An Experimental Evaluation of Performance and Emission Characteristics for Modified Diesel Engine Using Mixed Biofuel

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***Abstract*- There are two main reasons for using alternative fuels in the transportation sector. One is to reduce the dependence on petroleum oil. The other to reduce emissions produced by on-road vehicles. Biodiesel is a renewable fuel that has been shown to reduce many exhaust emissions, except oxides of nitrogen (NOx), in diesel engine cars. This is of special concern in inner urban areas that are subject to strict environmental regulations, such as EURO norms. Also, the use of pure biodiesel (B100) is inhibited because of its higher NOx emissions compared to petroleum diesel fuel. The aim of this present work is to investigate the effect of the iodine value and cetane number of various biodiesel fuels obtained from different feed stocks on the combustion and NOx emission characteristics of a direct injection (DI) diesel engine. The biodiesel fuels were chosen from various feed stocks edibles as well as non-edibles oils such as coconut and Karanja oil. From the literature the experimental results show an approximately linear relationship between iodine value and NOx emissions. The biodiesels obtained from coconut showed lower NOx levels than diesel, but other biodiesels showed an increase in NOx. It was observed from the literature that the nature of the fatty acids of the biodiesel fuels had a significant influence on the NOx emissions. Also, the cetane numbers of the biodiesel fuels are affected both premixed combustion and the combustion rate, which further affected the amount of NOx formation. It can be concluded that NOx emissions are influenced by many parameters of biodiesel fuels, particularly the iodine value and cetane number. The coconut oil has lower iodine value and higher cetane value; hence to improve the property of other biodiesel, mixing of coconut biodiesel may be done. With this aim this work is proposed to be carried out which is virgin course of this kind of study. The effect of coconut oil, karanja oil biodiesel and diesel oil and its mixed effect will be compared on the basis of experimentally evaluated performance and emission characteristics parameters. The current research shows renewed interest on biodiesel as fuel in diesel engines, although concept of using vegetable oil as engine fuel is as old as the engine itself. The lower cost of the petroleum diesel has so far attracted the world to use it as fuel in diesel engines until now. But nowadays due to global political turmoil and other reasons, the cost of petroleum diesel has been increasing exponentially. Moreover, the emission norms are more stringent as ever before. In this context, many biodiesels have been used by different countries, but only a very few and non-edible type such as Jatropha, Karanja , and Mahua and edible like coconut oils can be considered to be economically affordable to some developing nations like India in particular. Transesterification process is the most widely used technology for producing biodiesel from vegetable oil. In the present investigation, Karanja biodiesel (KB100), Coconut biodiesel (CB100) and mixed Karanja -coconut methyl ester is produced through transesterification process by considering karanja (K50) and coconut oil (C50) in equal proportions using NaOH catalyst under lab set up. The obtained biodiesel (KCBO50:50 i.e. KCBO) is blended with petroleum diesel for various ratios of KBD 50:50, CBD 50:50 and KCBO 50:50 to evaluate its fuel properties. Experimental investigations were conducted on unmodified single cylinder diesel engine using different blends of mixed biodiesels at variable loads and fixed injection pressure. The result indicates that fuel properties and engine performance are better for KCBO 50:50 mixed biodiesel blend.**

Keywords: Biodiesel feed stocks, Iodine value, Cetane number, Mixed biodiesel, Coconut oil, Jatropha oil

