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EFFECT OF KARANJA BIODIESEL BLENDS ON THE CHARACTERISTICS OF DIESEL ENGINE

Summary. Extensive research is being conducted to create and use a wide range of alternative fuels to accommodate the world's growing energy needs. The objective of this experimental investigation was to analyze the effects of Karanja biodiesel blends on the performance, combustion, and emission characteristics of a compression ignition (CI) engine vis-a-vis neat diesel. Important physical parameters of Karanja oil were examined experimentally after transesterification and determined to be within acceptable limits. BTE of Karanja biodiesel blends was about 3-8% lower than diesel. For Karanja biodiesel blends, BSFC was about 2-9% higher than diesel but exhaust gas temperature and volumetric efficiency were lower. Emissions characteristics such as nitrogen oxides, hydrocarbons, and carbon monoxide were also analyzed for various tested fuels. Karanja biodiesel blends resulted in lesser CO and HC formation. Nonetheless, NOx emissions were around 10% greater than diesel. Peak cylinder pressure, heat release rate, and maximum rate of pressure rise versus crank angle were among the combustion characteristics parameters considered in this study. Combustion analysis revealed that for Karanja biodiesel blends heat release rate

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and peak cylinder pressure were lower than for neat diesel. Findings indicate that Karanja biodiesel can be considered a viable diesel engine fuel.

Keywords: Diesel engine, Karanja biodiesel, performance, combustion, emission

1. INTRODUCTION

Rapidly increasing worldwide demand and limited resources of fossil fuel have encouraged the scientific community to find alternative sources for depleting sources of energy. The usage of these conventional fuels is the major source of pollution and is extremely harmful to humanity today. The reduction of emissions is an important research topic since the government implements strict emissions laws. Many technologies like intake temperature management, exhaust gas recirculation and combustion chamber design have been tried to decrease emissions in diesel engines [1]. Thus, edible and non-edible oils have gained popularity as substitute fuels for CI engines, since they have properties comparable to diesel. Numerous studies have been conducted to investigate the use of biodiesel as a sustainable renewable fuel having better performance, emission and combustion parameters. Findings indicate that edible and non-edible oils might be considered viable sources in this pursuit [2]. Compression ignition (CI) engines may operate on biodiesel blends with little or no modification. A variety of edible and non-edible oil like mustard, Jatropha, Karanja, etc. can be used in the production of biodiesel. When it comes to food ingredients, the usage of edibles is a major concern. Hence, using non-edible oil to produce biodiesel is justified [3]. Over the last few years, significant research has been conducted using various biodiesel fuels, such as mustard, coconut, peanut, rape, sunflower, cotton, Jatropha, Karanja, Neem, linseed and castor in CI engines [4 - 8]. Because of its low volatility and high viscosity, straight use of these vegetable oil results in incomplete combustion, carbon deposits in combustion space, clogging injectors, and oil ring sticking. Many techniques have been used to lower their viscosity, including preheating the oil, pyrolysis, dilution, micro emulsification, and transesterification. The most popular method for converting oil to methyl ester is transesterification [9]. Studies have shown that some orange and canola based biodiesels have a lower density than standard diesel [10]. Various studies have revealed considerable reductions in particulate matter, carbon monoxide and hydrocarbons emission; however, a rise in NOx emission using blends of vegetable oils compared to mineral diesel [11-13]. Further, other studies have also revealed that a full load B20 blend of Karanja biodiesel with diesel reduces NO_X emissions by 4% [14]. Although the production of biodiesel from edibles via transesterification is easy and has become successful, while powering CI engines, caution must be exercised to avoid a food versus fuel crisis [15].

Karanja oil is widely available in India, although it is non-edible and has no substantial usage. Therefore, in this study, raw Pongamia oil is used to prepare biodiesel through the transesterification process and exposed to experimental analysis [16]. It was observed that diesel fuel with a B20 blend of Karanja oil reduces exhaust gas temperature, brake thermal efficiency, nitrogen oxide and smoke formations by 1.64, 1.82, 3.83 and 13.63%, respectively, whereas BSFC improved by up to 8.5 % [17]. The experimental result shows that usage of algal biodiesel reduced brake thermal efficiency by 2.73 %, temperature of exhaust gas by 1.6%, torque by 6.66 %, NOx by 0.5%, carbon dioxide by 6.1% and particulate matter by 60% when compared to diesel; however, the BSFC at 17.5 compression ratio increased by 6.4% [18]. Investigation revealed that mixing of up to 20% Karanja biodiesel into mineral diesel by volume resulted in no substantial variations in BTE; however, neat biodiesel had a reduced BTE due to the lower calorific value. Research indicates that Karanja biodiesel produces less CO, HC and

Particulate matter than diesel. Owing to the high percentage of O_2 in the biodiesel, NOx, as well as CO_2 emissions, were greater in Karanja biodiesel [19]. Furthermore, it was also observed that a steady flow of hydroxy gas combined with biodiesel lowered BSFC by 17.53% and improved BTE by 21.67% with respect to pure diesel at full load. Except for NOx discharge, there is a noticeable decrease in unburned HC, CO, CO_2 and particulate matter formations [20]. The experimental result suggests that diesel fuel can be replaced with a 40% Karanja blend for reduction of emissions and enhancement of CI engines performance. Subsequently, the experimental result indicates that BSFC for blends B20 and B40 was less than and equivalent to diesel, respectively, at all load conditions. All Karanja biodiesel blends emit less CO and HC but greater NO_X and CO_2 emissions than pure diesel [21]. It was also found that BTE was reduced by 3-5%, carbon dioxide and NOx emissions were higher, whereas unburned HC and CO formations were lower with Karanja biodiesel compared to diesel [22].

