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Performance and Emission Characteristics of a Direct Injection Diesel Engine using Biodiesel Produced from Karanja Oil

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Abstract: The increasing vehicular population leads to consumption of petroleum fuels at a faster rate. This problem results increase in the danger of petroleum fuels depletion and the remarkable increase in high crude oil prices. The increasing consumption of petroleum products has been a matter of great concern for the country for the financial growth as well as environmental pollution abatement. The situation offers us a challenge as well as opportunity to look for substitutes of fossil fuels by utilizing vegetable oil for both economic and environmental benefits to the country. In the present experimental study, biodiesel produced from Karanja oil (KB) has been selected. It has been tested on single cylinder, four stroke, water cooled, direct injection diesel engine for the performance and emissions using fuel samples containing different blends of KB (0%, 10%, 20%, 30%, 40%, 50%, 75% and 100%) and conventional diesel. Engine performance and exhaust emission characteristics have been measured and analyzed. The highest brake thermal efficiency has been found to be 27.99% and lowest brake specific fuel consumption of 0.303kg/kw hr has been found with KB20 blend. It is also found that emissions of carbon monoxide and un-burnt hydrocarbon reduce as load increases for all the blends of biodiesel tested on the engine up to 80% of rated brake load (i.e. 88.98 N or 20 lbs.) beyond that, these emissions further increase. It has been found that nitrogen oxides emission increases as the brake load increases on the engine up to 80% of rated brake load beyond that it further decreases. This may be due to the presence of oxygen available in biodiesel. Hence biodiesel from karanja oil (pongamia pinnata) can be used as potential alternative fuel in future.

Keywords: Alternative fuels, Biodiesel, Blends, Diesel engine, Emissions, Karanja and Performance.

1. Introduction

Increase in the consumption pattern of petroleum fuels in India due to the growth in transport sector which is a major consumer of the liquid petroleum fuels, leads to petroleum crisis in India. Hence, the search of proper alternative replacement of petroleum fuel is urgently needed. Biodiesel produced from Vegetable oils either edible or non-edible can be used as an alternative to diesel since it is produced from renewable sources and it has almost similar properties. Many researchers have studied the use of biodiesel prepared from vegetable oils in diesel engines. Biodiesel prepared from Vegetable oil may produce almost the same brake power with a small reduction in thermal efficiency of a diesel engine. Karanja (Pongamia pinnata) is one such forest-based tree which produces non-edible oil from its seeds. Biodiesel prepared from karanja oil and its blends with diesel has been used in the present investigation. The properties of biodiesel have been determined and their combustion and emission characteristics have been studied on a direct injection diesel engine.

2. Literature Review

Heywood [1] has reviewed the future options for fuels for automotive engines. It has been suggested in it that after 2030, use of alternative fuel will dominate. Onion and Bondo [2] have surveyed worldwide activities related to oxygenated fuels for diesel engines. Raheman and Phadatare [3] have carried out an experimental investigation with the aim of obtaining comparative measures of torque, power, specific fuel consumption and emissions such as CO, smoke density and NOx to evaluate and compute the behavior of the diesel engine running on karanja methyl ester (KME) and its blend with diesel from 20-80% by volume. It has been concluded that the reduction in exhaust emissions together with increase in torque, brake power, brake thermal efficiency and reduction in brake-specific fuel consumption made the blends of karanja esterified oil (B20 and B40), a suitable alternative fuel for diesel.

Agrawal [4] has discussed the applications of biodiesel as fuel for internal combustion engine and has reviewed the production, characterization and current status of vegetable oil and biodiesel as well as the experimental research work carried out in various countries.

Kalbande et al.[5] have tested biodiesel produced from raw jatropha and karanj oil, and its blends with diesel for power generation in a 7.5 kVA diesel engine generator set. The overall efficiency of the generator for 6,000 W loading conditions has been improved for jatropha and karanj biodiesel blends and has been found in the range of 31–33% and 33–39%, respectively. Biodiesel blends B80 and pure biodiesel of karanja have produced more power, and maximum overall efficiency in comparison to diesel fueled generator. The overall efficiency on jatropha-biodiesel-blended fuel is found to be less than that of diesel-fueled generator.