1.0 INTRODUCTION

The current research shows renewed interest on biodiesel as fuel in diesel engines, although concept of using vegetable oil as engine fuel is as old as the engine itself. The lower cost of the petroleum diesel has so far attracted the world to use it as fuel in diesel engines until now. But nowadays due to global political turmoil and other reasons, the cost of petroleum diesel has been increasing exponentially. Moreover, the emission norms are more stringent as ever before. In this context, many biodiesels have been used by different countries, but only a very few and non-edible type such as Jatropha, Karanja, and Mahua can be considered to be economically affordable to some developing nations like India in particular. Mahua biodiesel is one of the most promising biodiesel options among these. Mahua is one of the forest-based tree-borne non-edible oils with large production potential of about 65 million tons per annum in India [Abu-Zaid, 2004]. The kernel of the Mahua fruit contains about 55% oil, but the oil yield is 33–36% by small expeller. The excluded block is relevant to recover the residual oil. As Mahua grows mainly in jungle area, and also in waste and uncultivated land, its cultivation would not produce any impact on food production but would in long way improve the environmental condition by massive afore station. Mahua oil is an underutilized nonedible vegetable oil, which is available in large quantities in India. Many experimental studies of biodiesel as a diesel substitute have been reported in the survey. Yet, experimental study of effects of Mahua biodiesel on diesel engine is rarely appeared. The major properties of Mahua biodiesel include calorific value, diesel index, flash point, fire point, cloud point, pour point, specific gravity, and kinematic viscosity. The various physicochemical properties of diesel and Mahua biodiesel are measured and listed in Table 1 for comparison. It can be noted that the calorific value of Mahua biodiesel is less than 3% of that diesel [Adebowale and Adedire, 2006], [Agarwal et al, 2009], [Bobade and Khyade, 2012], [Kadota and Yamasaki, 2002], [Prasad and Agrawal, 2012], [Hossain et al, 2012],[Navindgi et al 2012].This might be due to the presence of oxygen atoms in the fuel molecule of Mahua biodiesel. The specific gravity and kinematic viscosity are, respectively, 1.68% and 21.36% greater in the case of Mahua biodiesels than that for diesel. The higher specific gravity of Mahua biodiesel makes the fuel scatter narrow and its penetration deeper. The higher viscosity of Mahua biodiesel could potentially have an impact on the combustion characteristics because the high thickness affects its atomization quality slightly. The higher diesel index value of Mahua biodiesel is conducive to low engine operating noise and good starting characteristics. The pour and cloud points of Mahua biodiesel are not favorable. However, the flash and fire points of Mahua biodiesel are much higher than that of diesel, which make Mahua biodiesel safer than diesel from ignition due to accidental fuel spills during handling. It can be seen that the properties of Mahua biodiesel are found to be within the limits of biodiesel specifications of many countries. A biodiesel production, combustion, emissions and performance are reviewed. They reported that short-term engine tests using vegetable oils as fuels were very promising, but the long-term test results showed higher carbon built up, and lubricating oil contamination, resulting in engine failure. It was reported that the combustion characteristics of biodiesel are similar as diesel. The engine power output was found to be equivalent to that of diesel fuel. The potential and economic feasibility of large-scale bio energy production from Vegetable oils for national and international markets are presented. The effect of biodiesel on engine performance and emissions are reviewed and reported that with biodiesel (particularly with pure biodiesel), engine power will drop due to the loss of heating value of biodiesel. But some authors found that the power loss was lower than expected because of power recovery. The torque and power reduced by 3–6% for pure cotton seeds biodiesel compared to diesel, and they claimed that the heating value of biodiesel was less 5% than that of diesel has been found.

2.0 FATTY ACID COMPOSITION

The performance of an ester as diesel fuel depends on the chemical composition of the ester, particularly the carbon chain length and the degree of saturation and instauration of the fatty acid molecules (Knothe & Steidley, 2005). The feed stock dependent fatty acid composition (hydrocarbon chains) varies from C8 to C24for the selected biodiesel fuels (White, 1980), (Apple, 1980), (Gunstone, 1994), (Shasikant, 2005), (Vigya Kesari et al, 2010), Fatty acids that do not contain double bonds are referred to as saturated because they contain the maximum number of hydrogen atoms that a carbon molecule can hold. Fatty acids that contain one double bond are called monounsaturated (MUFA), while fatty acids that contain two or more double bonds are called polyunsaturated (PUFA). The coconut oil methyl ester (COME) consists of 91% saturated fatty acids (SFA), while the sesame seed methyl ester (SSME) consists of just 13% (Refael, 1990; Apple, 1980; Gunstone et al., 1994). The pongamia pinnata oil methyl ester (POME) has the highest percentage of MUFA (55%), and the SSME contains the highest percentage of PUFA (45%), (Raheman & Phadatare, 2004), (Knothe & Steidley, 2005).