Karanja is a plant that grows throughout India in Southeast Asia. It is a non-edible oil kernel tree native to semi-arid regions and belongs to the Leguminosae family. Karanja exhibits excellent potential in the fields of medical sciences and biodiesel manufacturing. According to the literature, biodiesel prepared from vegetable oil could be a substitute fuel for pure diesel, wherein biodiesel fuel is mixed with diesel or preheated to reduce its viscosity. In this work, biodiesel was made using Karanja oil through the transesterification method and B5 (5% Karanja biodiesel + 95% Diesel), B10 (10% Karanja biodiesel + 90% Diesel), B20 (20% Karanja biodiesel + 80% Diesel) and B50 (50% Karanja biodiesel + 50% Diesel) blends of Karanja biodiesel were prepared. Tests were carried out at constant speed (1500 rpm) and various engine load conditions of 25, 50, 75, and 100% (full load) with blend ratios of 5, 10, 20, and 50% by volume. The performance, emission and combustion parameters of these Karanja biodiesel blends with neat diesel were investigated in this experimental study. The experimental results were then compared to the baseline result of mineral diesel.

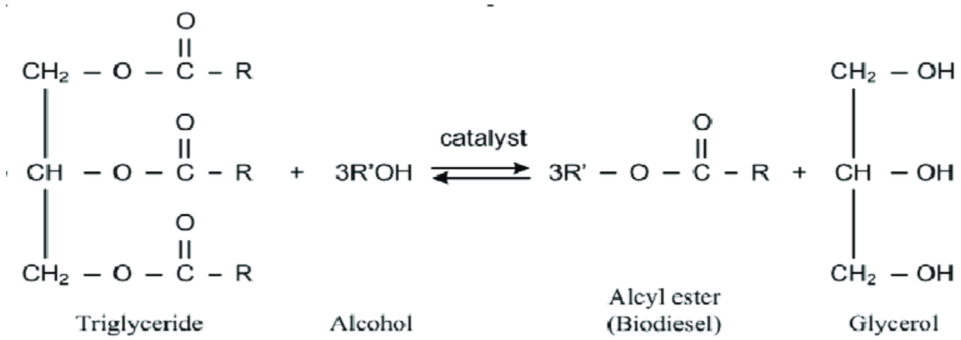
2. MATERIALS AND METHODS

2.1. Biodiesel preparation

Karanja (Pongamia Pinnata) is a moderate size tree with a height of up to 15 to 25 meters. It is a robust, drought-resistant, and salinity-tolerant plant that grows naturally throughout much of arid India. The kernel yield per Karanja tree is between 8 to 24 kg, with oil content varying from 27 to 40% [23]. Mechanical extraction was used to obtain oil from the Karanja kernel. The crude Karanja oil, in particular, has a high viscosity value. Acid esterification and transesterification methods were used to maximize biodiesel production, as crude Karanja oil contained more than 6% free fatty acids. Esterification is a chemical process that converts an FFA to a methyl ester, lowering the acid value as described by Equation 1 [24]. The accompanying reaction is expected to happen at a significant rate due to a mineral acid catalyst (H_2SO_4).

$$\underset{\text{FFA}}{RCOOH} + \underset{\text{Alcohol}}{R'OH} \rightarrow \underset{\text{Water}}{H_2O} + \underset{\text{Ester}}{RCOOR'} \tag{1}$$

Filtered and processed oil feedstock having less than 4% FFA was fed directly to the transesterification process, together with any acid esterification products, to reduce moisture content and contaminants. The catalyst KOH was dissolved in methanol before being added to the preheated (65°C) oil. The major by-products were acyl ester and glycerol as shown by Equation 2 [25]. Acyl ester and glycerol were divided into two layers upon completion of the reaction. To separate biodiesel (acyl esters) and glycerol layers, the product was allowed to stand overnight. Further, to remove traces of glycerol and any other impurities, the top biodiesel layer was detached from the bottom glycerol layer and then cleaned using warm distilled water. The important physicochemical properties of Karanja biodiesels in comparison to standard diesel fuel are presented in Table 1.



(2)

Tab. 1

Important physical properties of the tested fuels

S. No	Properties	ASTM method	Diesel	Karanja Biodiesel (KB)
1	Density (kg m^{-3})	D4052	833.0	880.00
2	Kinematic viscosity at 40°C (mm^2 s^{-1})	D445	2.7	4.85
3	Calorific value (MJ/kg)	D4809	42.5	38.91
4	Flash point (°C)	D93	65.0	168.00
5	Cetane number	D613	48.0	52.10
6	Acid value	D664	0.2	0.12

2.2. Experimental setup

All tests were carried out on a four-stroke, single-cylinder, water-cooled, constant-speed CI engine (Figure 1). All essential instruments and sensors are included in the engine setup. To collect and analyze data for the performance and combustion parameters, a data acquisition system and "ICEngineSoft" analysis software were used. The technical specifications of the CI engine used are listed in Table 2. All tested fuels were evaluated at 25, 50, 75, and 100% of rated load and constant speed (1500 rpm) using an eddy current dynamometer. The exhaust gas composition was determined using an AVL Di-Gas analyzer (model AVL Di-gas 4000 light). CO_2, CO, NO and HC emissions were measured using the exhaust gas analyzer. The resolution of all the instruments used is shown in Table 3.