Ghosh et al. [6] have conducted an experimental investigation to make the comparison of fuel properties, performance and emission characteristics of three biodiesels i.e. karanja, putranjiva and jatropha. Experiments have been carried out in Ricardo variable compression engine and evaluated the best one for diesel engine application. It has been found that in case of B100 karanja and blends of jatropha have shown better efficiency. Jatropha has shown maximum reduction in emissions, and fuel economy than others. Considering the results of fuel properties, performance and emissions, jatropha appears to be the best alternative fuel than putranjiva and karanja.

Banapurmath et al.[7]have conducted an experimental investigation on a single-cylinder, four stroke, direct-injection, CI engine operated with methyl esters of honge oil, jatropha oil and sesame oil and found higher brake thermal efficiency and lower emissions (HC, CO, NOX) with sesame oil methyl ester operation as compared to methyl esters of honge and jatropha oil operation.

Wu et al. [8] have experimentally investigated the performance and emissions on a Cummins ISBe6 Euro III diesel engine using five methyl esters with different sources such as cottonseed methyl ester (CME), soybean methyl ester (SME), rapeseed methyl ester (RME), palm oil methyl ester (PME) and waste cooking oil methyl ester (WME). It has been found that the use of different methyl esters results in large PM reductions ranging from 53- 69%, which includes the dry soot (DS) reduction ranging from 79-83%. Different biodiesels increase NOx emission by 10-23% on average. All biodiesels produce less HC and CO than diesel fuel.

Sahoo and Das [9] have carried out combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine. The major objective of the present investigations is to experimentally access the practical applications of biodiesel in a single cylinder diesel engine used in generating sets and the agricultural applications in India. Diesel, neat biodiesel from jatropha, karanja and polanga and their blends (20% and 50% by volume) have been used for conducting combustion tests at varying loads (0%, 50% and 100%). The engine combustion parameters such as peak pressure, time of occurrence of peak pressure, heat release rate and ignition delay have been computed. Combustion analysis has revealed that the neat polanga biodiesel results in maximum peak cylinder pressure have been the optimum fuel blend as far as the peak cylinder pressure is concerned. The ignition delays have been consistently shorter for neat jatropha biodiesel, varying between 5.9° and 4.2° crank angles lower than diesel with the difference increasing with the load. Similarly, ignition delays are found to be shorter for neat karanja and polanga biodiesel when compared with diesel.

Sahoo et al. [10] have tested ten fuel blends (Diesel, B20, B50 and B100) of non-edible jatropha (Jatropha curcas), karanja (Pongamia pinnata) and polanga (Calophyllum inophyllum) oil based methyl esters for their use as substitute fuel for a tractor engine and found that maximum power increased when 50% jatropha biodiesel and diesel blend is used at rated speed. Brake specific fuel consumptions for all the biodiesel blends with diesel increases with blends and decreases with speed. There is a reduction in smoke for all the biodiesel and their blends when compared with diesel.

Baiju et al. [11] have experimentally investigated the Performance and exhaust emission characteristics of the engine using petrodiesel as the baseline fuel and several blends of diesel and biodiesel as test fuels. Results show that methyl esters of Karanja oil produced slightly higher power than ethyl esters. Exhaust emissions of both esters are found to be almost identical.

Haldar et al. [12] have experimentally investigated the performance and emissions characteristics of non-edible straight vegetable oils of Putranjiva, Jatropha and Karanja after Degumming (which is a economical chemical process that is done by concentrated phosphoric acid) to find out the most suitable alternative diesel.Degumming process has been applied to the above-mentioned non-edible oils to remove the impurities for the improvement of viscosity, cetane number and better combustion in the diesel engine. Blends of diesel and degummed non-edible vegetable oils (10%, 20%, 30% and 40%) have been used in a Ricardo variable compression engine, the best results of performance and emissions have been found using 20% non-edible oil of Jatropha at high loads and 45^o crank angle before top dead centre (TDC) injection timing.

Singh et al. [13] have carried out the performance analysis of diesel engine using the biodiesel which was produced from used mustard oil and diesel blends. It has been found that dual fuel with a blend of 8% biodiesel yielded good efficiency in the diesel engines without the need for making any modifications in the engine. Ilkilic et al [14] have experimented with biodiesel produced from safflower in diesel engines and have concluded that the use of safflower oil biodiesel has beneficial effects both in terms of emission reductions and alternative petroleum diesel fuel. Ong et al. [15] have studied to investigate the performance and emissions produced from Jatropha curcas, Ceiba pentandra and Calophyllum inophyllum biodiesel and its blends of 10%, 20%, 30% and 50% in a diesel engine at full throttle load in compressed ignition engine. It has been found that 10% biodiesel blend shows the best engine performance in terms of engine torque, engine power, fuel consumption and brake thermal efficiency among the all blending ratios for the three biodiesel blends. Biodiesel blends have also shown a significant reduction in CO_2, CO and smoke opacity with a slight increase in NOx emissions.

