Experimental Investigation of Direct Injection Compression Ignition Engine Fueled With Blends of Karanja Methyl Esters and Diesel

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\textbf{ABSTRACT}
This paper deals with the study of the potential substitution of Karanja methyl ester blends for diesel as fuel for automobiles and other industrial purposes. The objective of this study is the analysis of the performance, combustion and emission characteristics of the Karanja methyl esters and comparing with petroleum diesel. The tests were carried out on a 4.4 kW, single cylinder, direct injection, Air-cooled diesel engine. The results of investigations carried out in studying the fuel properties of Karanja methyl ester (KME) and its blend with diesel fuel from 20 to 100\% by volume and in running a diesel engine with these fuels. Engine tests have been carried out with the aim of obtaining comparative measures of Brake power, specific fuel consumption and emissions such as CO\textsubscript{2}, CO, HC, smoke density and NOx to evaluate and compute the behavior of the diesel engine running on above mentioned fuels. The reduction in exhaust emissions together with increase in brake power, brake thermal efficiency and reduction in specific fuel consumption make the blends of Karanja esterified oil (B20) a suitable alternative fuel for diesel and could help in controlling air pollution.

\textbf{Keywords}
C.I Engine, Performance, Emissions, Combustion, Karanja methyl ester.

\textbf{Introduction}
Energy is an essential and vital input for economic activity. Building a strong base of energy resources is a pre-requisite for the sustainable economic and social development of a country. Indiscriminate extraction and increased consumption of fossil fuels have led to the reduction in underground-based carbon resources. Biofuels will mitigate the vulnerability and the adverse effects of use of fossil fuels. Several developed countries have introduced policies encouraging the use of biofuels made from grains, vegetable oil or biomass to replace part of their fossil fuel use in transport in order to achieve the following goals; to prevent environmental degradation by using biofuels made from grains, vegetable oil or biomass to replace part of their fossil fuel use in transport in order to achieve the following goals; to prevent environmental degradation by using biofuels made from grains, vegetable oil or biomass to replace part of their fossil fuel use in transport in order to achieve the following goals; to prevent environmental degradation by using biofuels made from grains, vegetable oil or biomass to replace part of their fossil fuel use in transport in order to achieve the following goals; to prevent environmental degradation by using biofuels made from grains, vegetable oil or biomass to replace part of their fossil fuel use in transport in order to achieve the following goals; to prevent environmental degradation by using biofuels made from grains, vegetable oil or biomass to replace part of their fossil fuel use in transport in order to achieve the following goals; 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of the conventional diesel fuel reduces exhaust emissions such as the overall life circle of carbon dioxide (CO2), particulate matter (PM), carbon monoxide (CO), sulfur oxides (SOx), volatile organic compounds (VOCs), and unburned hydrocarbons (HC) significantly. Furthermore, since biodiesel can be said a sulfur-free fuel, it has 99% less SOx emission than the diesel fuel. However, most of the biodiesel produce 10% to 15% higher oxides of nitrogen (NOx) when fueling with 100% biodiesel for a cleaner air and cleaner environment. Aside from being renewable and biodegradable, biodiesel reduces most emissions while engine performance and fuel economy are nearly the same as the conventional fuel. Biodiesel, therefore, is a very promising alternative fuel that can lead to a cleaner environment.

**Fatty acids composition of Karanja oil**

**Transesterification**

Transesterification (alcoholysis) is the chemical reaction between triglycerides and alcohol in the presence of catalyst to produce mono-esters. The long and branched chain triglyceride molecules are transformed to mono-esters and glycerin. Transesterification process consists of a sequence of three consecutive reversible reactions. That is, conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides. The glycerides are converted into glycerol and yielding one ester molecule in each step. The properties of these esters are comparable to that of diesel. The overall transesterification reaction can be represented by the following reaction scheme.

\[
\text{Triglyceride} + R\text{OH} \rightleftharpoons \text{Diglyceride} + R\text{COOR}
\]

\[
\text{Diglyceride} + R\text{OH} \rightleftharpoons \text{Monoglyceride} + R\text{COOR}
\]

\[
\text{Monoglyceride} + R\text{OH} \rightleftharpoons \text{Glycerol} + R\text{COOR}
\]

**CH3-COOH \text{ CATALYST CH2OH R\text{COOR}}**

**CH3-COOH II \text{ CH2OH R\text{COOR}}**

**CH3-COOH III \text{ CH2OH R\text{COOR}}**

**Triglyceride Methanol Glycerol BIODIESEL**

Where R\text{I}, R\text{II}, & R\text{III} are long chain hydrocarbons.