Tab. 2

Technical specification of the engine

Engine Parameters	Specifications
Manufacturer	Kirloskar
Model	TV1
Engine Type	Four Stroke, CI
Number of Cylinder	One
Bore × Stroke	87.5mm × 110mm
Compression Ratio	17.5
Displacement volume	661 cc
Rated Power	5.2kW @ 1500 rpm
Orifice Diameter	20 mm
Injection timing	23˚ bTDC
Dynamometer	Water cooled, Eddy current

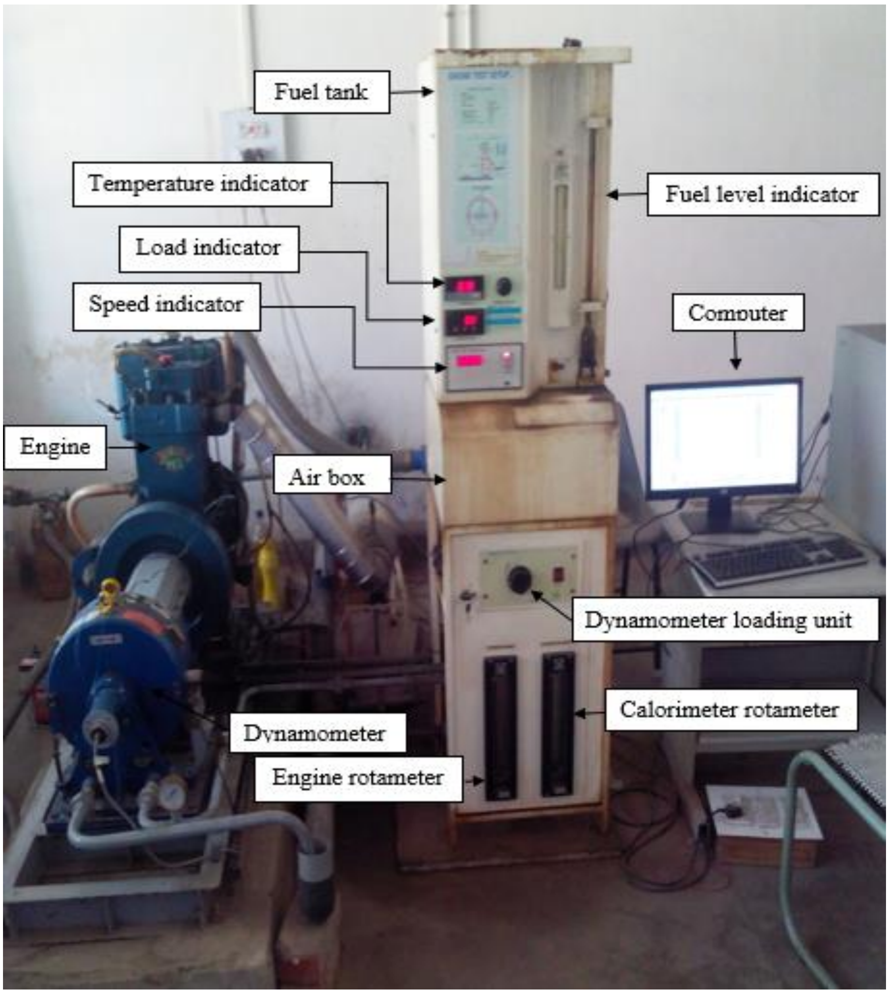


Fig. 1. Experimental research engine

Tab. 3

Measuring instruments full scale resolution

Measured parameter	Measuring instrument	Resolution
Temperature	Thermocouple RTD PT100	0.25%
Temperature	Thermocouple Type K	0.25%
Fuel flow rate	Differential pressure transducer	0.065%
Water flow rate	Rotameter	±2%
In-cylinder pressure	Piezo sensor	0.004%
Engine load	Load cell	0.025%
Air flow rate	Pressure transmitter	≤ 0.25%
CO emission	AVL Di-Gas analyzer	0.01% vol
HC emission	AVL Di-Gas analyzer	1 ppm
NOx emission	AVL Di-Gas analyzer	1 ppm

3. RESULTS AND DISCUSSION

3.1. Brake thermal efficiency (BTE)

This is a crucial parameter for determining how well a fuel's chemical energy is converted into work. The variability in brake thermal efficiency among all tested fuels to engine loads is presented in Figure 2. The investigation revealed that brake thermal efficiency improved with increased engine load. Pure diesel had maximum thermal efficiency among all tested fuels for all loading conditions. B50 had the lowest BTE of all the biodiesel blends in almost all of the loading conditions. Biodiesel blends had a lower efficiency due to the greater density, viscosity and lesser heat valve. During the atomization phase, greater viscosity of biodiesel blends causes a rise in fuel droplets, and therefore, an incorrect fuel-air mixing within the combustion chamber. Brake thermal efficiency was observed to be about 34.9, 34.1, 33.7 and 32.9%, respectively, at full load for blends B5, B10, B20 and B50 relative to 36% for pure diesel.

