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KARANJA OIL BIODIESEL: A POTENTIAL SUBSTITUTION FOR DIESEL FUEL IN DIESEL ENGINE WITHOUT ALTERATION

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ABSTRACT

Continually mounting utilization of fossil fuel and petroleum commodities has been a matter of great apprehension for developing countries like India. Augment in inflation, pollution and associated health hazards, global warming, energy security and exhaustion of fossil fuel have propelled alternative energy. An experimental analysis has been carried out to evaluate the performance and emission characteristics of a compression ignition engine fuelled with dissimilar compositions of karanja biodiesel and its blend at 5%, 10%, 20%, 25%, 50%, 75% and 100% with mineral diesel. HC, CO, CO_2 and smoke were measured, found lower with karanja biodiesel fuel. However, NO_x emissions of karanja biodiesel and its blend were higher than diesel. The combustion analysis was done using peak cylinder pressure and heat release rate with respect to crank angle. The peak cylinder pressure and heat release rate was lower for karanja biodiesel. Results confirm that the performance of the engine fuelled with karanja biodiesel and its blends with diesel fuel is by and large comparable with pure diesel.

Keywords: vegetable oil, karanja oil, biodiesel, transesterification, performance, emissions.

1. INTRODUCTION

Using straight vegetable oils in diesel engines is not a new idea. Rudolf Diesel first used peanut oil as a fuel for demonstration of his newly developed compression ignition (CI) engine in year 1910. Later with the availability of cheap petroleum, crude oil fractions were refined to serve as 'diesel', a fuel for CI engines. During the period of World War-II, vegetable oils were again used as fuel in emergency situations when fuel availability became scarce. Nowadays, due to limited resources of fossil fuels, rising crude oil prices and the increasing concerns for environment, there has been renewed focus on vegetable oils and animal fats as an alternative to petroleum fuels. Vegetable oils can be directly used in diesel engines as they have a high cetane number and calorific value very close to diesel. However, the brake thermal efficiency is inferior to diesel. They also lead to problems of high smoke, HC and CO emissions. This is because the high viscosity and low volatility of vegetable oils lead to difficulty in atomizing the fuel and in mixing it with air. Further, gum formation and piston sticking under long-term use due to the presence of oxygen in their molecules and the reactivity of the unsaturated HC chains are problems with vegetable oils [1, 2].

The uses of edible vegetable oils for biodiesel production has given rise to debate of 'food versus fuel' and have also resulted in increase of food price in the recent years. Moreover, edible oils would be more expensive to use as fuels as compared to conventional petroleum fuels. Hence, the use of non-edible oils such as Karanja (Pongamia) would be more sustainable for biodiesel production. Karanja tree is one of the underutilized types, grown for shade on the roadside. Its seeds remain unattended as a non-profitable business and goes waste. Such unused sources of biomass are required to be converted into a potential source of energy. In the present study, Karanja oil has been identified as a potential non-edible vegetable oil for biodiesel production. Biodiesel from Karanja oil was obtained by using transesterification and major physico-chemical properties were evaluated in accordance with relevant ASTM standards. The performance, emission and combustion studies were carried out on a medium capacity compression ignition engine which was fueled with Karanja methyl ester and its blends with diesel. Exhaustive experiments were carried out on the test rig to evaluate the performance, emissions and combustion characteristics of neat Karanja biodiesel and its blends with diesel fuel and the results were compared with baseline data of diesel.

2. KARANJA OIL

Karanja is a tree and is green during summer, adds to natural beauty, helps provide cool air, and shelter. It needs no pesticides for plantations and growing and average rainfall required is 500-2500 mm. The plant life is 80-100 years and seeds start yielding at $5^{th}/6^{th}$ year onwards and around 8/10 years onwards gives income up to Rs. 24,000 per year, per acre. Karanja trees can be normally planted along the highways, roads, and canals to stop soil erosion. Billions of trees exist all over India. If the seeds fallen along road side are collected, and oil is extracted at village level expellers, thousands of tons of oil will be available.

The karanja biodiesel used for this study is available commercially and conforms to the standards specified in ASTM-D-6751. The steps carried out during the preparation of biodiesel are shown in Figure-2. Seeds of karanja are crushed through an oil expeller, which separates oil and cake. The oil is filtered and passed through a chemical reactor for mixing it with methanol in presence of a catalyst. Here fatty acids are separated, and esterification process takes place. The end product is biodiesel. Byproduct glycerin is separated and excess methanol is recovered.

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Figure-1. Karanja tree and seeds.

2.1. Physical and chemical properties of Karanja oil

The physicochemical properties of karanja oil, which are shown in the Table-1.

Table-1. Physical and chemical properties of oil.

Properties	Unit	Test values
Density	gm/cc	0.927
Kinematic viscosity @ 40°C	mm^2/s	40.2
Acid value	mgKOH/gm	5.40
Pour point	°C	6
Cloud point	°C	3.5
Flash point	°C	225
Calorific value	MJ/Kg	8742
Saponification value		184
Carbon residue	wt%	1.51
Specific gravity		0.936

3. KARANJA OIL: A SOURCE OF BIODIESEL

Transesterification reaction

Transesterification or alcoholysis is the displacement of alcohol from an ester by another in a process similar to hydrolysis, except an alcohol is used instead of water [3]. This process has been widely used to reduce the high viscosity of triglycerides. The transesterification reaction is represented by the general equation as below:

RCOOR' + R"OH_RCOOR" + R'OH

Some feedstock must be pretreated before they can go through the transesterification process. Feedstock with less than 5% free fatty acid, do not require pretreatment. When an alkali catalyst is added to the feedstock's (with FFA > 5%), the free fatty acid react with the catalyst to form soap and water as shown in the reaction below:

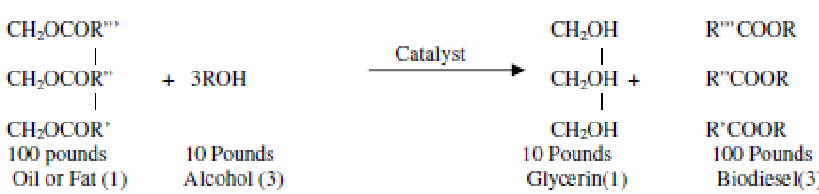

Figure-2. General equation for methanolysis of triglycerides.

