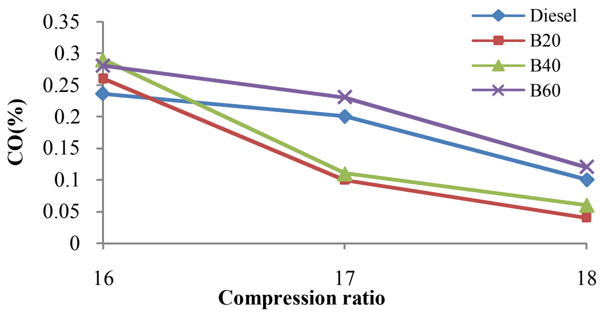

Figure 2. Variation of carbon monoxide with compression ratio for different blends of Biodiesel

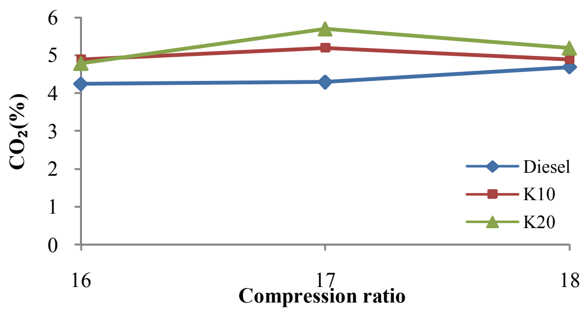

Figure 3. Variation of CO_2 with compression ratio for different neat karanja oil blends

CO_2 emission indicates complete oxidation of the fuel. The variation of CO_2 emission with different CR is shown in Figure 4. It shows that the CO_2 emission of KOME blends is higher at all compression ratios. The CO_2 emission using diesel, B20, B40 and B60 for CR 18 is found to be 4.4, 4.45, 4.43 and 4.3%, respectively. More amount of CO_2 is an indication of complete combustion of fuel in the combustion chamber. This may be due to the presence of oxygen in the biodiesel blends which improves the oxidation process, while increase in CR increases the peak cylinder temperature with improved atomization of the fuel leading to complete combustion of the fuel. In all compression ratios, B20 shows highest CO_2 emission followed by B40, diesel and B60. Reduction of CO_2 at higher blends indicates poor combustion, which may be due to higher viscosity and decrease in calorific value with increase in percentage of KOME blends.

3. 3. Hydrocarbon Emission The variation of hydrocarbon emission with different compression ratios for different blends is given in Figure 5. It shows that blend K20 gives highest HC emission at lower compression ratios, but at higher compression ratios, K10 gives comparatively more HC emission. Physical properties of fuels such as density and viscosity influence the HC emissions. Increased HC emissions clearly show that the combustion in the engine is not proper. It is very clear that increasing percentage of neat Karanja oil in the blend increase the HC emissions. This may be attributed to poor spray formation of neat Karanja oil and improper mixing of the fuel with high density air, leading to partial combustion of the fuel. The HC emission using diesel, K10 and K20 for compression ratio 18 are 30, 42 and 35 ppm, respectively. HC emission is a complex issue in which the fuel composition can be of great importance. It consists of fuel that is completely unburnt, or only partially burned. Typically, HC emissions are serious problem at light loads for diesel engines. The variation of hydrocarbon emission with different compression ratios for blends of KOME and diesel is shown in Figure 6. The HC emission for diesel and B20, B40 and B60 for compression ratio 18 is 30, 22.5, 22 and 34.5 ppm, respectively. It indicates that the HC emission of B20 and B40 is lower than diesel at higher compression ratio while B60 shows highest HC emission. Increase in CR decreases the ignition delay of the biodiesel blends which improves the combustion process. At the same time, higher blends affects the atomization due to higher viscosity compared to conventional diesel leading to increase in HC emission. HC emission of the blend B40 is found to be better for all compression ratios as compared to others.