3.2. Brake specific fuel consumption (BSFC)

It is commonly used to compare engine efficiency with its power output. The variations in BSFC as a function of engine load for all tested fuel are presented in Figure 3. Mineral diesel had lower BSFC than Karanja biodiesel blends up to 50% for almost all load conditions. This is due to the combined effect of blends' greater density, viscosity and lesser calorific value. A higher density of Karanja biodiesel blends provides a higher rate of fuel flow for equal plunger displacement in the fuel injection pump, resulting in a higher BSFC [26]. At full load, for diesel, BSFC was observed at 0.23 kg/kWh, whereas for B5, B10, B20, and B50 it was around 0.234, 0.24, 0.243 and 0.251 kg/kWh, respectively.

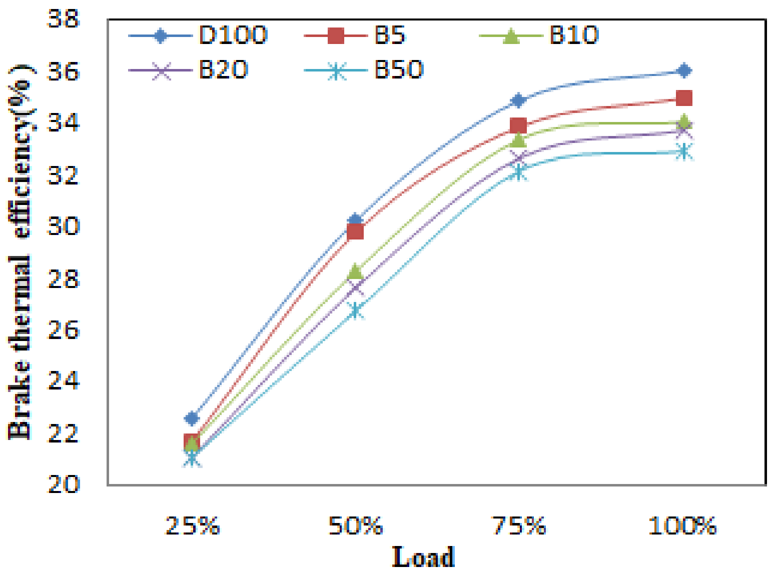


Fig. 2. Brake thermal efficiency with engine load

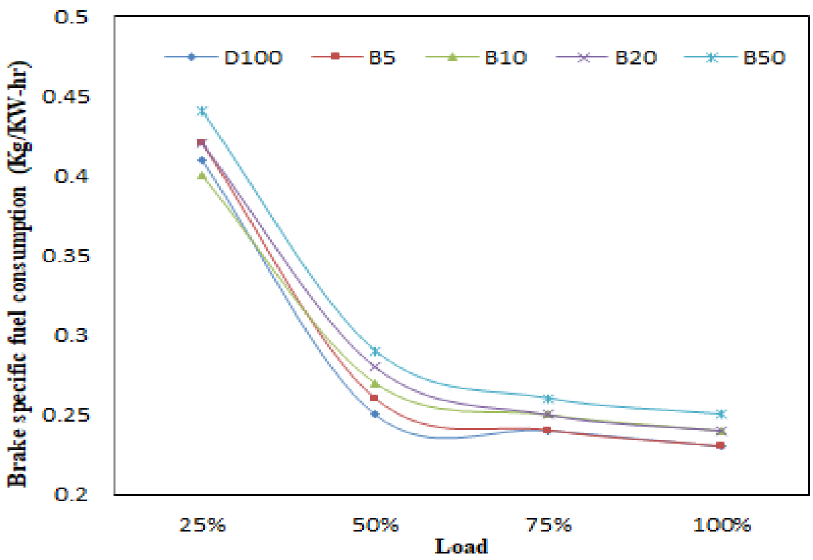


Fig. 3. Brake specific fuel consumption with engine load.

3.3. Volumetric efficiency

This important parameter indicates the engine's breathing capacity. The changes in volumetric efficiency as a function of engine load for various tested fuels are depicted in Figure 4. Karanja biodiesel blends were found to have a lower volumetric efficiency than pure diesel. The engine's inlet temperature and pressure have a direct impact on volumetric efficiency. As engine load increases, the volumetric efficiency of all tested fuels decreased slightly due to increased exhaust gas temperatures at higher engine loads. At full load, volumetric efficiencies of diesel, B5, B10, B20, and B50 were recorded as 84.53, 84.71, 84.99, 85.01, and 85.29 %, respectively.