Stoichiometrically, three moles of alcohol are required for each mole of triglyceride, but in practice a higher molar ratio is employed in order to displace the equilibrium for getting greater ester production. Though esters are the desired products of the transesterification reactions, glycerin recovery also is important due to its numerous applications in different industrial processes. Commonly used short chain alcohols are methanol, ethanol, propanol and butanol. The yield of esterification is independent of the type of alcohol used. Therefore, the eventual selection of one of these three alcohols will be based on cost and performance considerations. The methanol is used commercially because of its low price. Alkaline hydroxides are the most effective transesterification catalysts as compared to acid catalysts. Potassium hydroxide and sodium hydroxide are the commonly used alkaline catalysts. Alkaline catalyzed transesterification of vegetable oils is possible only if the acid value of oil is less than 4. Higher percentage of FFA in the oil reduces the yield of the esterification process.

**Experimental Procedure**

**Description**

Electrical swinging field dynamometer is used for measuring the brake power of the engine. This dynamometer is coupled to the engine by flexible coupling. This electrical dynamometer consists of a 5 KVA AC alternator (220V, 1500rpm) mounted on the bearings and on the rigid frame for the swinging field type loading. The output power is directly obtained by measuring the reaction torque. Reaction force (torque) is measured by using a strain gauge type load cell. A water rheostat is used to dissipate the power generated. A panel board consisting of ammeter, voltmeter switches and fuse, load cell indicator

**Procedure**

Before starting the experiments, all the equipments were calibrated according to the manufacturers’ guidelines. The engine was started by hand cranking and was allowed to warm up at no load condition. The engine was fueled with methyl ester, traditional diesel and blends containing 20 percent, 40 percent, 60 percent and 80 percent of methyl ester. For every fuel change, the fuel lines were cleaned, and the engine was left to operate undisturbed for at least 30 minutes to stabilize on the new conditions. The following measurements were made at various loads (0%, 25%, 50%, 75% and 100% of rated load).

- Fuel consumption
- Air flow rate
- Engine output
- In cylinder pressure data

Engine emissions, digital rpm readout etc, is also provided.

**Results and discussions**

**Performance Analysis**

**Specific Fuel Consumption**

![Figure 1: Comparison of Specific Fuel Consumption for KME/diesel blends](image1)

From the figure 1, it is observed that the methyl esters shows higher SFC compare to diesel as caloric value is less. It was observed that 20% blend is having comparable closer values with diesel. However SFC is higher for all the other blends. The SFC decreases with the increasing loads. It is inversly proportional to the thermal efficiency of the engine.

**Brake Thermal Efficiency**

![Figure 2: Comparison of brake thermal efficiency for KME/diesel blends](image2)
From the fig.2, it is observed that the BTE is slightly lower than the diesel for karanja methyl ester and its blends. The BTE is less for karanja methyl ester because of less calorific value.

From the fig.2, it is observed that brake thermal efficiency is low at low values of BP and is increasing with increase of BP for all blends of fuel. For a blend of 20% the brake thermal efficiency is high at low BP values when compared with other blends of fuel and is very close to diesel at high values of BP.ence at the blend of 20% of methyl ester the performance of the engine is good.

**Emission Analysis**

**CO\textsubscript{2} Emission**

From figure. 3, it is observed that CO\textsubscript{2} increases with increasing load for all the blends of Karanja methyl esters. If percentage of blends of Karanja methyl esters increases, CO\textsubscript{2} increases. The CO\textsubscript{2} emissions are directly proportional to the percentage of Karanja in the fuel blend. Since Karanja methyl esters is an oxygenated fuel, it improves the combustion efficiency and hence increases the concentration of CO\textsubscript{2} in the exhaust.

**CO Emission**

From figure.4, it is observed that CO decreases with increasing load for all the blends of Karanja methyl esters. If percentage of blends of Karanja methyl esters increases, CO reduces. The concentration of CO decreases with the increase in percentage of KME in the fuel. This may be attributed to the presence of O\textsubscript{2} in KME, which provides sufficient oxygen for the conversion of carbon monoxide (CO) to carbon dioxide (CO\textsubscript{2}). It can be observed that blending 20% KME with diesel results in a slight reduction in CO emissions when compared to that of diesel.

**HC Emission (in PPM)**

From figure.5 it is observed that hydrocarbon (HC) increases with increasing load for all the blends of Karanja methyl esters. If percentage of blends of Karanja methyl esters increases, HC reduces. The hydrocarbon emissions are inversely proportional to the percentage of KME in the fuel blend. A significant difference between KME and diesel operation can be inferred. The diesel oil operation showed the highest concentrations of HC in the exhaust at all loads. Since KME is an oxygenated fuel, it improves the combustion efficiency and hence reduces the concentration of hydrocarbon emissions (HC) in the engine exhaust. Blending 20% KME with diesel greatly reduces HC emissions especially at rated load condition.

