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Comparative Performance and Emission Analysis of Different Blends of Karanja Oil and Its Methyl Ester in a Twin Cylinder Diesel Engine

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Research Article

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ABSTRACT

In the present work, an experimental investigation is carried out to evaluate the performance and emission characteristics of a twin cylinder diesel engine using different blends of Karanja oil and its methyl ester with fossil diesel under different load conditions. Both the fuels are blended with diesel in proportions of 10% and 20% each by mass and studied under various load conditions in engine. The study reveals that the performance parameters are very close to that of fossil diesel. However, the brake thermal efficiency and brake specific energy consumption of 20% blend of methyl ester are better than fossil diesel under certain loads. The emission characteristics are also studied and found that all blended fuels show better emissions than pure diesel except K20 which shows higher CO emission compared to base line diesel. Again, it is observed that blending up to 20% both in neat oil as well as bio-diesel can be accepted as a suitable fuel for use in standard diesel engines without any engine modification.

INTRODUCTION

Due to higher brake thermal efficiency of diesel engine compared to gasoline engine, it is quite popular in agriculture and transport sector. Since, India being an agricultural country, huge amount of diesel fuel is consumed in agriculture sector. Due to rapid depletion of diesel fuel, its rising prices and hazards emissions from vehicles, an alternative fuel for diesel is critically important for our nation's economic growth and security. Keeping this in view, more interest is generated to do research work to find out the viable alternative fuel for diesel engine in India. Adaptation of bio-origin alternative fuels can address all the issues. Natural gas, LPG, Hydrogen and bio-derived gas such as Producer gas, Syngas etc, and liquids such as straight vegetable oil and biodiesel appear more attractive fuel in view of their eco-friendly nature [1,2]. Agarwal and Das [3] stated that the higher viscosity of plant oil creates some engine problems like poor fuel atomization which leads to poor engine performance, ring sticking, injector pump failure and injector deposit etc. Wang et al. [4] conducted experiment using vegetable oil blends with diesel and presented that lower NO_x and a small change in CO emission compared to diesel. Senthil et al. [5] carried out experiment using Jatropha oil-diesel blend and reported that EGT, HC, smoke and CO emissions are higher than base line diesel. Agarwal et al. [6] conducted experiments using preheated Karanja oil. It was observed that during the engine operation on Karanja oil both in preheated and blended form, the performance and emission parameters were found to be similar with fossil diesel for lower concentrations of blend. Whereas, for higher concentrations of blend, performance and emissions were observed to be marginally low. Deshpande [7] used blends of linseed oil and diesel to run the CI engine. Minimum smoke and maximum brake thermal efficiency were noted in this study. Nazar et al. [8] analyzed the performance of coconut oil in diesel engine in bio-diesel and neat mode. It was reported that neat coconut oil and its methyl ester can be directly used in diesel engines without any modifications. Engine performance with coconut oil methyl ester was better than with neat coconut oil. Alltiparmak et al. [9] examined the effect of blends of tall oil bio-diesel with diesel fuel as substitute fuels for diesel. It was found that the performance parameters such as power output and engine torque with tall oil biodiesel-diesel blends increased up to 5.9% and 6.1% respectively. It was also observed that

CO emissions decreased to 38.9% and NO_x emissions increased up to 30% with this fuel blends. The variation of smoke opacity was insignificant. Malhotra et al. [10] conducted experiments taking Karanja and Jatropha bio-diesel in diesel engine with and without catalytic converter. It was reported that Bio-diesel blending in diesel helps to improve the physico-chemical properties. Blends of biodiesel in diesel had shown significant benefits in terms of emissions particularly those of CO and particulate matter. Use of catalytic converter found to be helpful in reduction of CO emissions in a diesel vehicle. The use of bio-diesel which has in-built oxygen further helps in improving the efficiency of catalytic converter; there by further reduction of CO. Nabi et al. [11] investigated the exhaust emissions and combustion characteristics using neat diesel oil and diesel–biodiesel blends. From the investigation it was found that diesel-bio-diesel blends showed lower carbon monoxide (CO) and smoke emissions but higher oxides of nitrogen (NO_x) emission as compared to conventional diesel fuel. However, when EGR was applied, NO_x emission with diesel–biodiesel blends was slightly reduced as compared to diesel. Cetinkaya et al. [12] conducted experiments with objective to reduce the production cost of Biodiesel using low cost feedstock such as waste oils, used cooking oil and animal fats. They investigated the road performance of diesel engine fuelled with used cooking oil biodiesel. The results showed that the performance parameters like engine torque and brake power using used cooking oil bio-diesel were 3-5% less than those of base line diesel. Dincer [13] reported that use of biodiesel in diesel engine shows lower emission parameters such as CO, CO_2, ozone-forming hydrocarbon and particulate matter and higher NO_x emission compared to fossil diesel.