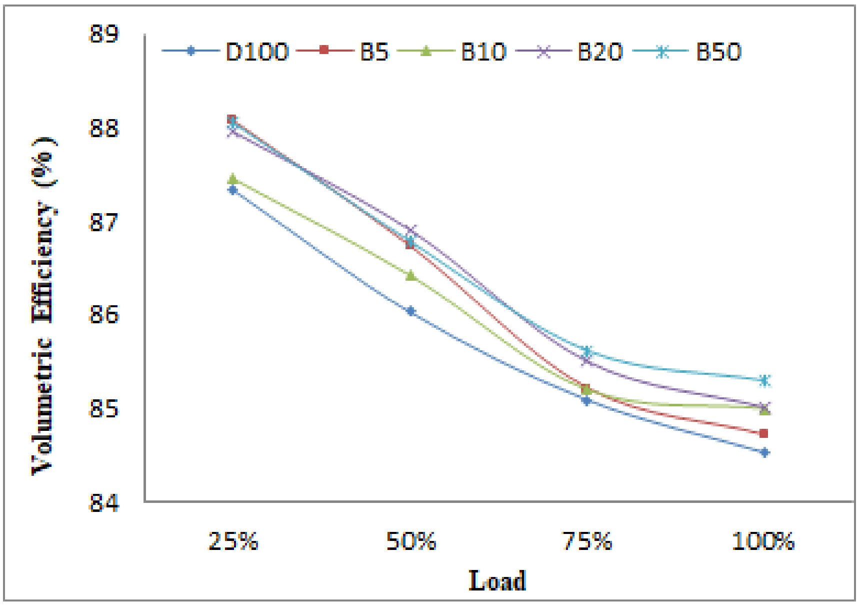


Fig. 4. Volumetric efficiency with engine load

3.4. Exhaust gas temperature (EGT)

The variations in exhaust gas temperature as a function of engine load for various tested fuels are depicted in Figure 5. The temperature of exhaust gas increases as engine load increases for all tested fuels. Rise of EGT is related to the higher fuel required to provide additional power to handle increased loads. At higher engine loads, a higher EGT indicates a larger heat loss, implying that available heat energy is not being effectively used to produce useful work. Exhaust gas temperature is controlled by the premixed combustion duration and oxygen concentration of the fuel [27]. The EGT decreased as the proportion of biodiesel in the blend increased, probably due to a change in ignition delays. The EGT for diesel, blend B5, B10, B20 and B50 were found to be 408.2, 406.9, 400, 387.4 and 353.7 K, respectively, at full load conditions.

3.5 Cylinder pressure

The variations of cylinder pressure versus crank angle for various blends at full engine load are shown in Figure 6. It was found that pure diesel shows higher cylinder peak pressure than various biodiesel blends. Findings indicate that as engine load increased, so did cylinder pressure. Maximum cylinder pressure is entirely determined by the amount of fuel injected into the combustion chamber. Karanja biodiesel blends had significantly lower cylinder pressure than pure diesel at higher load conditions. Since mineral diesel has higher volatility, it contributes to improved air-fuel mixing, resulting in a greater heat release while the piston is nearly at TDC. This also means that pure diesel has higher thermal efficiency than biodiesel blends. Karanja biodiesel blends exhibit a delayed pressure rise when compared to diesel fuel. Mineral diesel starts combustion earlier than Karanja oil blends at all engine loads [28]. For all tested fuels, peak cylinder pressures were found to be approximately close to 373.5°CA. Cylinder peak pressure was recorded as 67.95 bar for B5, 66.75 bar for B10, 62.16 bar for B20, 102.23 bar for B20, and 60.59 bar for B50 at full loads, versus 70.32 bar for diesel.