3. Experimental Method

3.1 Blends Preparation:

In order to evaluate biodiesel as Compression Ignition Engine Fuel, various blends of karanja biodiesel (KB) and conventional diesel have been prepared by mixing different amount of biodiesel and diesel. The properties of diesel & karanja biodiesel have been measured (Table 1). The properties of different blends of biodiesel and diesel have been calculated using mixture rule. The blends were designated by "KB". For example, KB20 indicates that it contains 20% of karanja biodiesel and remaining 80% is diesel. For finding the optimum ratio, the blends KB10, KB20, KB30, KB40, KB50, KB75 and KB100 have been prepared. Experiments have been conducted with KB0 (Pure diesel) and KB100 (Pure biodiesel) also.

Table 1: Properties of Diesel & Karanja Biodiesel

Blend	Density (Kg/m^3)	Kinematic Viscosity (mm^2/sec) at 40 ^oC	Flash Point (^oC)	Calorific value (MJ/kg)
Diesel(KB0)	815	2.75	50	43.35
KB100	889	5.71	181	39.132

3.2 Experimental set-up: The study has been carried out in the laboratory on a diesel engine. The schematic diagram of test engine set-up is shown in figure 1.

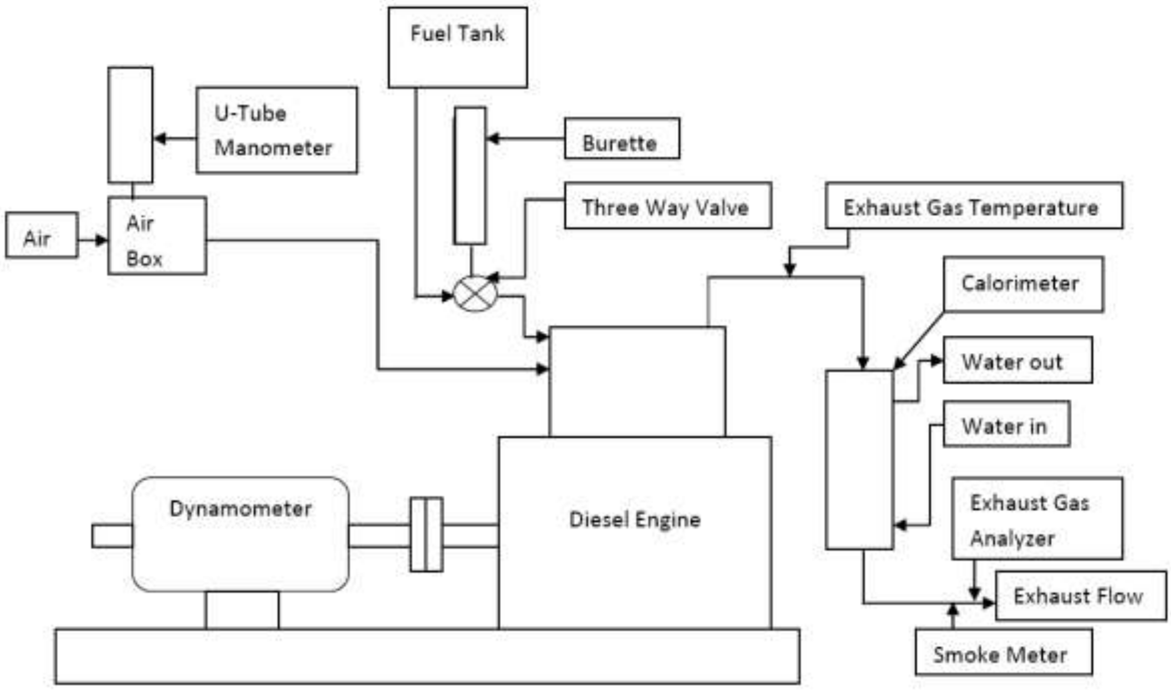

Figure 1: Schematic Diagram of Test Engine Set-up

The specifications of test engine set-up are given in table 2.