3. 4. Nitrogen Oxides Emission The variation of nitrogen oxides (NO_x) emission with respect to different compression ratios for different blends is shown in Figure 7. The NO_x emission for diesel and other blends increases with increase of compression ratio. Diesel gives higher NO_x emission followed by K20 and K10. It was also observed that with increasing the percentage of Karanja oil blend, there is a trend of decreasing NO_x emission. This may be due to lower calorific value and higher viscosity of blends that affect the spray formation of fuel at higher compression ratios which in turn affects the combustion process leading to decrease in combustion temperature.

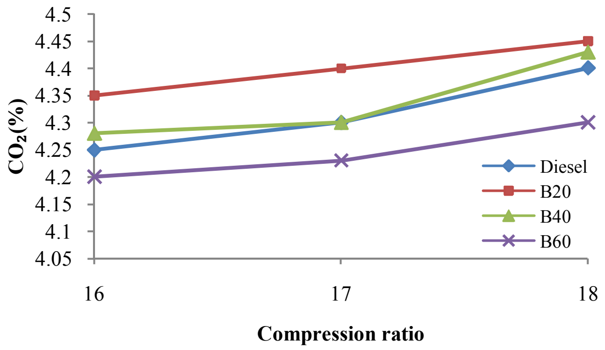

Figure 4. Variation of carbon dioxide with compression ratio for different blends of biodiesel

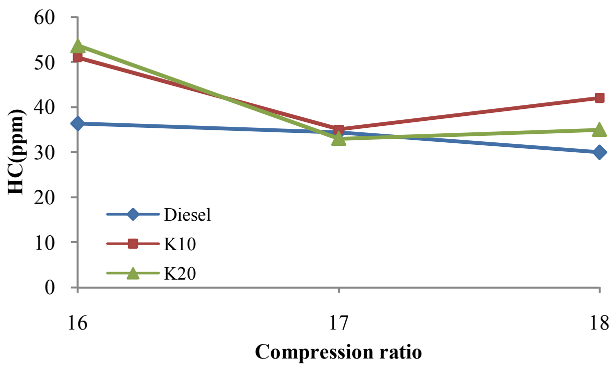

Figure 5. Variation of hydrocarbon with compression for different neat karanja oil blends

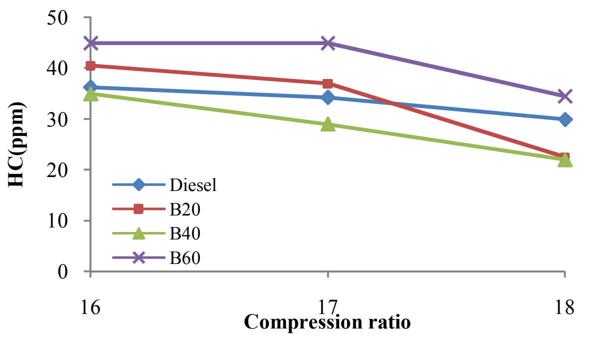

Figure 6. Variation of HC emission with compression ratio for different blends of karanja biodiesel

At compression ratio 18, NO_x emission for diesel, K10, and K20 are 550ppm, 493ppm, and 524ppm respectively.

NO_x formation rate strongly depends upon in-cylinder gas temperature, and oxygen content within the cylinder. Hence, the fuel distribution within the cylinder and its combustion process affects the NO_x formation. Generally, NO_x forms at the high temperature burnt gas regions. The variation of NO_x emission with respect to different compression ratios for all fuels is shown in Figure 8. The NO_x emission for diesel, B20, B40 and B60 for compression ratio 18 is found to be 551, 634.5, 552 and 590 ppm, respectively. The NO_x emission for diesel and other blends increase with increasing compression ratio.

This may be due to better mixing of fuel and air at higher compression which ratios improves the combustion process leading to higher combustion temperature. Simultaneously, additional oxygen molecules present in the biodiesel increases the oxygen concentration in the combustion chamber which enhances NO_x emission. From the figure, it is observed that for all CR values, B40 shows lowest NO_x emission. This may be due to comparatively low calorific value of B40 than B20 that leads to low in cylinder temperature resulting comparatively low NO_x emission.

