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Evaluation of Straight Karanja Oil (Pongamia Pinnata) as a Compatible Fuel for Compression Ignition Engines

Kamta Prasad Tiwari, Ram Narayan Singh*

School of Energy and Environmental Studies, Devi Ahilya Vishwavidyalaya, Takshshila Campus, Khandwa Road Indore, MP, India

ABSTRACT

The increasing energy demands, depletion of traditional energy sources, and significant environmental changes have necessitated the search for alternatives to petroleum fuels. Among the available alternatives, straight vegetable oil (SVO) is a viable option due to its properties being similar to fossil diesel (FD). This study shows that the viscosity of straight Karanja oil significantly decreases and aligns with FD when heated to temperatures between 105°C and 110°C. The viscosity of Karanja oil was reduced using a specially developed coiled-type heat exchanger to recover waste heat from engine exhaust flue gas. A compression ignition (CI) engine was operated at a constant speed (1,500 rpm) under varying loads from 10% to 100% of engine rated capacity in 10% increments. While FD exhibited superior performance due to its lower viscosity, heating Karanja oil to 105°C reduced its viscosity, enhancing engine performance However, the brake thermal efficiency (BTE) was poor and brake-specific fuel consumption was higher when using heated Karanja oil compared to FD. Preheated straight Karanja oil (PSKO) showed better performance as compared to unheated straight Karanja oil (USKO). The highest BTE for all tested fuels was recorded at 80% of the engine's rated load. Although NOx concentration was lower in USKO than FD, however, when PSKO was used, NOx emissions started increasing while CO emissions were decreased. the best diesel engine performance and the lowest emission levels were achieved with Karanja oil heated at 105°C.

Keywords: *Preheated Straight Karanja Oil, Waste Heat Recovery, Heat Exchanger, Diesel Engine, Brake Thermal Efficiency*

1. Introduction

Ecological concerns, declination of fossil fuel reserves, escalating industrialization and transformation of the global world have led researchers worldwide to seek alternatives from renewable resources. Studies suggest that pure vegetable oils could serve as a viable commercial option that could reduce the dependence on fossil fuels. In India, farmers mostly use diesel engine (DE) for agricultural work. Vegetable oils have unique characteristics, and their properties (Table 1) are comparable to fossil diesel, bio-degradable, locally and readily available in nature [1]. However, instead of the unique feature to allow use of neat vegetable oil (VO) in the engine, it has certain limitations. Straight vegetable oil (SVO) causes carbon depositions in the combustion chamber, piston top, incomplete burning, and other problems, like blockage of fuel injectors, sticks piston rings, and etc. [1-7]. To o bvercome these problems, a number of methods have been tried; however, preheating the unprocessed VO prior to injection is best suited to decrease the viscosity [7-11]. The higher energy requirement and response time make it unpopular to proven technique like transesterification. Apart from that, few studies found higher NOx emissions than fossil diesel (FD) [1-8, 12]. Although, the use of SVOs in DE, creates various operational issues that affect the performance and emission level of the engine [1-10, 13]. However, these problems have significantly appeared during the engine's long-run operation rather than the short-run operation.

SVO not only reduces dependency on crude oil but also helps to decrease the effects of climate change by storing carbon [14-16]. Edrisi, et al. [17] reported that a 5-year-old Karanja SVO not only reduces dependency of crude oil but also helps to reduce the effect of climate change by storing carbon [14-16]. Moreover, this 5-year-old Karanja (Pongamia pinnata) plantation has a carbon sequestration capacity of around 49.28 tonnes per hectare [17]. A study [18] estimates that there are around 9.1 million Karanja trees in India, which collectively sequester 2.53 metric tons of CO_2 (carbon dioxide equivalent) across the country [15, 16].

Table 1: Thermo- Physical properties of Non-Edible VOs

Properties	Value in Range
Kinematic Viscosity [cSt at 38°C]	32.6-76.4
Density [kg/m^3]	870-970
Flash Point[°C]	110-330
Cloud Point [°C]	−11.6 to 23
Pour Point [°C]	- 40.0 to 31
Carbon Residue [% w/w]	0.22-0.64
Free Fatty Acid [%w/w]	1–5%
Calorific Value [MJ/kg]	34–42.15
Cetane number	32– 59.5