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The fatty acid composition of Pongamia oil is shown in Table-2, which shows that the oil is composed of mainly unsaturated fatty acids. Due to this reason the oxidation stability of biodiesel is very severer thereby the resulting biodiesel is unstable in its fuel characteristics [4]. This will result in formation of gums and leads to higher viscosity. The measurement of fuel properties of various blends of Pongamia biodiesel and diesel is shown in the Table-3 [3].

Table-2. Fatty acid composition of Karanja oil.

Fatty acid	Molecular formula	Percentage	Structure
Palmitic acid	C16H32O2	11.65	CH3(CH2)14C00H
Stearic acid	C18H36O2	7.5	CH3(CH2)16COOH
Oleic acid	C18H34O2	51.59	CH3(CH2)14(CH=CH)COOH
Linoleic acid	C18H32O2	16.64	CH3(CH2)12(CH=CH)2COOH
Eicosanoic acid	C20H40O2	1.35	CH3(CH2)18COOH
Dosocasnoic acid	C22H44O2	4.45	CH3(CH2)20COOH
Tetracosanoic acid	C24H48O2	1.09	CH3(CH2)22COOH
Residual		6.83	

Table-3. Fuel properties of various blends of Karanja biodiesel.

Properties	Unit	Karanja oil	Karanja oil methyl ester	Diesel
Density@ 15^0C	gm/cc	0.9358	0.797	0.850
Viscosity@ 40^0C	cm^2/s	38.8	7.0	2.6
Flash Point	^{0}C	212.0	97.8	70.0
Cloud Point	^{0}C	2.0	-7	-16
Pour Point	^{0}C	-4	-6	-20
Water Content	%	<0.05	0.03	0.02
Ash Content	%	0.05	0.02	0.01
Carbon Residue	%	0.8	0.35	0.17
Sulphur Content	%	0.025	Nil	-----
Acid Value	mg of KOH/gm	16.8	0.42	0.35
Calorific Value	Kcal/kg	8742	3712	4290
Cetane Number		38.0	42.9	46

4. RESULTS AND DISCUSSIONS

4.1. Performance characteristics

The tests were conducted on a direct injection diesel engine for different blended of karanja (Pongamia) methyl ester with diesel. Analysis of performance parameters and emission characteristics such as brake power, brake specific fuel consumption brake thermal efficiency, exhaust gas temperature, hydrocarbon, carbon monoxide, carbon dioxide, oxides of nitrogen etc are determined.

Avinash Kumar Agarwal [5] observed that the thermal efficiency of all fuel blends except K100 is higher than mineral diesel however on preheating the fuel samples, all blends and K100 show visibly higher thermal efficiency compared to mineral diesel. Preheating the fuel samples, which have higher viscosity than mineral diesel at room temperature, reduces the viscosity and increases the volatility. This enhances the fuel atomization leading to improved fuel air mixing. Oxygenated fuel gives a better fuel combustion delivering improved thermal efficiency. It was observed that the Brake specific fuel consumption (BSFC) for unheated Karanja oil blends up to 50% is lower than mineral diesel. This is mainly due to the combined effects of the fuel density, viscosity and lower heating value of blends. Higher density of blends containing higher percentage of Karanja oil leads to more fuel flow rate for the same displacement of the plunger in the fuel injection pump, thereby increasing BSFC. It was noticed that the exhaust gas temperature for unheated and

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preheated Karanja oil and its blends with respect to mineral diesel, found Exhaust gas temperature is higher for all Karanja oil blends compared to mineral diesel.

B.S. Chauhan [6] noticed that BTE of mineral diesel is higher than any of the biodiesel based fuel and its blends (Figure-3). The BTE of biodiesel based fuel samples were found to be decreasing with increasing biodiesel content in the biodiesel/diesel blends. It was also observed that the power produced with biodiesel based fuels is lower than mineral diesel. This may be due to the lower calorific value of biodiesel and its higher density. The lower BTE obtained for B100 fuels could be due to the reduction in calorific value and increase in fuel consumption as compared to diesel fuel. Figure-4 shows the variation of exhaust temperature of diesel fuel and Karanja biodiesel and its blends. It was also observed that that the exhaust gas temperature increases with increase in brake power for all the test fuels. The maximum exhaust temperature of all the biodiesel fuels is lower than diesel. It was also observed that the exhaust gas temperature of all the biodiesel based fuels were lower than the petroleum diesel. It is also seen that as the biodiesel substitution in diesel is increased, the exhaust gas temperature reduces. This may be due to the reason that the exhaust gas temperature is affected by the change in ignition delay. Longer ignition delay results in a delayed combustion and higher exhaust gas temperature.

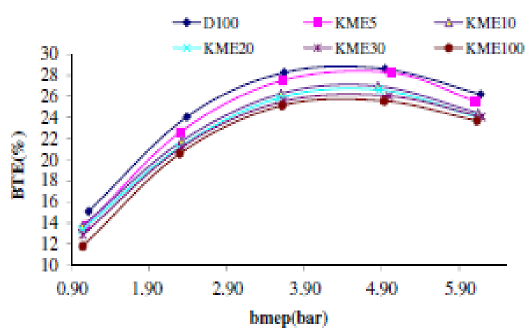

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Figure-3. BTE Vs BMEP.