Table 2: Specification of Test Engine Set-up

S No	Parameter	Details
1	Make	Kirloskar
2	Model	1M 11x11
3	Engine type	Single cylinder, vertical, constant speed diesel engine
4	Bore and stroke	110mm x110mm
5	Swept Volume	1046 cc
6	Compression Ratio	16.5:1
7	Rated power	7.46 KW (10 BHP) at 1500 rpm
8	Engine cooling	Water cooled

4. Experimental Procedure

The experiments have been conducted on the diesel engine. The engine has been then tested from no load to full load at the interval of 10% of rated load. For varying the load, hydraulic dynamometer has been used. For which the given arm length of 0.535 m, 88.97 N is full load at rated power of 7.46 KW and rated speed of 1500 rpm. The engine at the above mentioned loads has been tested with pure diesel, 10%, 20%, 30%, 40%, 50%, 75% blends of karanja biodiesel with diesel and 100% karanja biodiesel. Measurement of exhaust gas emissions and smoke opacity has been done using Indus five gas analyzer-model PEA205 and Netel's smoke meter-model NPM-SM-111B respectively.

5. Results & Discussion

Figure 2 shows the variation of BTE (brake thermal efficiency) and engine load for diesel and diesel- karanja biodiesel blends. It is observed that as the load increases, BTE increases for all the fuel samples tested including diesel up to 80 % of rated brake load. This may be due to increase in power developed with increase in load associated with less increase in energy input. The maximum value of efficiency has been found for KB20 fuel sample as 27.99% which is 3.7 % higher than diesel for 80% of rated brake load. After mixing biodiesel in diesel oil, the brake thermal efficiency of the engine improves as biodiesel provides better lubricity to the fuel resulting in lower loss of power in fuel pump. The oxygen molecules available in esters enhance the combustion quality. As the karanja biodiesel content increases in the fuel sample, BTE increases up to KB20 blend, beyond this blend, it further reduces for all the loads. It may be due to larger concentration of biodiesel (above KB20), in the blend which tends to reduce the net calorific value of the mixture leading to increase in fuel consumption as compared to KB0-KB20 fuel samples.

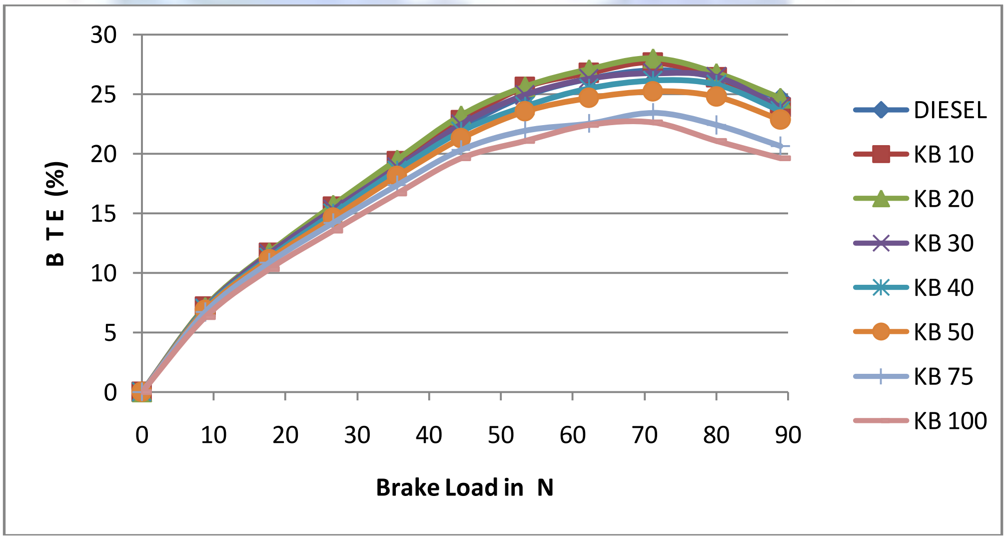

Fig. 2 Variation of brake thermal efficiency with engine load for the different blends of karanja biodiesel and conventional diesel

The fuel samples KB10 and KB20 perform better than diesel. KB100 blend is not observed to be better for any load as compared to diesel, this may be due to high viscosity and improper mixing of fuel.