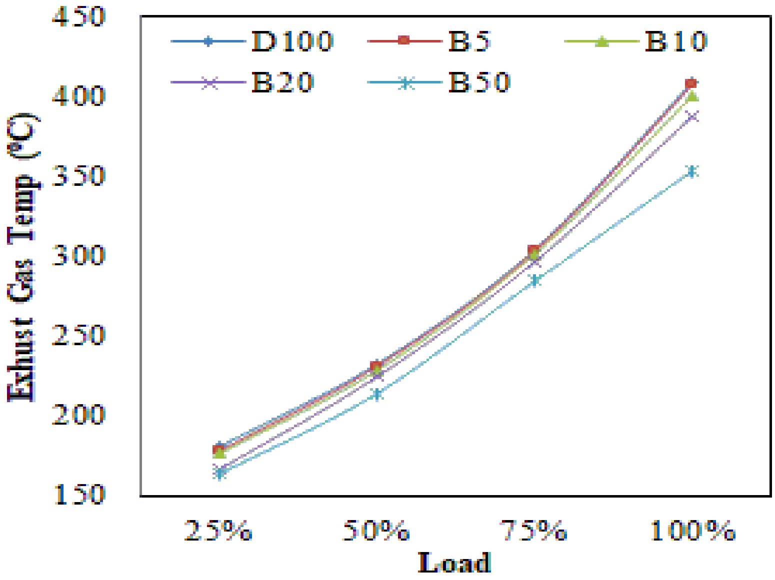


Fig. 5. Exhaust gas temperature with engine load

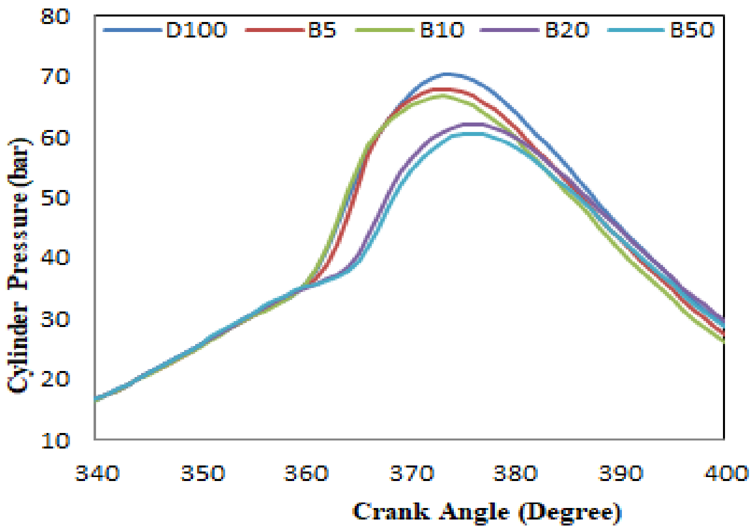


Fig. 6. Cylinder pressure with crank angle at full engine load

3.6. Maximum rate of pressure rise (MRPR)

In CI engine combustion, the rate of pressure rise is very significant as it affects the smooth progress of the combustion process. It was noted that the pressure rise rate increased as the load increased for all tested fuels. This happens because more fuel injection takes place under a higher load. However, due to the lesser calorific value of Karanja blends pressure rise was smaller for blends at a higher load compared to diesel fuel. The pressure rise rate decreases as the fraction of biodiesel in the blend rise at lower engine load. Because biodiesel molecules have a longer carbon chain structure, they have a higher boiling point and less volatility. At higher load conditions, elevated cylinder temperatures exist, allowing these less volatile fuel components to evaporate and mix correctly into the air, resulting in a higher MRPR for higher

Karanja blends [29]. High rate of pressure rise contributes to knocking, greater noise and reduced engine life, so it should be less than 8 bar/deg. for any loading condition. The variations in MRPR for all blends regarding engine load are shown in Figure 7. For neat diesel, B5, B10, B20 and B50, MRPR were reported around 8.15, 7.55, 6.41, 6.25, and 6.12 bar/deg., respectively, at full engine load. For all engine load conditions, the MRPR of Karanja biodiesel blends was less than 8 bar/deg., indicating that the combustion of the blends is smooth and does not induce knocking, thus increasing engine life.

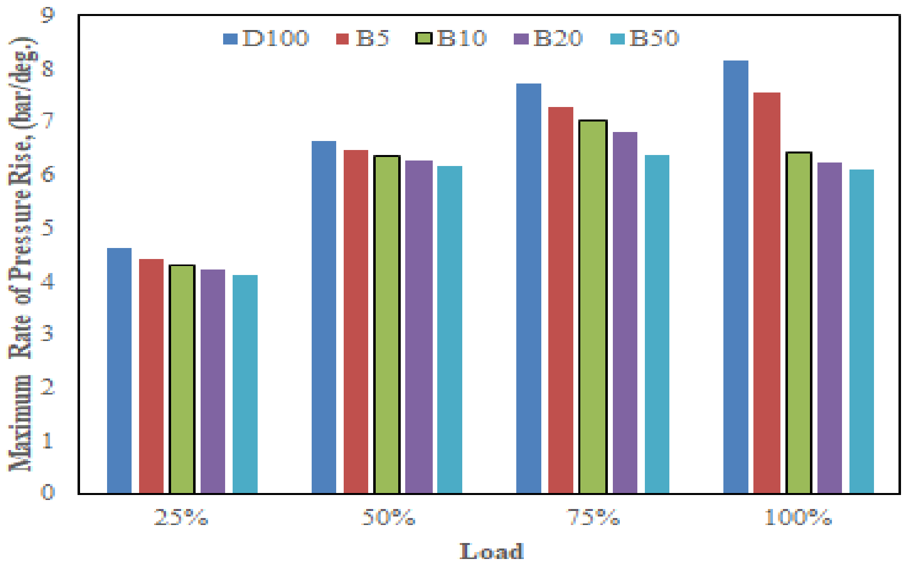


Fig. 7. Maximum rate of pressure rise with engine load

3.7. Heat release rate (HRR)

The heat release rate describes how much heat must be supplied to the cylinder to achieve the desired pressure. Figure 8 represents the change in the heat release rate versus the crank angle at full engine load. Pure diesel releases heat at a faster rate than biodiesel blends. Ignition delay period of all the blends reduces as engine load rises. Since the mixture temperature within the cylinder is higher at higher load conditions, it reduces the available time for vaporization of fuel and diffusion mixing. Premixed air-fuel mixture burns rapidly after the ignition delay stage, leading to a relatively higher HRR. Due to the air-fuel mixing process, the combustion rate in the following diffusion combustion stage was considerably slower. Because pure diesel has a lower boiling temperature and viscosity than Karanja biodiesel blends, it has a greater premixed combustion heat release at lower loads, resulting in properly atomized and mixed fuel droplets in the cylinder. Due to its relatively low volatility and high viscosity, Karanja biodiesel blends exhibit a relatively high rate of heat release during the controlled combustion stage at higher loads. Consequently, the combustion of Karanja biodiesel blends was initially slow but picks up near the end of the combustion process. The maximum heat release rates at full engine load were observed as 83.27, 82.27, 81.77 and 76.27 J/°CA for B5, B10, B20 and B50 blends, respectively, compared to 88.81 J/°CA for diesel fuel. The heat release rate $\left(\frac{dQ_n}{d\theta}\right)$ is determined by Equation 3 [13].

$$\frac{dQ_n}{d\theta} = \left[\left(\frac{\lambda}{\lambda-1} P \frac{dV}{d\theta}\right) + \left(\frac{1}{\lambda-1} P \frac{dp}{d\theta}\right) + Q_{LW}\right] \quad (3)$$

Where, λ, V and P were the specific heat, cylinder volume and pressure, respectively.