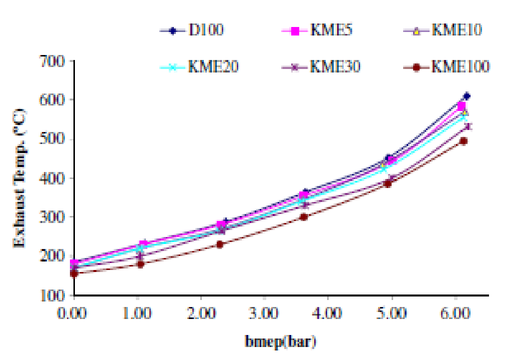

Figure-4. Exhaust temperature Vs BMEP.

B. Baiju [7] tested Methyl and ethyl esters of Karanja oil (biodiesel) separately as the fuel for compression ignition engine without any engine modifications. The performance and emissions of the engine with diesel, blends of biodiesel and diesel, and neat biodiesel are presented and discussed below. Figure-5 shows the variation of brake thermal efficiency (BTE) with load. The brake thermal efficiency is highest with diesel in all loads. In the part load operation, B20KOEE shows the minimum efficiency. The low efficiency may be due to low volatility, slightly higher viscosity and higher density of the ethyl ester of Karanja oil, which affects mixture formation of the fuel and thus leads to slow combustion. A slight lower efficiency with diesel was reported for the esters due to the lower heating value of the esters than with diesel. Figure-6 shows the variation of brake specific fuel consumption (BSFC) with load for different diesel-biodiesel blends and neat diesel fuel. As the load increases, BSFC decreases for all fuel blends. At 100% load, B20KOME shows the lowest fuel consumption. It can be due to the fact that engine consumes more fuel with diesel- biodiesel blend fuels than with neat diesel fuel to develop the same power output due to the lower calorific value of diesel-biodiesel blend fuel.

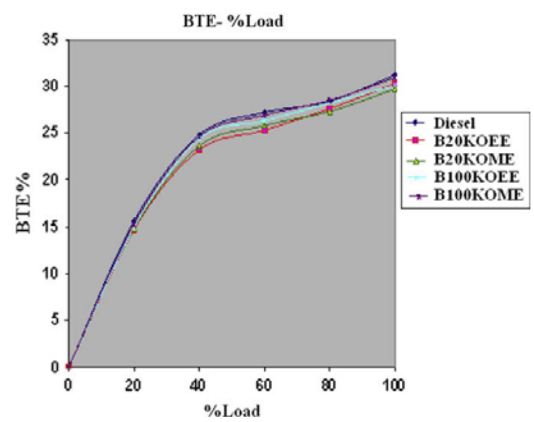

Figure-5. BTE Vs load.

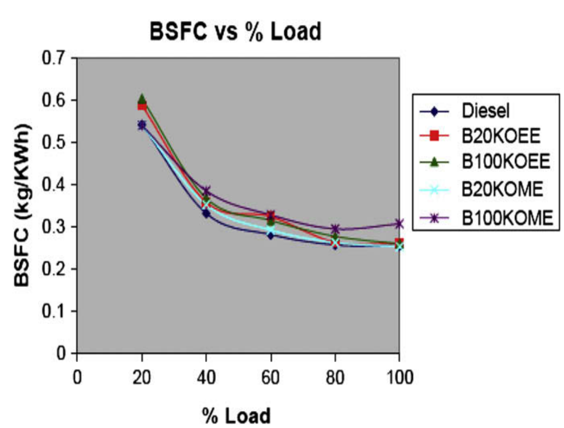

Figure-6. BSFC Vs load.

Gaurav Dwivedi [8] reports the result of BSFC which states that as the load decreases the fuel consumption for different blends of biodiesel increases. The possible reason may be that, at lower loads, significant proportion of the fuel inducted through the intake does not burn completely due to lower quantity of pilot fuel, low cylinder gas temperature and lean fuel air mixture. The BSFC depends on fuel specific gravity, viscosity and calorific value. The specific gravity increases and calorific value decreases and more amount of fuel is needed to produce the same amount of energy. As the Pongamia biodiesel proportion in blend is increased BSFC also increases. It was noticed that the BTE of Pongamia biodiesel is about 24% almost similar to that of diesel at full load condition. A slight lower efficiency with diesel was reported for the biodiesel due to the lower heating value of the biodiesel than with diesel and also due to presence of higher unsaturation in Pongamia biodiesel. The low efficiency may be due to low volatility, slightly higher viscosity and higher density of the biodiesel of Pongamia oil, and also due to presence of higher unsaturation in Pongamia biodiesel which affects mixture formation of the fuel and thus leads to slow combustion.

H. K. Amarnath [9] was observed that BSFC decreases sharply with increase in load for all fuels and at any combination of compression ratio and injection pressure. The main reason for this can be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads. It is seen that the values of BSFC for karanja biodiesel and its blends with diesel are very close to those with diesel. At full load, BSFC for B100 is higher by about 9% more as compared to diesel. Similar findings are also reported by other researchers also [10-12]. At This trend of increase in BSFC with increase in concentration of biodiesel in the blend observed is due to the lower heating value and higher viscosity of biodiesel. It should be noted that the heating value of karanja biodiesel is 6.44% lower than that of petroleum-based diesel. It is seen that BTHE is found to increase significantly with increase in load as lesser losses are encountered at higher loads. This trend is also reported by Labeckas and Slavinskas [13-14]. The main reason for this is that relatively less portion of power is lost with increasing load. The values of BTHE for diesel and karanja biodiesel are very much close to each other. The addition of karanja biodiesel in the blend decreases the heating value of the blend. Hence, lower BTE is obtained for higher blends. It was observed that the exhaust gas temperature (EGT) does not vary much with the content of biodiesel in diesel. However, EGT for B100 is slightly less as compared to that of diesel. With the increase in load, EGT is observed to increase due to higher temperature of combustion inside the cylinder as more fuel is burnt to meet the load demand. EGT for almost all fuels is found to double from no load condition to full load condition.