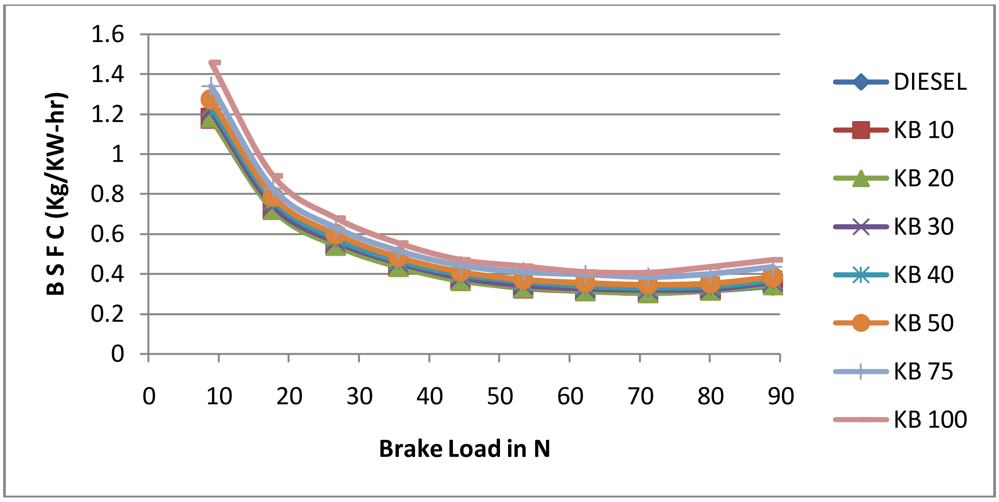

Fig. 3: Variation of brake specific fuel consumption with engine load for the different blends of Karanja biodiesel and conventional diesel

The variation of brake specific fuel consumption (BSFC) with brake load for different blends of fuels is presented in figure 3. It is observed that BSFC decreases with increase in the engine load for all the blends of fuel tested on the engine till 80% of the rated load, beyond that it further increases. This may be due to the fact that as engine load increases, the brake power increases for better utilization of injected fuel. The increase in brake power is more as compared to the increase in fuel consumption resulting in lower BSFC. Using lower percentage of biodiesel in diesel blends (up to KB20), the BSFC of the engine is lower than that of diesel for all loads. In case of KB30-KB100 blends, the BSFC is found to be higher than that of diesel. It is observed that a larger amount of biodiesel is supplied to the engine compared to that of conventional diesel.

Figure 4 shows the variation of exhaust gas temperature (EGT) with brake load for different blends of bio-diesel and conventional diesel in the test engine. It is observed that EGT of karanja biodiesel is found to be lower than the conventional diesel. The EGT of diesel at rated load is 515^{o}C where as for karanja biodiesel, it is 492^{o}C. It is also observed that EGT increases with the increases in engine load for the fuel samples tested. Although, EGT upto KB30 has been found higher than diesel. The maximun EGT has been found as 523^{o}C for KB30 at 100 % rated load. As the biodiesel content increases in fuel sample, EGT reduces. It may be due to the reducing trend of calorific value of fuel samples. The high EGT enhances the oxidation of un-burnt hydrocarbon in tail pipe.