Table 1: Comparison of properties between Mahua biodiesel and diesel

Fuel properly	Unit	Diesel	Mahua biodiesel
Kinematic viscosity at 40^oC	Cst	4.57	5.6
Specific gravity at 15^oC		0.87	0.89
Flash point	^0C	71	172
Fire point	^0C	82	181
Pour point	^0C	-16	3
Cloud point	^0C	-3	11

Diesel index		50.2	51.3
Calorific value	Kj/kg	42858	42297

Many authors investigated the effects of diesel-biodiesel blends on performance and emission characteristics in diesel engine and concluded that partial or full replacement of diesel with biodiesel is feasible. However, the experimental study of performance and emission characteristics of Mahua biodiesel on diesel engine is hardly reported. Therefore, such an attempt is made in the present work, to experimentally investigate the performance (brake thermal efficiency, brake-specific fuel consumption, and exhaust gas temperature) and emission (carbon monoxide, unburned hydrocarbon, nitrogen oxides, and smoke) parameters of Mahua biodiesel and diesel-Mahua biodiesel blends as fuel in diesel engine.

3.0 METHODOLOGY

3.1 Transesterification process

The use of vegetable oils in place of diesel fuel in conventional diesel engines requires certain variation of their properties like viscosity and density. Transesterification is the general term used to describe the important class of organic reactions, where an ester is changed into another ester through interchange of alkyl groups and is also called alcoholysis. Transesterification is a balance reaction and the transformation occurs by mixing the reactants. In the transesterification of vegetable oils, a triglyceride reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acid alkyl esters and glycerol. In the base-catalyzed process, the transesterification of vegetable oils proceeds faster than the acid catalyzed reaction. The biodiesel is obtained from Vegetable oil in the following steps:

- The Vegetable oil is heated to 100^0 C temperature and maintained for 15 minutes. It is allowed to stay for one day for removal of water.
- Sodium hydroxide (NaOH) is added to ester and stirred thoroughly to produce sodium meth oxide.
- The prepared sodium meth oxide is poured into the mixture and the mixture is heated to 550C and the whole reaction is maintained.
- After heating for one hours the oil should be poured into decanter.
- Glycerin is removed and water wash should be done with Phosphoric acid.
- After washing the neat bio diesel is heated to 100^{0}**C** to remove the traces of water.
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3.2 Determination of the properties of Diesel, Rice Bran Oil and Blends

The blending of the mixed oil with diesel by volume was first done by measuring KBO and CBO using the graduated beakers and adding to the measured diesel. The blends were then vigorously shaken in a sealed container. The blends were tested and evaluated for density, viscosity, calorific value, flash point, fire point and compared with the same properties of diesel. The above properties were determined by conducting the tests as per the Bureau of Indian Standards, and are as summarized in Table 2.

Table 2: Comparison of measured Properties of Blends of Fuels

BLENDS	Fuel Blend specification By Volume	Density kg/m^3 at 15 ^{0}C	Viscosity Cst	Flash Point, ^{o}C	Fire point, ^{o}C	Heating Value in mJ / kg	Cetane Index
HSD	100% High Speed diesel	780	3.84	50	55	43.35	48
KBO	100% KARANJA BIO DIESEL	886	4.76	146	150	36.05	54
CBO	100% COCONUT BIO DIESEL	890	5.5	56	152	38.8	55
KCBO	50% KBO + 50% CBO	888	5.4	58	151	42.1	56
KCBOD	50% KCBO 50% HSD	790	4.2	59	153	41.8	51
KBOD	50% KBO + 50% HSD	819	4.6	62	116	41.0	50
CBOD	50% CBO + 50% HSD	824	4.7	68	110	42.1	52

3.3 Experimental investigation and set up

The measured blends were kept for settling for a few hours and then the tests were conducted on the test rig to determine their operation parameters as a fuel. Experiments were conducted at injection pressure of 180 bar. The detailed specification of the engine and the test rig are tabulated in Table 3. A five gas exhaust gas analyzer was used to note exhaust emissions like CO, CO_2, O_2, NOx and HC. The schematic layout of the experimental setup is shown in Fig. 1. The experimental procedure adopted for the conduct of experiments is mentioned below:

- The engine was initially run at an injection pressure of 180 Bar, then the engine was initially started with 100% high speed oil in the fuel tank of the engine and after it operated for a few minutes at the rated rpm of 1500, without any load the initial base readings for the high speed diesel were noted. An eddy current dynamometer was used to load the engine from no load to 25 kg at an interval of 5 kg.
- The engine parameters such as fuel consumption, exhaust gas temperature, inlet and outlet coolant (water) temperature were noted automatically by the sensors of the test rig.
- Then, fully replacing the fuel and draining the fuel lines, KBO, CBO and diesel was used to obtain the readings, as described above in paragraph 1. Similarly recordings for various blends as specified in the Table 1 were thus obtained.
- Exhaust emissions were noted using a 5 gas analyzer.
- The engine was run with KBO and CBO and mixed KCBO for 24 hours continuously to check for fuel clogs, injector clogs and carbon deposits on the combustion chamber.

3.4 Experimental set up:

The experiments were conducted on a Kirloskar made TV -1 four stroke single cylinder water cooled direct inject compression ignition engine without any hardware modifications. Mixed Karanja Coconut biodiesel blends (KBD 50:50, CBD 50:50 and KCBO 50:50) and diesel was used to test a conventional engine. The engine test was conducted for various loads with constant engine speed of 1500 RPM. Performance parameters like brake power, brake specific fuel consumption, brake thermal efficiency and emissions like HC, CO, Smoke and NOx were evaluated. The engine specifications are given in the Table 3.

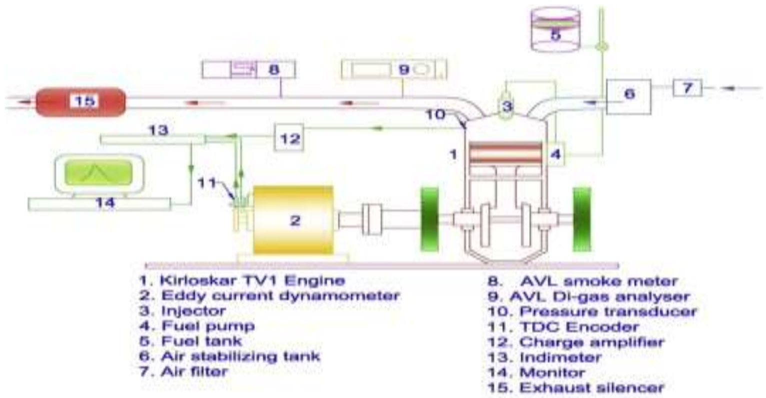

Figure 1. Experimental set up

Table 3: Engine Specifications

Engine	Kirloskar make, Model TV1, Single cylinder, 4 stroke, water cooled, stroke 110 mm, bore 87.5 mm, 661 cc with a rated power of 5.2 kW at 1500 rpm, Compression Ratio(CR) 16.5 :1
Diesel mode	3.5 kW, 1500 rpm, Injection variation:0 to 25^0 BTDC
Dynamometer Type	Eddy current, water cooled, with loading unit and connected by Propeller shaft With universal joints to the Engine
Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 litre, Type: Dual compartment, with fuel metering pipe of glass Calorimeter Type Pipe in pipe
Sensors	Piezo sensor, Crank Angle Sensor, Temperature sensor and transmitter, Load Sensor, Fuel flow transmitter, Air flow transmitter and Data acquisition device
Software	"Lab view"based "Engine soft" Engine performance analysis software
Rotameter	Engine cooling 40 to 400 LPH; Calorimeter 25to 250 LPH with a Monoblock pump