N. Shrivastava [15] was noticed that the brake specific fuel consumption was decreased with increase in load. The values of BSFC of the KOME and its blends were found slightly higher than neat diesel under all range of engine loads. The B20, B50 and B100 reported 6.4, 15 and 28 percent average increased fuel consumption than the neat diesel fuel. The reason of higher BSFC of KOME and its blend was due to lower calorific value and hence higher amount of fuel was required to produce the same amount of energy. Some researcher reported the similar trend [16-19]. The values of BTE were increased with increasing load in all cases. This was due to reduction in heat losses at higher load. The BTE of neat KOME and its blends showed lower brake thermal efficiency compared to diesel fuel. The B20, B50 and B100 KOME showed average 5.26, 8.16 and 11.03 percent reduction in BTE respectively. This reduction can be attributed to the lower calorific Value which leads to increase in the specific fuel consumption. Some of the researchers have found no significant change in thermal efficiency while using diesel, biodiesel and the different blends [20]; some have reported increased efficiency with all the blends of biodiesel [21]. Increasing the load showed increase in the exhaust gas temperature. This is due to the higher amount of fuel injected at higher load. KOME and its blends showed higher exhaust gas temperature than the diesel fuel. The 20, 50 and 100 percent KOME blend showed average 3.75, 9.30 and 15.19 percent increased temperature compare to average diesel temperature. This can be due to the higher amount of fuel injected during combustion which indicates the higher heat loss in the form of exhaust gas temperature.

A. Haiter Lenin [22] observed that the brake power increases the brake thermal efficiency also increases. At low load condition the bio diesel blends have the higher brake thermal efficiency than the diesel fuel. At mean full load conditions the fuel blends (B75 and B100) have lower thermal efficiency than the diesel fuel. The brake thermal efficiency depends upon the viscosity and intermolecular friction of the fuel. When the viscosity and friction increase the brake thermal efficiency decreases. With high viscosity of the fuel blends the brake thermal efficiency reduces compared to diesel fuel. With increase in the brake power, the specific fuel consumption reduces at all load conditions. The specific fuel consumption depends upon the engine friction and the heat release rate. The B75 and B100 have higher specific fuel consumption than the diesel due to high heat release and the friction at all loads condition. When the brake power increases the exhaust gas temperature also increases. The exhaust gas temperature depends upon the flash point and viscosity of the fuels. As the flash point and viscosity increase the exhaust gas temperature also increase. The B75 and B100 have the high flash point and viscosity than diesel fuel. So the exhaust gas temperatures of the fuel blends are higher than the diesel fuel. But at the low load condition the B75 and B100 give the same value of the diesel fuel.

M. Prabhahar [23] observed in all the cases brake thermal efficiency is increased with increase in load due reduced heat loss. The maximum efficiency obtained in this experiment was 29.53 for (B20) and 28.6% (B100), whereas for the diesel it is 30.45% at full load. It is

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observed that the decrease in thermal efficiency is lower for pure biodiesel and its diesel blend at full load. This decrease in efficiency may be due to low calorific value and poor atomization of biodiesel, resulting in poor combustion. The variation of brake specific fuel consumption with load for diesel and biodiesel is illustrated in Figure-3. For all cases BSFC reduces with increase in load. The reverse trend in the BSFC may be due to increase in biodiesel percentage ensuring lower calorific value of fuel. The maximum value of BSFC for diesel, B20 and B100 are .2402 kg/kW h, 0.2557 kg/kW h and 0.275 kg/kW h at full load.

N. Haribabu [24] noticed that the PME consumption is increasing at higher loads with the decrease of methanol flow rate but compared to neat PME specific fuel consumption of PME is lesser for the methanol flow rate of 16.2 mg/s at all loads but for at full load with a marginal increase (Figure-7). Brake thermal efficiency has increased with the increase of methanol equivalence ratio and with respect to load. Increase of methanol flow rate from 16.2 mg/s to 37.9 mg/s increased the thermal efficiency by 1.65 % at 0.25 full loads and by 1.8 % at full load. From the research survey the exhaust gas temperature increase is there with the implementation of biodiesel which is reflecting in these measurements also. Addition of methyl alcohol decreased very marginally and this is because of low temperature combustion involving methanol (Figure-8).

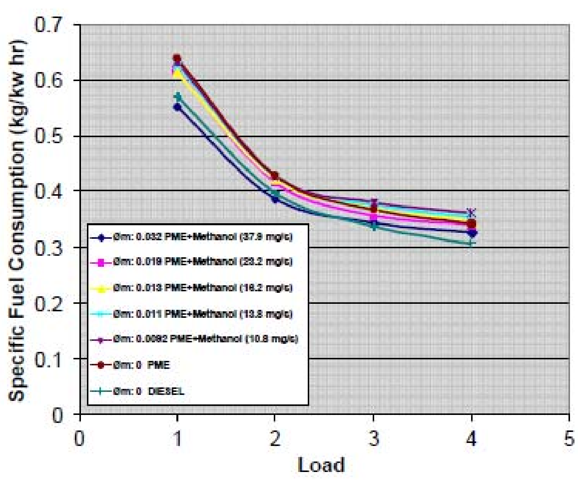

Figure-7. Load Vs SFC.

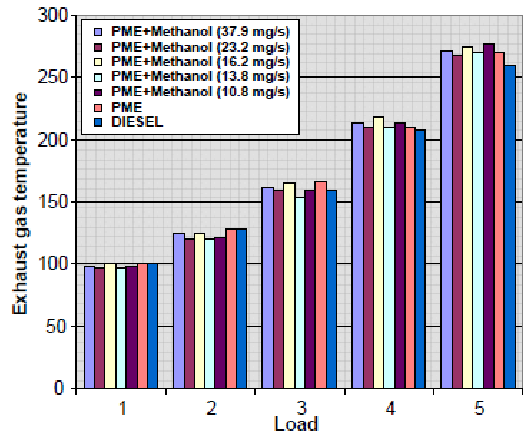

Figure-8. Load Vs EGT.