Karanja (*Pongamia pinnata*) Oil as a fuel for diesel engine

Karanja is a non-edible vegetable oil which is available plentily in northern and eastern states of India. It is a medium sized tree, yielding fruits after 4-6 years. Its production rate in India is 135,000 metric tons per year. Seeds are light brown coloured and contain 30-40% oil. This oil contains high amount of triglyceride and has a bitter taste and odour due to the presence of falconoid composition i.e. pongamiin and karanjin. Due to this bitter in taste, it is not considered for edible purpose. It is extensively used as a lubricant, medicine and pesticide. The presence of oxygen bonding in this oil reduces its calorific value as compared to diesel. It has been tested as a fuel in diesel engine and shows good thermal efficiency [14]. The constituents of this oil are 27.5% fatty oil, 19% moisture, 17.4% protein and 6.6% starch [15].

Development of Karanja oil methyl ester or bio-diesel as a fuel for diesel engine

Firstly, the crude Karanja oil was collected from the crusher mill, which is a clear, viscous and dark brown in colour. Then it is filtered with a nylon mesh cloth filter. After filtration, it is applied to degumming process in which phosphorus is removed from crude oil in a chemical process by using suitable chemical like 1% v/v phosphoric acid in necessary method. After degumming, it is applied to estrification process which is a chemical process. In this process degummed Karanja oil is mixed with 22% volume/volume (v/v) ratio methanol and 1% v/v ratio sulphuric acid. The mixture is then stirred for a period of one hour at a temperature of 65˚C. This esterified mixture is then applied to transestrification process. In this process, acid esterified Karanja oil was taken in transestrification unit in which a reagent mixture is mixed with this esterified oil. A reagent mixture was prepared with anhydrous methanol (22% v/v) and base catalyst KOH (0.5% v/v). The total mixture is then continuously stirred at a constant speed below a temperature of 65˚C (i.e. the boiling point of methanol) for about 1.5-2.0 hours. Then the stirring and heating is stopped and the mixture is allowed to settle down for about 24 hours. After settling, glycerol which is dark in colour was obtained in the lower layer and separated through separating valve. The upper layer which is Karanja methyl ester was collected separately. Then water washing of methyl ester was performed 2 - 3 times to remove extra esters and KOH. It was then heated above 65˚C to remove additional methanol to obtained pure Karanja bio-diesel.

Blend oils preparation method

In the present work, the blends used are K10, K20, B10 and B20. The blend K10 is prepared by mixing 10% Karanja oil with 90% diesel and B10 is prepared by mixing 10% Karanja bio- diesel with 90% diesel in weight basis followed by the preparation of other blends. Firstly, the sample of various concentrations of this oil and diesel were weighed and taken in a container. The mixture formed is stirred for one hour by a stirring unit. After preparation of the above blends, some of the important properties of the test fuels were carried out before use in engine. Fuel properties like density, kinematic viscosity, calorific value, flash point, fire point etc. are estimated using various ASTM methods and instruments. The fuel properties are shown in **Table 1**.

Table 1: Properties of diesel, K10, K20, B10, B20, Karanja oil & its bio-diesel.