3.5 RESULTS AND DISCUSSION

The non-edible oil KBO, edible oil CBO and mixed KCBO has a higher viscosity as compared to diesel. The flash point and the fire point of KBO, CBO and KCBO at 150^0 **C**, 152^0 **C** and 151^0 **C** and fire point at150^0 **C**, 152^0 **C** and 151^0 **C** as compared to 50 and 55 for diesel. So all mixed biodiesel blends are less explosive. With a kinematic viscosity of KBO, CBO and KCBO 4.76 Cst, 5.5 Cst, and 5.4 Cst, as against the 3.84 Cst, it is less volatile and therefore it does not have storage and transport related issues that need specialized storage and handling. The calorific value of KBO, CBO and KCBO is around 85% to 88% that of diesel. Fig. 3 shows the brake thermal efficiency at various loading conditions. The Brake Thermal efficiency increases as the type of biodiesel blend changes from KBO, CBO to KBDO, CBDO and KCDO. This may be explained by the fact that increase in the better composition blend with diesel leads to faster heat release.

4.0 SPECIFIC FUEL CONSUMPTION

Specific fuel consumption is a measure of the fuel efficiency of an engine. It is the rate of fuel consumption divided by the power produced. Fig. 2 shows the variation of specific fuel consumption with load for Mixed Karanja and Coconut biodiesel blends for a conventional engine. From Fig.2 it is observed that mixed biodiesel blends KCBO and KCBDO have specific fuel consumption close to diesel. It is also observed that the specific fuel consumption of all the biodiesel blends is higher than diesel at all the loads. A higher proportion of mixed oil in the blends increases the viscosity which in turn increased specific fuel consumption due to poor atomization of the fuel.

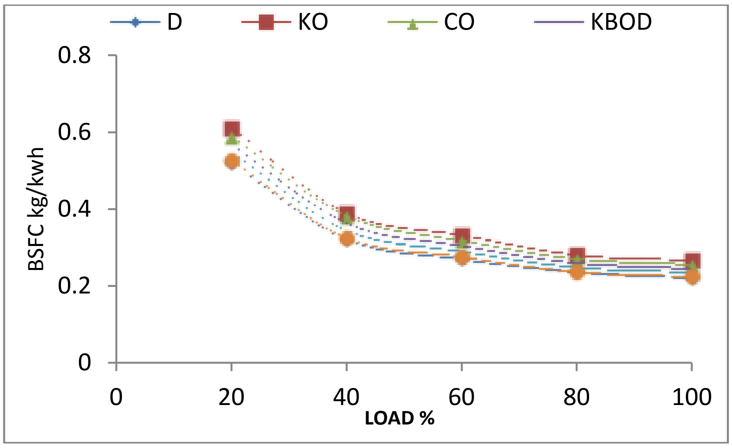

Figure 2. Variation of specific fuel consumption with load for Mixed Karanja and Coconut biodiesel

4.1 Brake thermal efficiency

Fig.3 shows the variation of Brake Thermal Efficiency with load for Mixed Karanja and Coconut biodiesel blends for a conventional engine. Brake Thermal Efficiency is defined as brake power of engine as a function of the thermal input from the fuel. From the Fig. 3 it is also observed that blends B20 and B30 have the efficiency comparatively closer to diesel. The maximum efficiency obtained for mixed biodiesel blend is 21.18% which is almost close to the efficiency of diesel. Blend B50 shows the minimum efficiency at all the loads. The decrease in brake thermal efficiency for higher blends may be due to the lower heating value and higher viscosity of blends with a higher proportion of biodiesel.