4.2. Emission characteristics

Avinash Kumar Agarwal [5] observed that the Karanja oil and blends exhibits lower HC emission at lower engine loads and higher HC emission at higher engine load compared to mineral diesel. This is because of relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at high engine load. It was noticed the blends higher than 20% showed higher CO emissions compared to mineral diesel at high engine load. Due to the high viscosity, the air–fuel mixing process is affected by the difficulty in atomization and vaporization of Karanja oil and blends. The resulting locally rich mixtures cause more incomplete combustion products such as CO, HC and PM because of lack of oxygen. Higher the engine load, richer fuel–air mixture is burned, and thus more CO is produced. It was noticed the emission of NO is found to be significantly lower for Karanja oil and blend (both unheated and preheated) at lower engine load. As the engine load is increased, the mass emission of NO reduces however the gap between the emissions from Karanja oil blends and mineral diesel gets narrowed. The most important factor for the formation of NO is the combustion temperature in the engine cylinder and the availability of oxygen. It was observed that the smoke opacity increases with increase in engine loads. Higher blend concentration gives higher smoke at even lower loads, and it was higher than that of mineral diesel but the increase was not as high. Higher smoke opacity may be due to poor atomization of the Karanja oil. Bulky fuel molecules, higher viscosity of vegetable oil and low volatility results in poor atomization of fuel.

B.S. Chauhan [6] noticed that the CO emission from the Karanja methyl ester and its blends is lower than neat diesel fuel as shown in the Figure-8. For all the biodiesel fuels and their blends, CO emissions were found to be lower. As the load is increased on the engine, there is an increase in CO emission for all the test fuels. The increase in CO emission levels at higher load is due to rich mixture at higher load condition than at lower load which results in incomplete combustion of fuel. The values of unburned hydrocarbon (UBHC) emission from the diesel engine in case of Karanja methyl ester and its blends is less than diesel fuel as evident from the Figure-9. Hydrocarbons emissions are mainly caused due to the incomplete combustion of hydrocarbon fuel. The maximum reduction in UBHC was achieved for neat biodiesel fuels. For the blended biodiesel fuel, the reduction in UBHC was lower than neat diesel.

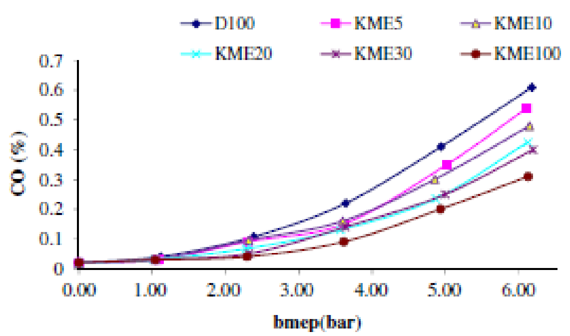

Figure-9. Carbon monoxide Vs BMEP.

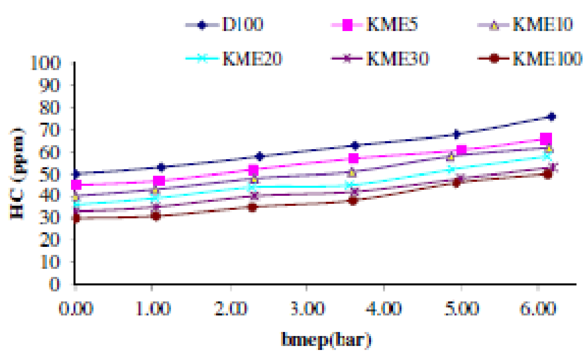

Figure-10. Hydrocarbon Vs BMEP.

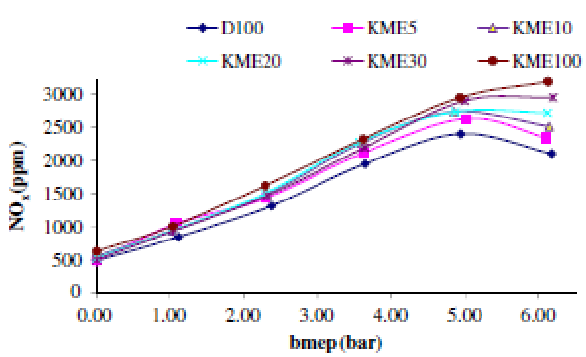

Figure-11. Oxides of Nitrogen Vs BMEP.

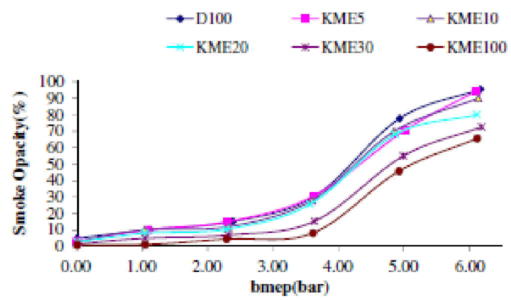

Figure-12. Smoke opacity Vs BMEP.

The variation of NOx emissions from Karanja methyl ester and itsblends with respect to diesel fuel are shown in Figure-10. The NOx emissions increased with the increasing engine load, due to a higher combustion temperature. The NOx emissions are determined by equivalence ratio, oxygen concentration, combustion temperature and time. NOx are formed in cylinder areas where high temperature peaks appear mainly during the uncontrolled combustion. The NOx emissions of biodiesel based fuels have been found higher than diesel on all load conditions. It is quite obvious, that with biodiesel addition in diesel, more amount of oxygen is present in combustion chamber, leading to formation of higher NOx in biodiesel fueled engines. Figure-11 shows the variation of the smoke opacity of Diesel and Karanja methyl esters and its blends at different bmep. It can be seen that smoke is high mainly at high power outputs. High loads imply that more fuel is injected into the combustion chamber and hence incomplete combustion of fuel is amplified. Reduction of smoke emissions for biodiesel based fuels in comparison to diesel fuel has been achieved for all load conditions. With an increase of biodiesel blends, smoke decreases at most of the operating conditions. Moreover, it was found that smoke opacity decreases more at higher loads than lower loads.