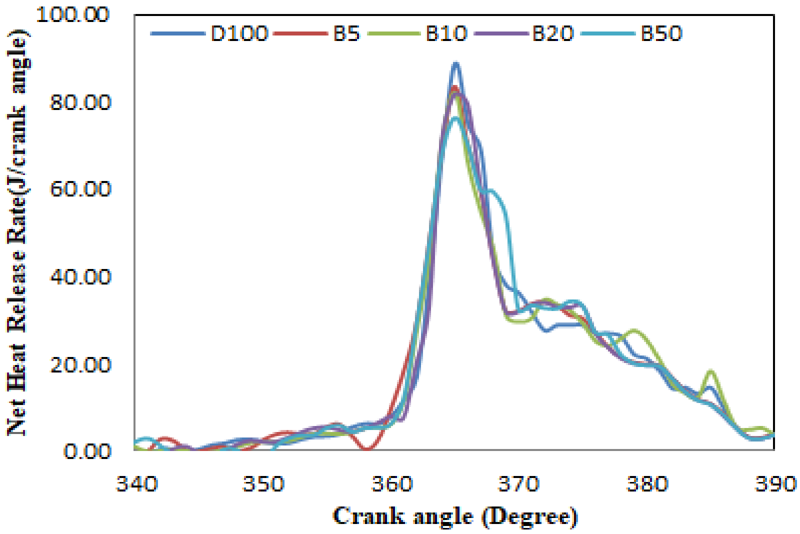


Fig. 8. Heat release rate with crank angle

3.8. Nitrogen oxides (NOx)

NOx emissions in all blends at varying engine loads are presented in Figure 9. Since the rise in combustion temperature is critical for the formation of NO_X emissions, NO_X emissions will begin to rise as engine load increases [30]. Equivalence ratio, compression ratio, cylinder temperature, oxygen content, and reaction time, all affect NO_X emission throughout the combustion process. NOx is produced in sections of the cylinder where the temperature is high, primarily during the uncontrolled stage of combustion. Diesel fuel had the lowest NOx emissions of all the test fuels. Adding biodiesel to the blends increases the oxygen concentration in the combustion chamber, resulting in increased NOx generation in Karanja biodiesel blends fuelled engines. NOx production was higher in blended biodiesel fuels than in pure diesel. The most dangerous gaseous pollutants from the engines are NOx emissions.

3.9. Carbon monoxide (CO)

The CO emissions for all test fuels at varying loads are presented in Figure 10. CO emissions rise as engine load increases for all fuels. CO emissions were higher at higher loads due to a richer mixture than at lower loads, resulting in incomplete fuel burning. Karanja blends yielded lesser CO emissions than diesel at greater load conditions, but higher biodiesel blends yielded greater CO emissions relative to pure diesel at lower engine load. Lower CO emissions were observed for Karanja blends than neat diesel at greater engine loads; however, at lesser engine loads mixed results were observed [31]. With proper air-fuel mixing, CO emissions could be decreased. Biodiesel's higher density, viscosity and evaporation energy results in improper air-fuel mixing, particularly at low load conditions. However, with higher cylinder temperature at high loads, appropriate air-fuel mixing would occur. Higher oxygen concentration of biodiesel blends helps to minimize CO formation.