Properties	Diesel	K10	K20	B10	B20	Karanja oil	Karanja bio-diesel
Density at 25˚C (kg/m^3)	825	832	837	827	831	925	885
Kinematic viscosity at 40˚C (cSt.)	2.76	3.7	4.36	2.92	3.88	28.69	5.12
Calorific value (MJ/kg)	42.5	41.72	40.91	42	41.5	34.7	37.5
Flash point (˚C)	73	89	109	79	81	219	161
Fire point (˚C)	103	119	135	102	109	235	189

EXPERIMENTAL SET UP AND PROCEDURE

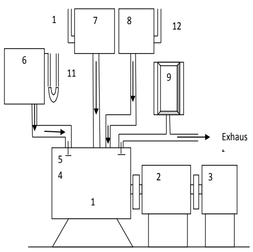
The experiment was conducted in a 4-stroke, single cylinder, water cooled, direct injection diesel engine generally used in the agriculture sector. The engine is coupled with an alternating current (AC) alternator for engine loading purpose. The detailed specification of the engine and alternator are shown in **Table 2**. The photograph of the test engine is shown in **Figure 1**. The test fuels used are fossil diesel (FD), blends of K10, K20, B10 and B20. The tests were conducted at no load, 20, 40, 60, 80 and 100% of rated load. The engine speed was maintained at 1500 rpm (rated speed) during all experiment. Initially, the engine is started with fossil diesel and then switched on to blended fuels. For all fuel samples, fuel consumption for 10 cc of oil consumption, exhaust gas temperatures, air manometer reading for air consumption were measured. The AVL make 5-gas analyzer (model Photograph of test engine setup.

Table 2: Test engine & Alternator specifications.

Make	Prakash Diesel Pvt. Ltd.
Rated horse power	14 Hp (10.44 kW)
No of cylinder	Two
No of stroke	4-stroke
Rpm	1500
Compression ratio	16.5:1
Bore diameter	114 mm
Stroke length	110 mm
Injection pressure	220 bar
Injection timing	23˚ BTDC
Alternator	10.3 kW, directly coupled to engine 15 KVA, 21 amp, 3-phase, 415 volt

Figure 1: Photograph of test engine setup.

no. AVL Digas 444) and AVL smoke meter is used to measure exhaust gas emission parameters and smoke opacity respectively. The parameters like CO, HC and CO_2 are measured by NDIR (Non-dispersive infrared) method and NO and O_2 are measured by using electro chemical method. The final readings of all the above said parameters are checked by repeating the experiments. The schematic diagram of the experimental setup is shown in **Figure 2.**



1. Engine, 2. Generator, 3. Loading unit, 4 & 5. Exhaust & inlet valve, 6. Air tank 7. Diesel tank, 8. Blended tank, 9. Exhaust gas analyzer, 10&12. Fuel burret.

Figure 2: Schematic diagram of the test engine set up.

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RESULT AND DISCUSSION

Brake specific energy consumption

Figure 3 shows the variation of the brake specific energy consumption with brake power. When two different fuels of different heating values are blended together, the fuel consumption may not be reliable, since the heating value and density of the two fuels are different. In such cases, the brake specific energy consumption (BSEC) will give more reliable value. It is observed that with increase in load up to 8 kW, BSEC decrease for all test fuels due to better combustion as a result of higher cylinder charge temperature. However, at highest load, this value decreases for all test fuels due to insufficient oxygen or fuel richness. Again, it is observed that the BSEC for B20 is slightly lower than diesel fuel. The reason being; the availability of oxygen in the Karanja methyl ester-diesel fuel blends may enables complete combustion and the negative effect of increased viscosity would not have been initiated. However, the blends K10 and K20 shows somewhat higher BSEC compared to base line diesel. This could be due to the lower calorific value and higher viscosity of K10 and K20 compared to diesel and other test fuels.