B. Baiju [7] observed that at lower loads, there is not much variation for CO emissions for all fuels. At full load, B20KOEE shows the highest CO emissions (Figure-13). Methyl esters emit less CO compared to ethyl esters. This may be due to the enrichment of oxygen owing to biodiesel addition, which results in better combustion. Figure-14 shows the variation of NOx emission with load. NOx emissions of biodiesel blends and pure biodiesel are higher than diesel part loads. From this curve, two observations can be made. First, NOx emissions are a direct function of engine loading. This is expected because with increasing load, the temperature prevailing inside the combustion chamber increases and NOx formation is a strongly temperature dependant phenomenon. The second observation is that higher NOx is due to higher temperatures prevailing in the combustion chamber of the biodiesel- fuelled engine. This is also reflected by the higher exhaust gas temperature from the biodiesel-fuelled engines. At higher loads, diesel is emitting more NOx than

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biodiesel fuels. Among the esters, ethyl esters are emitting more NOx than methyl esters. This may be due to higher bulk modulus of ethyl ester than methyl ester.

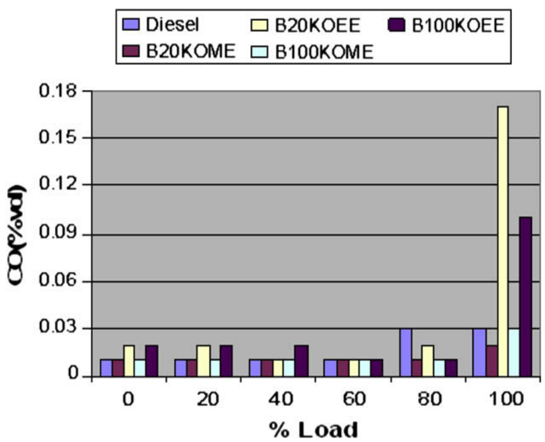

Figure-13. Carbon monoxide Vs load.

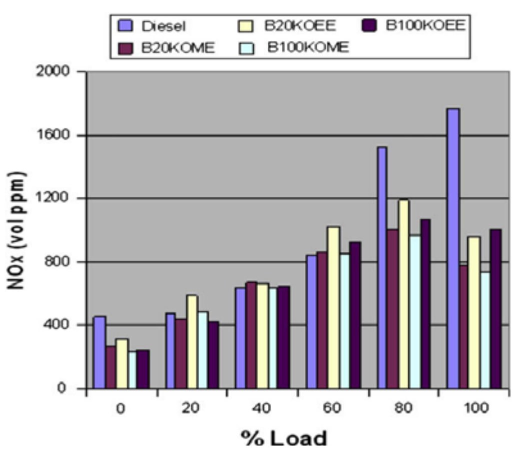

Figure-14. NOx emissions Vs load.

Gaurav Dwivedi [8] noticed a large reduction for all blends as compared to neat petroleum based diesel fuel. The CO and HC emissions are drastically reduced by increasing the percentage of biodiesel. NOx emissions for the case of Pongamia biodiesel were lower at 100% load. These lower NOx emissions could be due to lower temperatures in the combustion chamber using Pongamia blends.

H. K. Amarnath [9] was found that with the increase in load the carbon monoxide emissions increase. Puhan [10] also found a similar trend. This can be attributed to more fuel being consumed at higher loads. CO emissions are due to unburnt fuel, which is in turn due to incomplete combustion. As biodiesel contains more oxygen, with the increase in biodiesel content in blend the CO emissions reduce. This is because larger fractions of the fuel carbon are converted to CO. It is found that the CO emissions increase up to 45% from no load to full load condition. With the increase in blend ratio up to 66% reduction is observed in CO emissions. At higher loads, NOx emissions are higher as fuel is burnt. Biodiesels are fuels with higher oxygen content than diesel. So, when more oxygen is available during combustion of fuel, nitrogen from air readily gets combined with oxygen and forms compounds like nitrogen oxide and nitric oxide. NOx emissions are more for biodiesel. This is due to the presence of inherent oxygen in it. It is noticed that the variation of HC emissions with load. Similar trend is also reported by Lakshmi Narayana Rao [25]. However, the study shows that with higher biodiesel blend, the quantity of HC emissions is reduced. This can be attributed to the higher oxygen content in biodiesel due to which smooth and complete combustion of biodiesel takes place inside the cylinder. With the increase in blend ratio from 20% to 100% up to 50%, reduction is observed in HC emissions.

N. Shrivastava [15] observed that the increasing the load decreases CO emissions. The maximum and minimum value of CO emission for the neat diesel was 433, 174ppm and that of neat KOME was 340 and 143ppm, respectively. The diesel fuel showed highest CO emission and the KOME blends showed reduction in CO emission. The 20, 50 and 100 % blend showed 6.46, 11.13 and 14.54% average reduction compared to neat diesel fuel. The reduction in the CO emission may be attributed to the conversion of the CO into CO_2 by taking the oxygen present in the KOME molecules. The CO emission also depends upon the Carbon to hydrogen ratio and the cylinder temperature. Similar finding was reported by [17, 18, 19, 26, 27]. It was observed that the increasing the load increases HC emission and the blending of KOME with diesel fuel decreases the hydrocarbon emission. Diesel fuel showed highest HC emission where as B100 showed lowest. The 20, 50 and 100 % blend showed average reduction of 4.87, 10.47 and 14.88 % respectively compared to diesel fuel. The reduction in HC emission is the indicative of cleaner combustion which could be due to the presence of oxygen in the KOME with high combustion temperature make the HC oxidation easier. Similar finding was reported by [18, 19, 26, 27]. NOx emission increased with the engine load. The diesel fuel showed lowest NOx emission and the blending with KOME showed increased NOx emission. Comparatively higher NOx emission was observed at higher load. The neat KOME showed highest NOx emission of 847ppm and where as neat diesel showed 715ppm at the BMEP of 0.5MPa. The 20, 50 and 100 percent blend showed an average of 3.42, 11.12 and 18.11% increase NOx compared to diesel fuel. The increase in the NOx emission may be attributed to injection advance due to physical properties of biodiesel (viscosity, density, compressibility, sound velocity). It was observed that the increasing the load increases smoke emission. The blending of KOME with diesel fuel decreases the smoke emission. No significant changes in smoke was observed at lower load, however higher load showed highest of 23.6 %t reduction in smoke with neat KOME. The 20, 50 and 100 % blend showed average reduction of 6.6, 7.17 and 11.76 % respectively compared to diesel fuel. The possible reason