**NOx Emission**

From figure.6, it is observed that NOx increases with increasing load for all the blends of karanja methyl esters. If percentage of blends of karanja methyl esters increases, NOx increases. It can be seen that NOx emissions increase with increase in percentage of KME in the diesel-KME fuel blend. The NOx increase for KME may be associated with the oxygen content of the KME, since the fuel oxygen may augment in supplying additional oxygen for NOx formation. Moreover, the higher value of peak cylinder temperature for KME when compared to diesel may be another reason that might explain the increase in NOx formation.

**Smoke density**

From figure.7, it is observed that smoke density increases with increasing load for all the blends of Karanja methyl esters. If percentage of blends of Karanja methyl esters increases, smoke density decreases. Because of increasing the load the fuel entering in to the cylinder increases in that proper oxygen is not allowed for that the smoke density is high for the diesel.
Combustion Analysis

Figures 8–12 show the variation of cylinder pressure with crank angle at rated power (4.4kW) for diesel, blends of 20%, 40%, 60% and 80% and 100% of KME. All the blend fuels show the same trend except for slight changes in values of pressure at various crank angles. There are three distinct regions:

Region I (From the start of combustion to 40° bTDC): The cylinder pressure is higher for methyl ester and its blends compared to diesel. In this region, the cylinder pressure increases with the increase in percentage of methyl ester in the blend. This is due to the lower ignition delay of methyl ester and its blends. The combustion starts earlier and the motion of the piston towards TDC also helps the rise in gas pressure.

Region II (40° bTDC to 100° aTDC): In this region the cylinder pressure is lower for all the blends of methyl esters compared to diesel. This is mainly because of the lower heat release of methyl esters and its blends due to their lower calorific values. Since the specific heat capacity of exhaust gas of methyl ester operated engines is high compared to diesel, it absorbs more heat energy thereby reducing the high temperature and pressure of the gas in the cylinder.

Region III (after 100° aTDC): The methyl ester and its blends show slightly higher pressure in cylinder due to the late combustion of higher fatty acid components in methyl ester.

It is also observed that the crank angle at which peak pressure occurs shifts away from TDC slightly. For example, the peak pressure at rated power (4.4kW) occurs at 8°CA aTDC for diesel, 20B KME, 40B KME, 60B KME, 80B KME and 7°CA aTDC KME.

Conclusion

The Performance, Combustion and Emissions characteristics of a 4.4 kW direct injection compression ignition engine fuelled with KME and its blends have been analyzed, and compared to the baseline diesel fuel. The results of present work are summarized as follows:

• The specific fuel consumption increases with increase in percentage of KME in the blend due to the lower calorific value of KME.
• The brake thermal efficiency decreases with increase in percentage of KME in the fuel.
• Increase in oxygen content in the KME-diesel blends as compared to diesel results in better combustion and increase in the combustion chamber temperature. This leads to increase in NOx. KME recorded higher values of NOx compared to diesel at rated load.
• Emissions of CO and HC decrease with increase in percentage of KME in the blend.
• It is also observed that smoke density increases with increasing load for all the blends of Karanja methyl esters. If percentage of blends of Karanja methyl esters increases, smoke density decreases.
• It is observed that the crank angle at which peak pressure occurs shifts away from TDC slightly. The peak pressure at
rated power (4.4kW) occurs at 8°CA aTDC for diesel (74.629 bar), 20B KME (70.215 bar), 40B KME (70.847 bar), 60B KME (70.991 bar), and KME 7°CA aTDC (69.554 bar).

References

Table 1: Composition of Karanja oil

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<tr>
<th>Sl.No.</th>
<th>Fatty acids</th>
<th>Composition (%)</th>
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<tr>
<td>1</td>
<td>Palmitic (C16:0)</td>
<td>11.6</td>
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<tr>
<td>2</td>
<td>Stearic (C18:0)</td>
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<td>3</td>
<td>Oleic (C18:1)</td>
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<td>Linoleic (C18:2)</td>
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<td>8</td>
<td>Behenic (C22:0)</td>
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<td>9</td>
<td>Lignoceric (C24:0)</td>
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Table 2: Specifications of CI Engine

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<th>Engine Type</th>
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<td>Make</td>
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<td>Model</td>
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<tr>
<td>Maximum Power</td>
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<td>Maximum Torque</td>
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