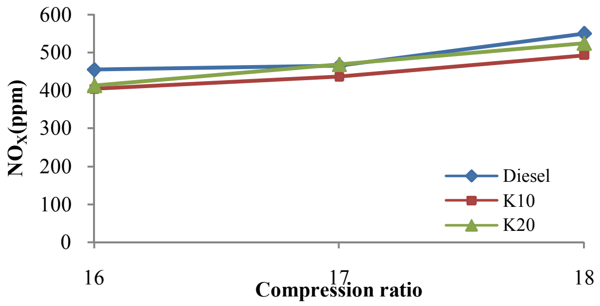

Figure 7. Variation of NO_X with compression ratio for different neat karanja oil blends

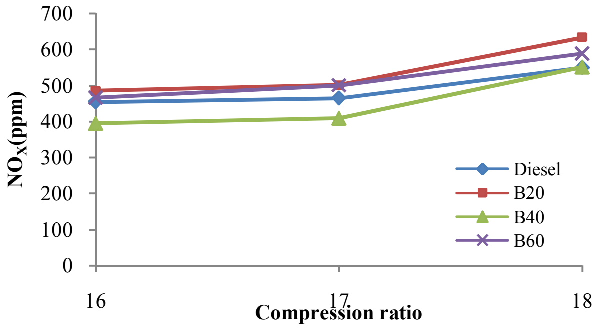

Figure 8. Variation of NO_X with compression ratio for different blends of biodiesel

3. 5. Smoke Opacity

The variation of smoke opacity with respect to different compression ratios for different blends of neat Karanja oil and diesel is shown in Figure 9. The formation of smoke primarily results from the incomplete combustion of the hydrocarbon fuels. It is observed that smoke opacity decreases with increase in compression ratio.

This may be due to better mixing of fuel and air at higher compression ratios. The smoke opacity for diesel, K10 and K20 for compression ratio 18 is 88.75, 96 and 97.8%, respectively. K10 and K20 give higher smoke opacity compared to diesel. This can be attributed to higher ignition delay and higher viscosity of K10 and K20 resulting in incomplete combustion of the fuel. The formation of smoke primarily results due to incomplete combustion of the hydrocarbon fuels.

The variation of smoke opacity with respect to different compression ratios for different blends of KOME and diesel is shown in Figure 10. Smoke opacity decreases with increasing compression ratios. This may be due to better mixing of fuel and air at higher compression ratios. The smoke opacity for diesel, B20, B40 and B60 for compression ratio 18 is 88.75, 71.5, 90 and 94%, respectively. B40 and B60 give higher smoke opacity than B20 and diesel. This can be attributed to higher ignition delay and higher viscosity of B40 and B60 resulting in incomplete combustion of the fuel. B20 shows the lowest smoke opacity at all compression ratios.

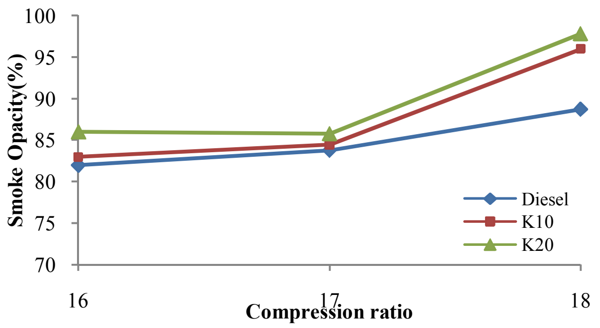

Figure 9. Variation of smoke opacity with compression ratio for different neat karanja oil blends

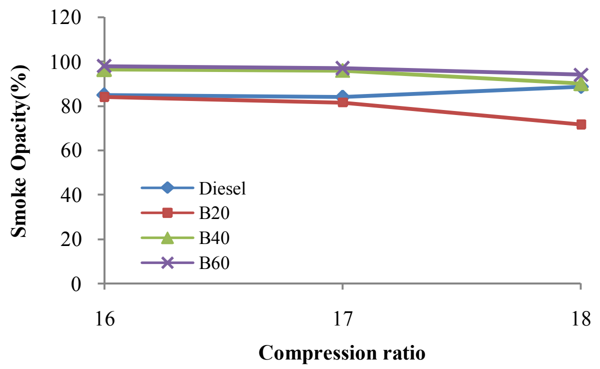

Figure 10. Variation of Smoke opacity with compression ratio for different blends of biodiesel

4. CONCLUSION

The emission characteristics of a variable compression ratio engine with KOME blends have been investigated and compared with that of conventional diesel.