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of smoke reduction could be attributed to the presence of fuel bound oxygen, even in the regions of combustion chamber with fuel rich diffusion flame.

A. Haiter Lenin [22] noticed that at low and medium load condition the fuel blends B75 and B100 give almost the same value of the diesel fuel. At maximum load condition the carbon monoxide of the fuel blends suddenly increases. The hydrocarbon emission depends upon the carbon residue and the hydrogen content. The B75 and B100 have lower carbon residue and the hydrogen content than diesel fuel, resulting in low hydrocarbon emission. The graph shows the B75 and B100 have low hydrocarbon emission than the diesel fuel. The hydrocarbon emission also depends upon the exhaust gas temperature. When the exhaust gas temperature increases the hydrocarbon emission reduces. The fuel blends have high exhaust gas temperatures. So the hydrocarbon emission is lower than diesel fuel. When the brake power increases the quantity of oxides of nitrogen also increases. The oxides of nitrogen emission depend upon the peak combustion temperature and high residence time of the high temperature gases in the cylinder. The B75 and B100 have higher gas temperatures. So the oxides of nitrogen emission are higher than the diesel fuel at all load condition. When the brake power increases the smoke density also increases. The smoke density depends upon the specific gravity and the density of the fuel. The fuel blends B75 and B100 have higher smoke density than the diesel fuel due to the high specific gravity and density. The smoke density also depends upon the better spray formation than the fuel blends due to the viscosity of the fuel. The diesel fuel has lower viscosity. So the smoke density is lower than the fuel blends.

M. Prabhahar [23] observed the variation of carbon monoxide produced with diesel and diesel blend. For B20 blend the maximum CO emission produced is 0.04 %Vol and for the B100 it is 0.05 %Vol and for the diesel it is 0.06 %Vol at full load. The lower CO emission for the biodiesel blend B20 at full load is an indication of the complete combustion of biodiesel being an oxygenated fuel. The decrease in carbon monoxide emission for biodiesel and its blend is due to more oxygen molecule present in the fuel as compared to that of diesel. The shorter ignition delay associated with biodiesel higher cetane number could also reduce the over mixed fuel which is the primary source of un-burnt hydrocarbons. For B20 the maximum HC produced is 37ppm and for B100 is 48ppm at full load. The HC emission for B20 is almost equal to that of diesel fuel, which is 35ppm at full load. The decreases in HC emission may be due to better combustion of biodiesel blend which\h contain more oxygen contents, resulting in better combustion. The variation of nitrogen oxide emissions at different engine load are presented in Figure-6. The formation of nitrogen oxides is significantly influenced by the cylinder gas temperature and the availability of oxygen during combustion. The NO emission for B20 is 526ppm and for B100 is 568ppm whereas for the diesel it is 486ppm at full load conditions. The smoke emission increases with an increase in the load for all fuels. The smoke density for diesel is 3.6 BSU at full load, whereas for B20 and B100 it is 2.7 BSU and 2.5 BSU at full load. The decrease in smoke may be due to more oxygen atom present in the biodiesel, resulting in better combustion of biodiesel.

N. Haribabu [24] noticed that the HC emission has increased with the dual fuel. The HC emission of neat PME and diesel fuel operation maintained minimum throughout at all loads when compared to the PME and Methanol combinations. The higher HC emission is observed at lower loads when the methanol induction is higher and recorded maximum (450ppm) at no load operation because of flame quenching due to cold combustion (Figure-15). CO emission is least for methanol mass flow 16.2 mg/s. With this combination the values ranging from 0.04% to 0.03% at no load to full load gives best reduction with respect to neat PME (Figure-16). CO emission for the low temperature combustion will be more but for the flow rate of 16.2mg/s and its neighbouring flow rate 13.8 mg/s remained efficient in controlling the combustion. Increase in NO emission with the increase of load is observed for neat PME and also PME, methanol combinations. The NO emission for the Methanol mass flow 16.2 mg/s is minimum i.e. 605ppm at full load operation and again increased with the decrease of methanol flow rate. It is a known fact that biodiesel produces more NO than the Petro diesel. Higher flame velocities also produce higher NO and that happens in case of dual fuel operation (Figure-17). Smoke emission is comparable with neat PME applications (Figure-18). Smoke emission is more when methanol flow rate 37.9 mg/s at all loads. This is due to low temperature combustion generated by the induction of methanol. Cold combustion effect prevails in most of the methanol combinations and the flow rate in the vicinity of 16.2 mg/s i.e. 13.8 mg/s is reducing smoke at part loads.