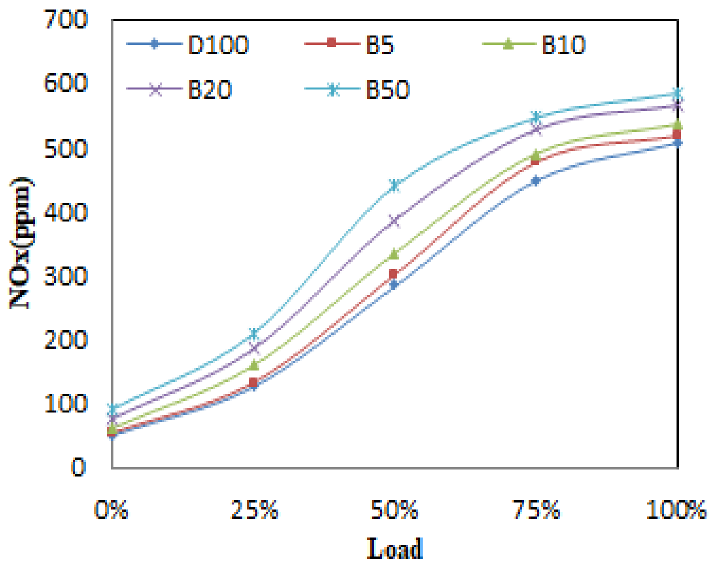


Fig. 9. NOx emission with engine load

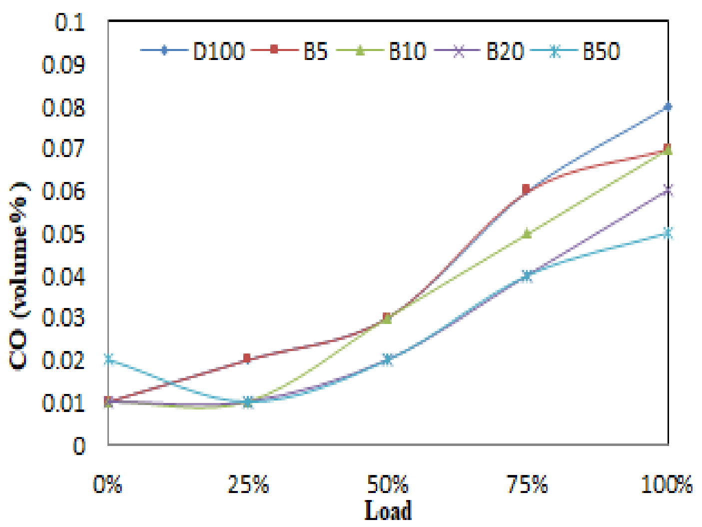


Fig. 10. Variation of CO emission with engine load

3.10. Hydrocarbons (HC)

The HC emissions for all the test fuels at varying loads are presented in Figure 11. Karanja biodiesel blends were noticed to produce fewer hydrocarbons compared to pure diesel. At lower engine loads, all tested fuels exhibited higher HC emissions, and as the load on the engine increased, the amount of HC emissions decreased. This happens because when extra fuel is fed into the cylinder under higher load conditions, there is less oxygen available for the reaction. The two sources of HC emissions in CI engines are fuel over-rich zones and over-leaning of the air-fuel mixture. At lower engine loads, over-leaning predominates, while at higher engine loads, over-rich mixing predominates [32]. HC emissions from high biodiesel blends at low load conditions were found to be comparable to pure diesel because of more fuel injection in the engine cylinders and poor biodiesel volatility, which extends to the high fuel zones. Oxygen found in biodiesel molecules contributes to reducing the HC productions at higher engine loads, while HC emissions are mainly produced due to oxygen deficiencies in fuel-rich areas.

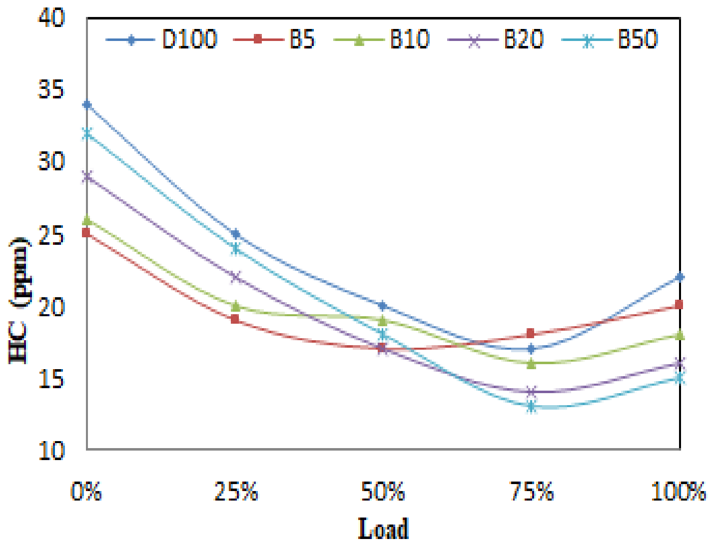


Fig. 11. HC emission with engine load

4. CONCLUSION

The characteristics of Karanja biodiesel blends were evaluated at different engine loads with a constant speed CI engine, and the findings were compared with baseline diesel fuel to explore the possibility of using Karanja biodiesel as a substitute for operating a CI engine. The following are important findings from this experimental study:

- As the amount of Karanja biodiesel in blends increased, the thermal efficiency of the CI engine slightly decreased below that of mineral diesel.
- BSFC was comparable to pure diesel for lower Karanja biodiesel blends, whereas BSFC increased as the quantity of Karanja biodiesel in blends increased.
- The EGT for the B20 blend was observed to be 5% lower than neat diesel at full engine load condition.
- Volumetric efficiency of the engine with Karanja blends was greater than neat diesel. Experimental results showed that the B50 and B20 blends, regardless of engine load, had the highest volumetric efficiency.
- The rate of pressure rise of Karanja blends was lesser than neat diesel, and MRPR for all tested fuels was lower than 8bar/deg, indicating a smooth combustion process, which reduces noise and extends engine life.
- Karanja biodiesel contains 10-12% more oxygen than diesel, which contributes to better combustion, even though its heat release rate was lower under each loading condition owing to lower calorific value and higher viscosity.
- Higher biodiesel blends lead to greater NOx emissions, especially at higher load conditions.
- Biodiesel blends generate less CO and HC emissions than mineral diesel at higher engine loads.

The optimization of the appropriate blend can be an area for future study of engine parameters.

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