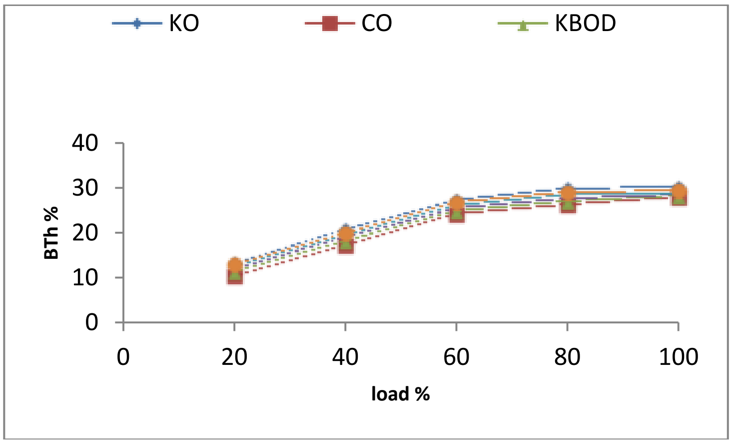

Figure 3. Variation of Brake Thermal Efficiency with Load

4.2 Engine Emissions

The engine emissions with karanja and coconut mixed biodiesel blends with diesel oil were evaluated in terms of CO, HC and NOx at different loading conditions of the engine is shown in the Figure 4. The emissions follow trends established by previous research.

4.2.1 Carbon Monoxide

Variation of CO emissions with engine loading for different fuel is compared in Figure 4. The minimum and maximum CO produced was 0.02% - 0.0.075 %, resulting in a reduction of 66% and 44 %, respectively, as compared to diesel. It is observed that the CO emissions for biodiesel and its blends are lower than for diesel fuel. These lower CO emissions of biodiesel blends may be due to their more complete oxidation as compared to diesel. Some of the CO produced during combustion of biodiesel might have converted into CO2 by taking up the extra oxygen molecules present in the biodiesel chain and thus reduced CO formation. It can be observed from Figure 4, 5 and 6 that the CO initially decreased with load and later increased sharply up to full load. This trend was observed in all the fuel blend tests.

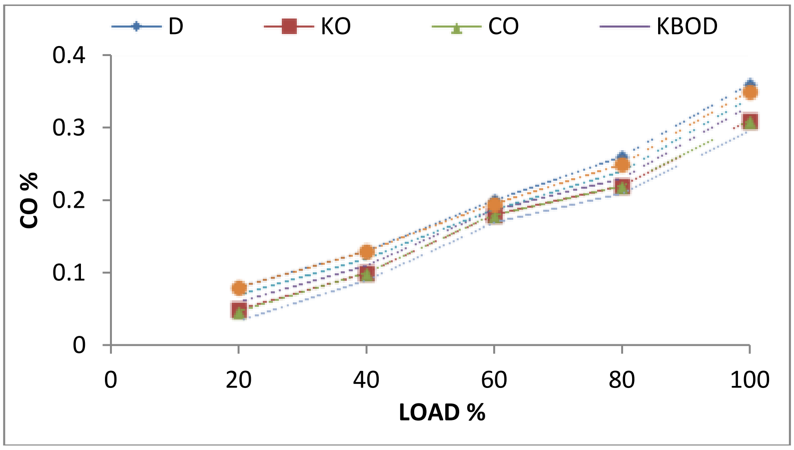

Figure 4. Variation of CO emissions with engine loading for different fuel

4.2.2 Hydrocarbons

The hydrocarbons (HC) emission trends for blends of mixed biodiesel blends oil and diesel are shown in Figure 5.

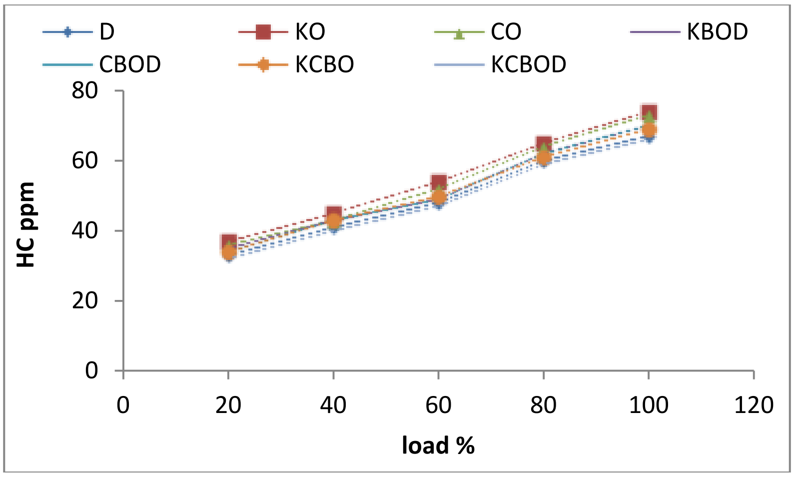

Figure 5. The hydrocarbons (HC) emission trends for blends of mixed biodiesel blends oil and diesel