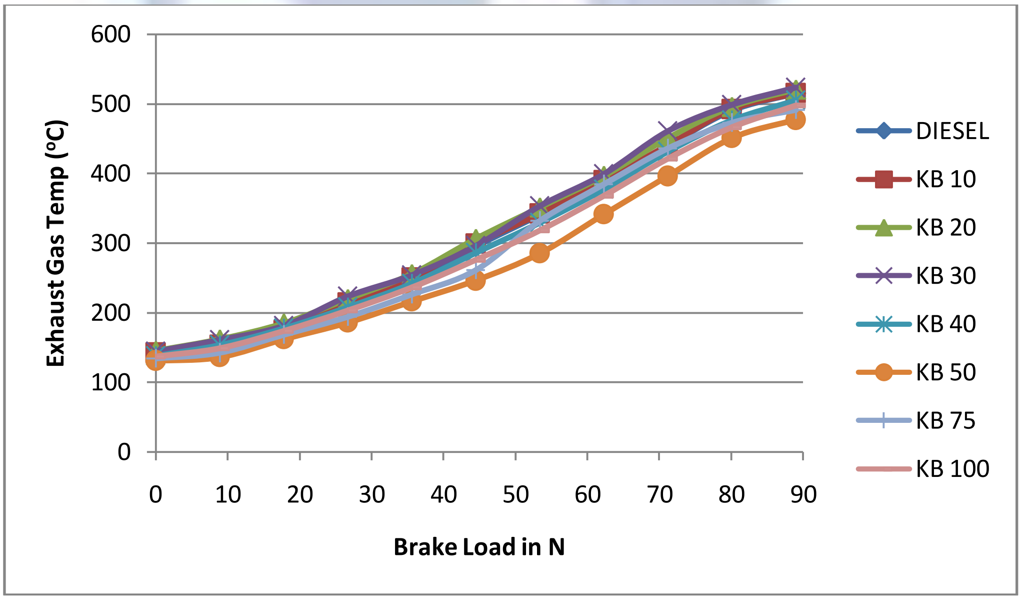

Fig. 4: Variation of exhaust gas temperature with engine load for the different blends of Karanja biodiesel and conventional diesel

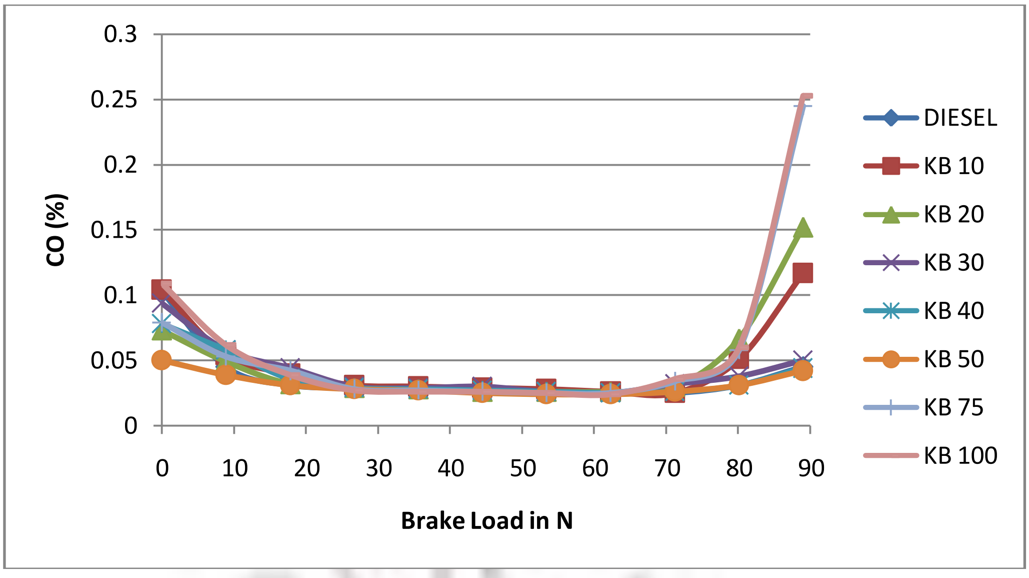

Fig. 5: Variation of carbon monoxide with engine load for the different blends of Karanja biodiesel and conventional diesel

Figure 5 shows the variation of carbon monoxide (CO) in exhaust gas with brake load for different blends of bio-diesel and conventional diesel in the test engine. It has been found that CO reduces in engine exhaust as load increases up to 70% of rated brake load and after that it further increases. At 70% of rated load (62.3N) KJ100 and KJ50 have produced 0.024% CO, which was the least and about 4% less than the CO produced by diesel at the same load condition. It may be due to improper combustion in higher range of load.