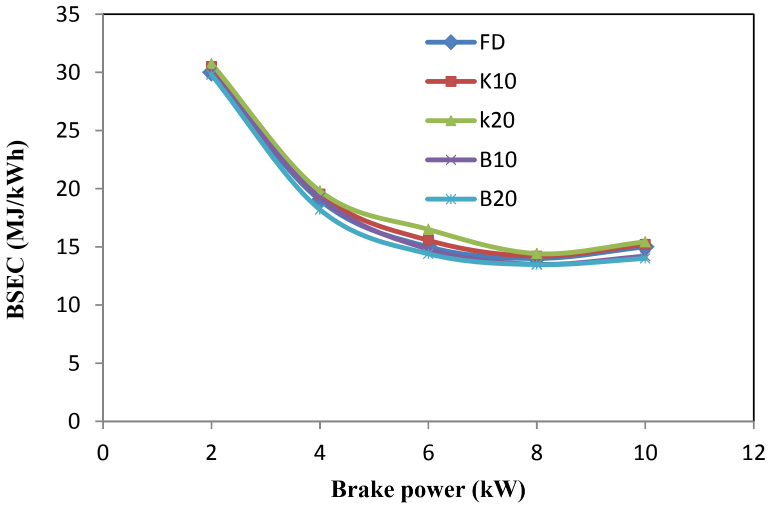

Figure 3: Variation of BSEC with brake power.

Brake Thermal Efficiency (BTE)

Figure 4 explains the variation of BTE for all test fuels under different brake power output. It is found that there is a con

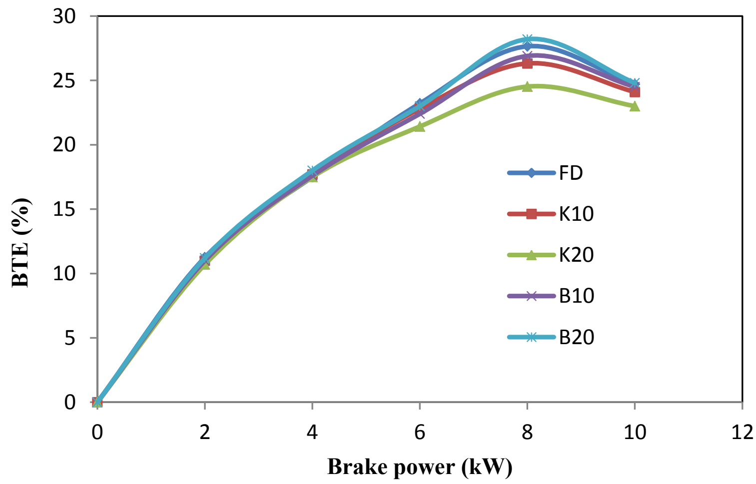

Figure 4: Variation of BTE with brake power.

tinuous increase in BTE for all test fuels up to 8 kW load. This is due to better combustion as a result of higher cylinder charge temperature. However, at highest load, the BTE decreases due to inferior combustion as a result of insufficient oxygen for all test fuels. Furthermore, the BTE for 20% blend of bio-diesel shows slightly higher value than diesel. The higher thermal efficiencies of B20 may be due to the additional lubricity as well as higher cetane number provided by the bio-diesel fuel blend. However, the blends B10, K10 and K20 show lower BTE compared to diesel. This may be due to lower calorific values and higher fuel consumption of the above fuel blends. The highest values of BTE are observed to be 28.2%, 27.65%, 26.9%, 26.32% and 24.52% for B20, FD, B10, K10 and K20 respectively, at 8 kW load.

Exhaust Gas Temperature (EGT)

The effect of EGT with brake power for all test fuels is shown in **Figure 5**. It is found that with increase in loads up to highest value, the EGT values increase for all test fuels. The reason being; with increase in loads, the energy input into the engine cylinder increases which enhances the EGT. Exhaust gas temperature is an indicative of the quality of combustion in the combustion chamber. All the blended fuels show higher EGT compared to base line diesel. This may be due to heat release occur in the later part of the power stroke as a result of higher viscosity and larger fuel droplet size of the blended fuels compared to diesel. So this may result in lower time for heat dissipation and higher exhaust gas temperatures.

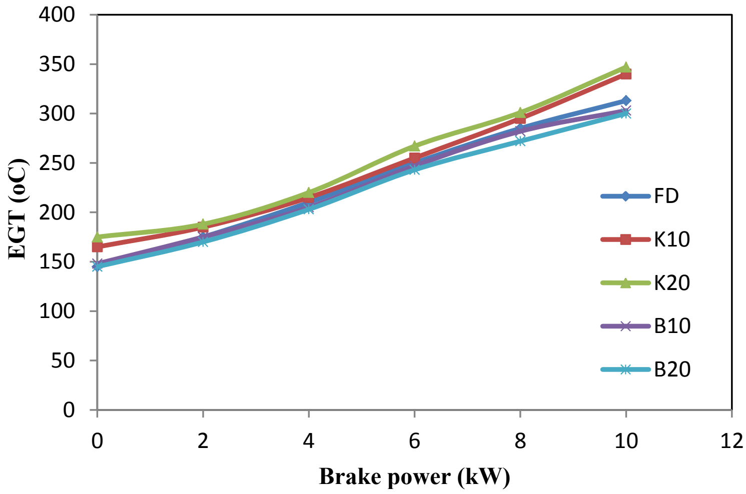

Figure 5: Variation of EGT with brake power.