Figure 5 shows the comparison of hydrocarbons with brake power for diesel, methyl ester of KBO, CBO and KCBDO oil and its blends
The reduction in HC was linear with the addition of biodiesel for the blends tested. These reductions indicate a more complete combustion of the fuel. The presence of oxygen in the fuel was thought to promote complete combustion. There is a reduction from 75 ppm to 45 ppm, resulting in a reduction of 40 %, as compared to diesel at the maximum power output.

4.2.3 Nitrogen Oxides

The variation of NOx with engine load for different fuels tested is presented in Figure 6. The nitrogen oxides emissions formed in an engine are highly dependent on combustion temperature, along with the concentration of oxygen present in combustion products. The amount of NOx produced for KBO, CBO, KCBO to KCBOD varied between 124 – 497 ppm, as compared to 120 – 439 ppm for diesel. An increasing proportion of biodiesel in the blends was found to increase NOx emissions slightly (16%), when compared with that of pure diesel. In general, the NOx concentration varies linearly with the load of the engine. As the load increases, the overall fuel-air ratio increases, resulting in an increase in the average gas temperature in the combustion chamber, and hence NOx formation, which is sensitive to temperature increase

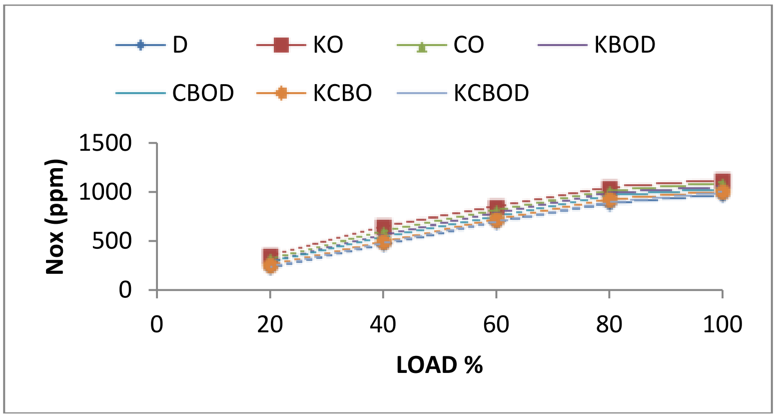

Figure 6: NOx emission at various loads for all blends

Fig. 6 shows that NOx decreases initially as the biodiesel blend shift from KBO, CBO, KCBO to KCBOD. Another observation is that NOx decreases as the coconut oil proportion increases and the NOx increases as the load increases. The vital factor that causes NOx formation is due to availability of oxygen and high combustion temperatures as coconut oil burns slowly with respect to time in combustion chamber. As the load on the engine increased so also the NOx emission increased, this is perhaps due to the increase in the combustion temperature.

CONCLUSIONS

A single step process i.e., Transesterification is carried out for the mixed Karanja and Coconut oil which contained low percentage of FFA to obtain the biodiesel. It was observed that the obtained biodiesel has very high density and viscosity which made it not possible to use in its pure form but it can be blended with diesel to obtain properties almost similar to that of diesel. The blends were prepared with biodiesel percentages of 10, 20, 30, 40 and 50 and the following conclusions were drawn from this investigation.Mixed Karanja and Coconut biodiesel satisfies the important fuel properties as per ASTM specification of biodiesel.
It is observed that for the biodiesel blends of 10% and 20% the density, fire point, flash point and calorific value were very close to that of diesel, which makes them suitable for using them as an alternative for diesel. The mixed Karanja and Coconut shows higher biodiesel yield of 72.5%.The mixed biodiesel blend B10 shows the higher brake thermal efficiency which is slightly less than that of diesel. The specific fuel consumption of mixed biodiesel blends B10 and B20 shows value closer to diesel. Mixed Karanja and Coconut biodiesel blends B10 and B20 can be used as alternative fuel in diesel engine

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