- The CO and CO_2 emissions of neat Karanja oil blends are higher than those of diesel. It is observed that by increasing compression ratio, CO emission decreases due to improved combustion.
- At 16 CR, all blends of KOME shows higher CO emission than diesel. It is observed that by increasing compression ratio, CO emission decreases. At compression ratio 18, B60 gives highest CO emission compared to other blends.
- Carbon dioxide emission of all fuels increases at higher compression ratios. CO_2 emission of the B20 and B40 is found to be higher for all compression ratios as compared to diesel and B60 indicating better combustion.
- The HC emission of K10 and K20 is higher than that of diesel at lower compression ratio, while HC emission decreases when compression ratio is increased from 16 to 17 and again increases with increase in compression ratio.
- The hydrocarbon emissions of all blends are lower at higher compression ratios. HC emission of the blend B40 is found to be better for all compression ratios as compared to other fuels.
- The NO_x emission of K10 and K20 is lower than diesel at all compression ratios. May be due to comparatively lower calorific value.
- NO_x emission from B20 and B60 is higher than that of diesel at higher CR while B40 shows lowest NO_x emission at all compression ratios.
- Smoke opacity decreases with increase in compression ratio. K10 and K20 give higher smoke opacity than that of diesel.
- B40 and B60 give higher smoke opacity compared to that of B20 and diesel.

From the above observation, it has been found that the B40 blend of KOME shows improved characteristics of emissions compared to other blends of KOME and diesel. It shows slightly higher CO emission than B20. So, for fuelling of compression ignition engine with B40 blend stands as a suitable substitute for conventional diesel with reduced emission characteristics.

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Effect of Compression Ratio on Emission of CI Engine using Neat Karanja Oil and KaranjaOil Methyl ester Blends

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چکیده

پارامترهای طراحی استاندارد یک موتور احتراق تراکمی با سوخت روغن‌های گیاهی خالص از گیاه‌های مختلف قادر به تامین کارایی مشخص شده نیستند. در این مطالعه اثر ضریب تراکم بر ویژگی‌های انتشار گازهایی مانند مونوکسید کربن (CO)، دی اکسید کربن (CO_2)، هیدروکربن (HC)، اکسیدهای نیتروژن (NO_x) و کدورت دود با در یک موتور دیزل تک سیلندر چهار زمانه با سوخت روغن Karanja تمیز مخلوط شده با سوخت دیزل به نسبت‌های حجمی ۱۰ و ۲۰ درصد و Karanja و همچنین متیل استر به نسبت‌های حجمی ۲۰ ، ٤۰ و ٦۰ درصد (KOME) بررسی و با سوخت دیزل مقایسه شده است. آزمون‌ها در ضریب‌های تراکم ۱٦:۰۱، ۱۷:۰۱ و ۱۸:۰۱ انجام شده است. در ضریب تراکم‌های بالاتر، حداقل مقدار CO برای KOME ۲۰درصدی (B20) به ۰.۰٤ به دست آمده است، در حالی که حداکثر CO_2 ٤/٤٥٪ بوده است. پایین ترین مقدار هیدروکربن و NO_x منتشر شده برای ٤۰KOME درصدی (B40) به ترتیب ۲۲ و ۵۵۲ پی پی ام است. تولید این گازها توسط سوخت‌های K10 و K20 فقط اندکی بیشتر از دیزل است. نتایج این پژوهش به طور کلی نشان می‌دهد که تولید گازها از سوخت با ترکیب B40 در نسبت‌های تراکم بالاتر، کمترین مقدار در میان سوخت‌های KOME است.

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