Carbon monoxide emission

Figure 6 shows the variation of CO emission with different brake power for all test fuels. It is observed that with increase in loads, the CO emission decreases and at highest load it increases for all test fuels. This is due to better combustion at higher loads as a result of higher charge temperature, but at highest load, the fuel richness causes incomplete combustion. Again, CO emission for blends B 20, B10 and K10 are considerable lower than diesel. This is due to availability of oxygen in blended fuels which enhances the combustion process. The other reason may be due to lower carbon to hydrogen ratio in the bio-diesel as well as neat oil. But, for blend K20, the CO emission is higher than diesel. This is due to the negative effect of increased viscosity of blended fuel suppresses the combustion process. Hence, more CO emission compared to base line diesel.

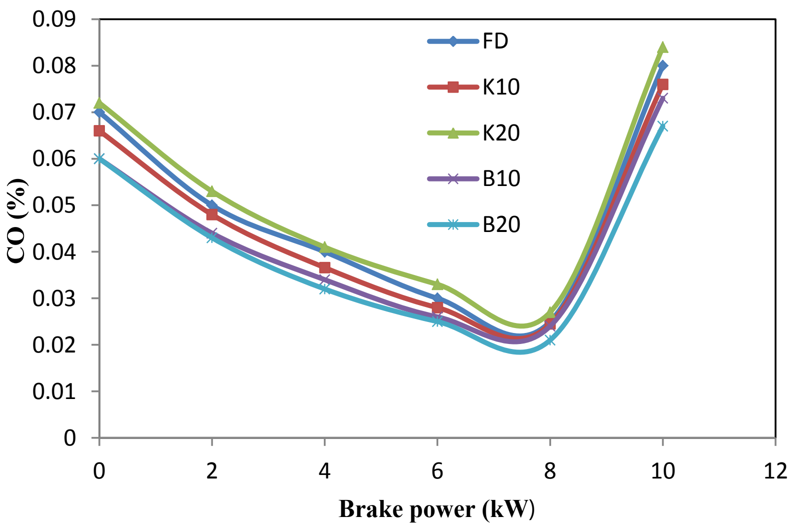

Figure 6: Variation of CO emission with brake power.

Hydrocarbon (HC) emission

Figure 7 indicates that the HC emission trends are similar with CO emission. However, a significant reduction in HC emission is achieved in case of all blended fuels compared to diesel. As the cetane number of methyl ester based fuel is higher than diesel, it exhibits a shorter delay period and results in better combustion leading to low HC emission. Also, the intrinsic oxygen contained by the vegetable oil is responsible for the reduction in HC emission.

Nitrogen Oxide (NO) emission

The variation of NO emission with brake power for all test fuels is shown in **Figure 8**. The NO emission depends upon availability of oxygen, combustion temperature and residence time. It is found that with increase in load, NO emission increases for all test fuels. The reason being; with increase in load, the energy input increases which increases the combustion temperature. Further, the NO emission decreases for all blended fuels. This could be attributed to the lower peak combustion temperature as a result of lower energy released by blended fuels. But the reduction is remarkable for the blend K20 due to larger droplet size.