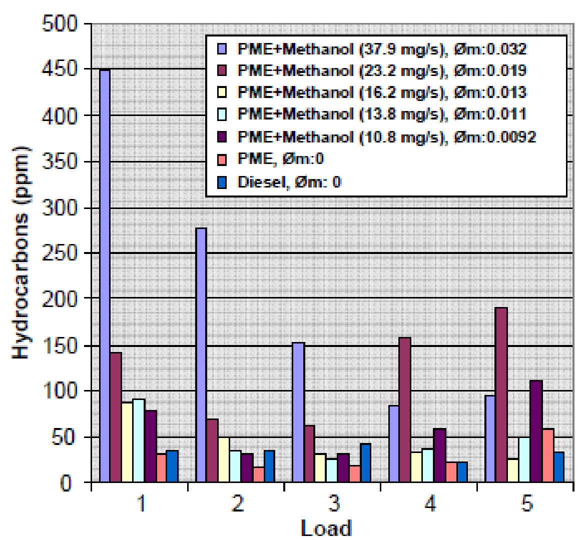

Figure-15. Load Vs HC.

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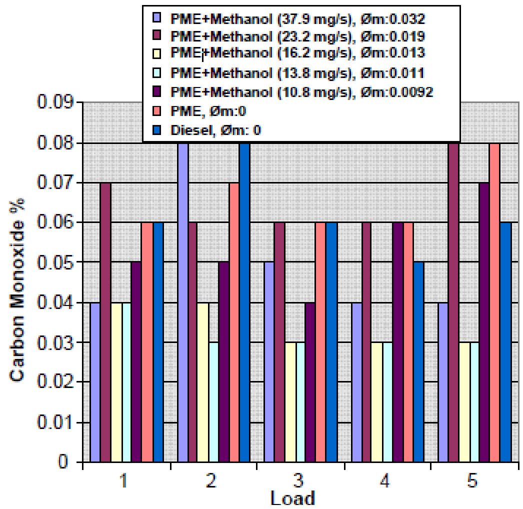

Figure-16. Load Vs CO.

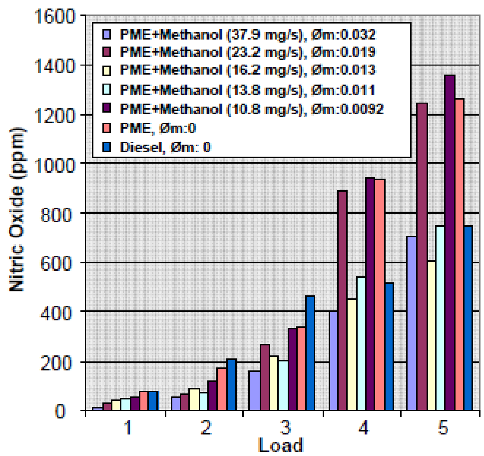

Figure-17. Load Vs NOx.

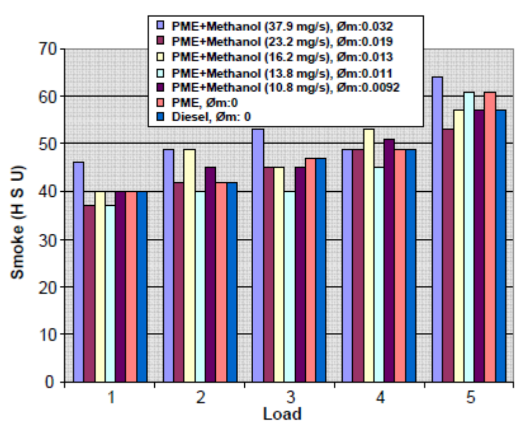

Figure-18. Load Vs smoke.

A. Swarna Kumari [28] observed the variation of hydrocarbon emission with brake power output for pongamia oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm^2. HC emission of 50% blend of pongamia oil has higher emission compared with all other blends. While, HC of Diesel and 25% blend of pongamia oil are near to pure diesel. NOx emission with brake power output for pongamia oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm^2. NOx of 25% blend of pongamia oil is less that the diesel. 50% blend has less NOx emission compared with all other blends throughout all brake power loads. Diesel has higher NOx emission compared with all other blends of pongamia oil. Diesel has lower smoke emission compared with all other blends of pongamia oil.

5. CONCLUSIONS

Diesel engine runs successfully during tests on Karanja oil and its blends even without preheating and require no modification in engine hardware. However while using preheated fuel, engine efficiency enhanced slightly. Performance and emission characteristics of Karanja oil and its blends were found to be similar to that of mineral diesel. Based on the study, the following conclusions are made:

- Biodiesel formed from karanja oil can be productively used as an alternative fuel in diesel engines without any major modifications. The engine is found to operate smoother, with less noise and vibrations, at higher compression ratios.
- BSFC decreases with increase in load, compression ratio, and injection pressure for all blend fuels. BSFC for B100 is found to be higher by about 9% as compared to that of diesel.
- At full load, BTHE for B100 is lower as compared to that of diesel. The addition of karanja biodiesel in the blend decreases the heating value of the blend. Hence, lower BTE is obtained for higher blends. The BTE was about 3-5% lower with Karanja biodiesel and its blends with respect to diesel. The low efficiency may be due to low volatility, slightly higher viscosity and higher density of the biodiesel of Pongamia oil, which affects mixture configuration of the fuel and thus leads to sluggish combustion.
- EGT for B100 is considerably less as compared to that of diesel. The highest value of EGT for B100 is 343.77^{0}C and that for diesel is 350.75^{0}C.
- It is observed that carbon monoxide and unburnt hydrocarbon emissions are less in case of biodiesel, whereas formation of NOx and smoke intensity is more with biodiesel. With the increase in blend ratio for B20 to B100 up to 33% increase, 66% decrease, and 50% decrease is observed in Smoke, CO emissions, and HC emissions, respectively. NOx emissions increase by 10-25% when fuelled with diesel- biodiesel fuel blends as compared to diesel fuel at part loads. At full load, diesel emits more NOx than esters,
- Methyl ester blends of Karanja oil showed performance characteristics close to diesel fuel.

Therefore Karanja methyl ester blends can be used in C.I engines without any engine alteration, in rural areas for meeting energy demands in various agricultural operations.

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