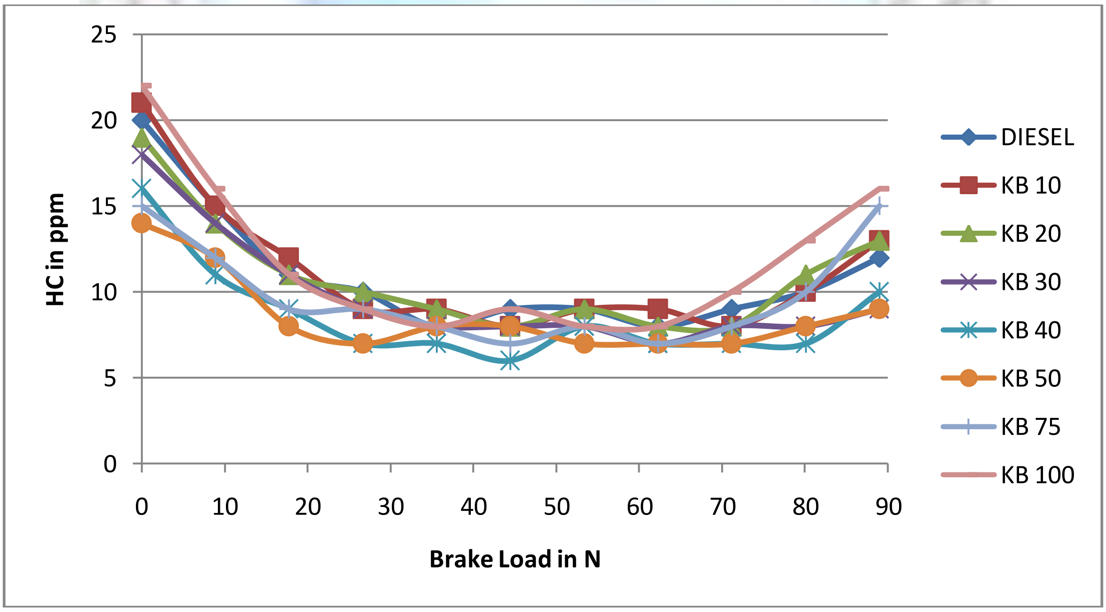

Fig. 6 Variation of un-burnt hydrocarbon with brake load for the different blends of Karanja biodiesel and conventional diesel

Figure 6 shows the variation of un-burnt hydrocarbon in exhaust gas with brake load for different blends of bio-diesel and conventional diesel in the test engine. It has been observed that for all the samples of fuel tested on engine, un-burnt hydrocarbon reduces with increase of load up to 60-70% of engine load, after that it further increases. It may be due to poor combustion at higher load. In the middle range of load, most of the blends show lower HC emissions. KB50 has shown the least HC emissions throughout the load range. At70% of rated load, KB50 blend has produced 12.5% less HC than diesel.

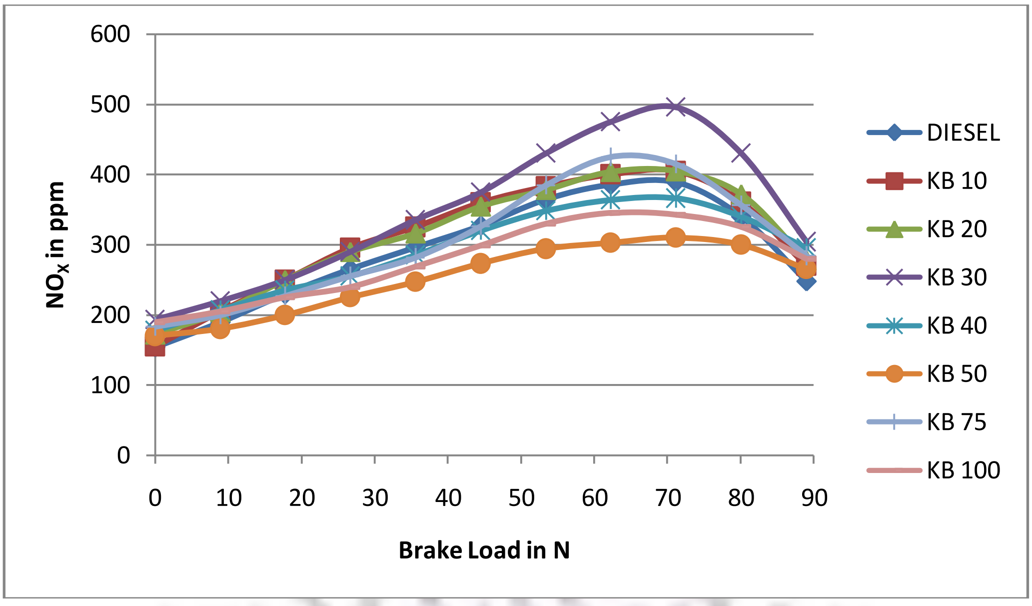

Fig. 7: Variation of nitrogen oxides with engine load for the different blends of Karanja biodiesel and conventional diesel

Figure 7 shows the variation of nitrogen oxides (NO_x) in exhaust gas with brake load for different blends of karanja biodiesel and conventional diesel in the test engine. It has been observed that as load increases, NO_x increases till 80% of rated load, beyond that it further reduces for most of the samples of fuel tested. It may be due to improper combustion at higher load. The maximum concentration of NO_x has been found 496 ppm for KB30 blend at 80% of rated load. The NO_x emission increases as biodiesel content in the fuel increases for the samples KB0-KB30, beyond that it further reduces. It may be due to proper combustion of fuel samples having low percentage of biodiesel content.