Smoke opacity

Figure 9 shows the variation of smoke opacity with brake power for all test fuels. It is observed that with increase in load smoke opacity increases. This is due to inferior combustion as a result of insufficient air with increase in load. Again, all blended

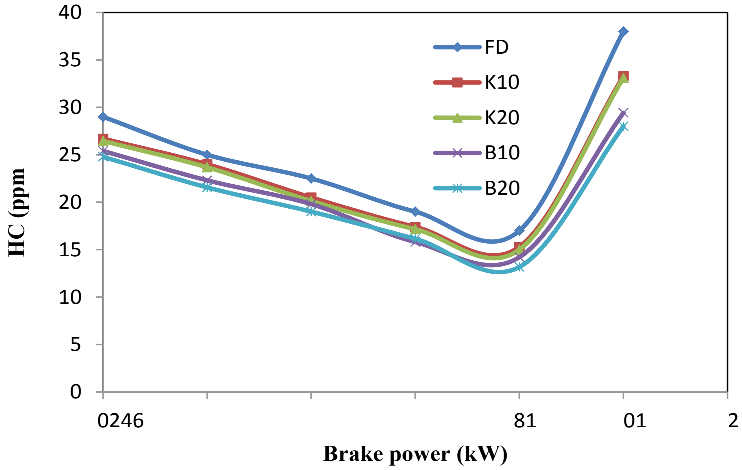

Figure 7: Variation of HC emission with brake power.

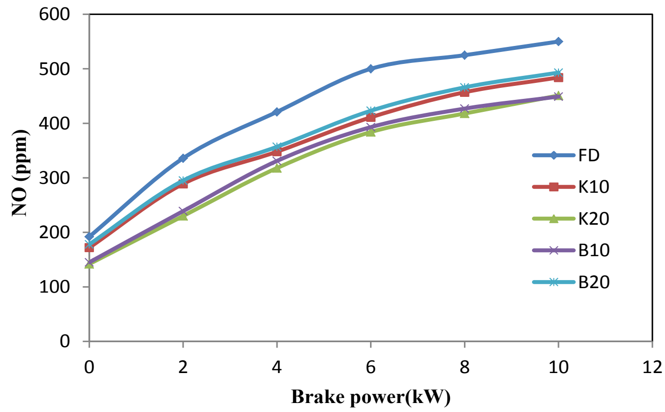

Figure 8: Variation of NO emission with brake power.

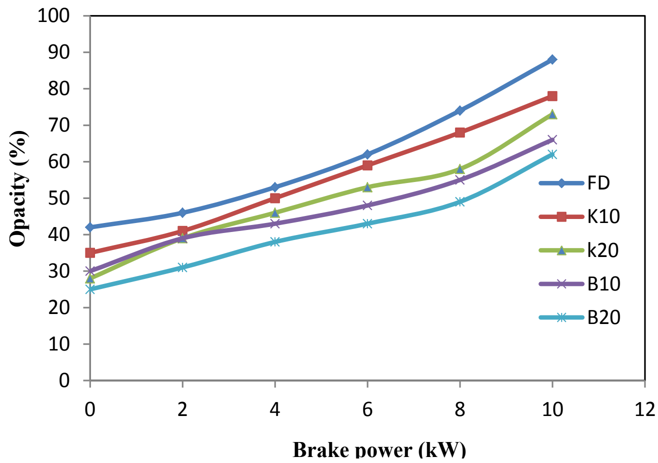

Figure 9: Variation of smoke opacity with brake power.

fuel shows lower smoke opacity compared to diesel. However, in comparison with blended fuels, B20 shows lower smoke opacity than other blends. The reason may be due to higher cetane number and presence of oxygen in molecular structure of bio-diesel which enhances the combustion.

CONCLUSIONS

- Blends of Karanja oil and its methyl ester seem to have a potential to use as alternative fuel in twin cylinder diesel engines. Blending with diesel decreases the viscosity considerably. The following results are made from the experimental study-
- The brake thermal efficiency of the engine with Karanja methyl ester-diesel blend (20%) is marginally better than with neat diesel fuel.
- Brake specific energy consumption of all blended fuels except B20 is higher than diesel at all loading conditions.
- The exhaust gas temperature in case of K10 and K20 is higher than diesel due to coarse fuel spray formation and delayed combustion. However, the EGT of B10 and B20 is marginally lower than diesel.
- The emission characteristics of all blended fuels are better than pure diesel except K20 which shows higher CO emission than base line diesel.
- Blending up to 20% both in neat oil as well as bio-diesel can be accepted as a suitable fuel for use in standard diesel engines without any engine modification.

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