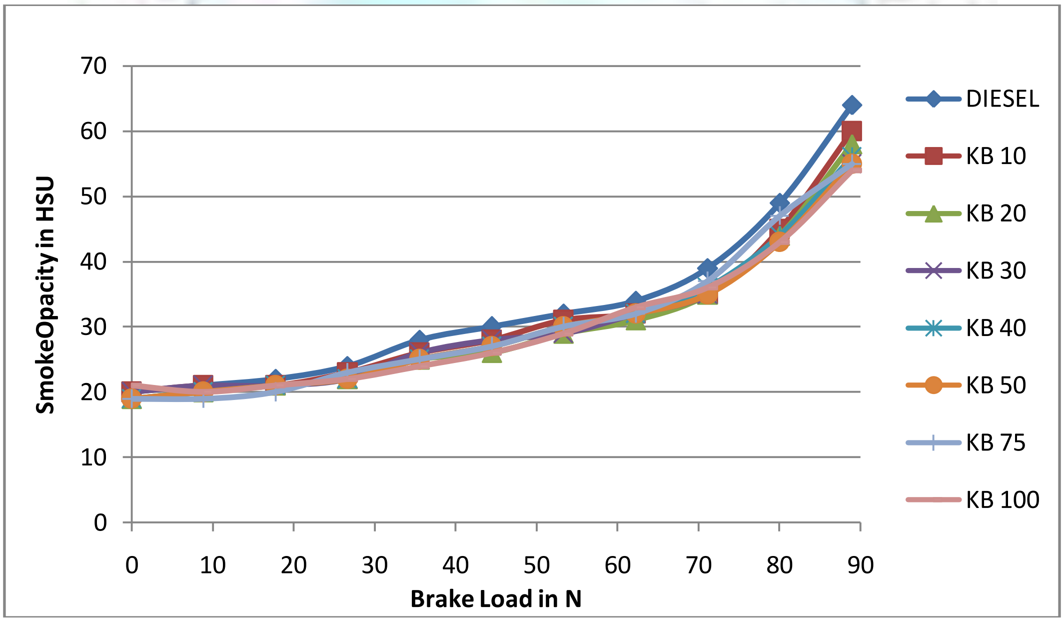

Fig. 8: Variation of smoke percentage with engine load for the different blends of Karanja biodiesel and conventional diesel

Figure 8 shows the variation of smoke percentage in exhaust gas with brake load for different blends of bio-diesel and conventional diesel in the test engine. It clearly shows that the smoke opacity increases as load increases for all the blends tested. It may be due to supply of more quantity of fuel and improper combustion of fuel at higher loads. The maximum smoke opacity in exhaust at full load for diesel fuel has been found to be 64% HSU where as for KB100, it is 54% HSU, which is 15.63% lower than diesel. It may be due to the availability of oxygen molecules in biodiesel blended fuel which enhances combustion quality.

6. Conclusion

Alternate fuels for diesel engines have become increasingly important due to decreasing petroleum reserves and the environmental consequences of exhaust gases from petro-fuel. Thus Karanja biodiesel can be adopted as an alternative fuel for the existing diesel without any major modification in the system hardware. The trend of performance and emission characteristics of Karanja biodiesel demonstrated are in close agreement with the diesel oil making it a potential candidate for the application in diesel engine for partial replacement of diesel fuel. It is observed that blend of 10-20% Karanja biodiesel with conventional diesel is found to be the best proportion as far as brake thermal efficiency and brake specific fuel consumption is concerned. The emission characteristics of engine shows that the use of Karanja biodiesel is reducing harmful emissions from the exhaust such as un-burnt hydrocarbon, carbon monoxide and smoke. Nitrogen oxide emission is found to be little bit higher with some blends of bio-diesel for some range of brake power.

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