Because of the higher viscosity and lower volatility, unheated straight Karanja oil (USKO) has very poor brake thermal efficiency (BTE) and higher brake-specific fuel consumption (BSFC) as compared to FD. To improve the performance and emission behavior, many researchers [19-23] incorporated the waste heat recovery based heat exchanger to preheat the straight Karanja oil for lowering its viscosity. With the application of preheated Karanja oil (70 to 130°C), the BTE and exhaust gas temperature (EGT) increased with the load. Regardless of loads, EGT was repeatedly noted to be higher than FD. It may be due to better spray and rich oxygen content in VO [19, 22-25]. It is well known that SVO is more beneficial than VO based biodiesel because the production cost and energy consumption of biodiesel is higher [22, 23]. Preheated straight Karanja oil (PSKO) bleached fewer CO_2 emissions

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*Corresponding author: rnsingh.seema@gmail.com

Fig. 1: Karanja (Pongamia pinnata) tree, flowering, fruiting, seeds and filtered oil

than USKO and FD. The CO emissions from USKO and PSKO were nearly similar to DF and increased with the load. Overall, the emissions characteristics, i.e., HC, NO, CO_2, and CO of PSKO were lower than that of FD [22, 23]. Acharya et al. [19] also reported higher BSFC, EGT and lower BTE for PSKO compared to FD at all loads. Additionally, they found no appreciable difference between PSKO and FD in terms of diesel engine performance.

This Article examines the operational and emission characteristics of CI engine fueled with raw, unblended unprocessed (or straight) Karanja oil at various fuel inlet temperatures and loads.

2. Materials and Methods

The study was carried out at the School of Energy and Environmental Studies (SEES), Devi Ahilya Vishwavidayala, Indore (MP) India. Considering the availability in Indore (Central India) region Karanja oil was chosen as the SVO.

2.1 *Test Fuel: Straight Karanja Oil*

Straight Karanja (Pongamia pinnata) oil was bought from Indore agro-vendors. For the long-term trials, more quantity of oil was needed, thus, seeds of Karanja were purchased from sellers in neighborhood markets in Indore and different areas of Chhattisgarh, India. A mechanical expeller was used to extract the oil from Karanja seeds. FD was purchased from the open markets of Indore. Figure 1 shows the tree, flowering, fruiting, and seeds of Karanja tree.

2.2 *Characterization of Straight Karanja Oil*

The Thermo-physical properties of the Karanja SVO and FD were performed as per the ASTM standard (Table 2). Redwood viscometer, Hydrometer, Pensky-Martin's apparatus, and a Bomb calorimeter were used to determine the viscosity, density, flash point, fire point, cloud point, pour point, and calorific value Karanja of respectively. Thermo-physical properties of the straight Karanja oil were compared with FD. It was observed that Karanja oil has greater density, viscosity, flash point and fire point compared to FD; however, it has a lower gross heating value. Since the viscosity is the function of temperature, thus to know the effect of temperature on the viscosity of Karanja oil, it was heated at different temperatures (40 to 140℃) (Table 3).

Table 2: Thermo-physical property of straight Karanja oil and FD (Diesel)

Property	Karanja oil	Diesel fuel	ASTM
Kinematic viscosity @ 40 ℃ [cSt]	34.5	2.9	D 445
Density @ 40 ℃ [kg/m^3]	933	866	D 1298
Flash Point [℃]	224	72	D 93
Fire Point [℃]	256	80	D 93
Cloud Point [℃]	4.2	-3	D 97
Pour Point [℃]	-2.1	-18	D 97
Calorific Value [kJ/kg]	38900	43800	D 240

Table 3: Effect of temperature on kinematic viscosity of Karanja oil

Temperature [℃]	Kinematic viscosity [cSt]
40	34.5
50	26
60	17
70	12.87
80	9.91
90	7.1
100	5.5
105	4.8
110	4.1
120	3.91
130	3.5
140	3.2

2.3 *Design and Development of Waste Heat Recovery Heat Exchanger*

In order to improve the engine performance and emission level, preheating of Karanja oil before injection is essential. In accordance with the temperature of the exhaust gas and its intended use, a variety of heat exchanger (HE) can be utilized to recover heat.

A diesel engine loses over 30% of its input energy through exhaust gas [26]. To utilize the exhaust gas waste heat, a helical coil HE was designed and developed. As helical coil HE has some advantage over other HE [26 -29].

To increase the rate of heat transfer, free flow of viscous fuel within the tube, avoiding leakage, cracks after heating, the inner diameter of copper coil tube (d) was considered as 8 mm, considering the thermo-physical property of Karanja oil, space available in the engine test rig to locate the HE and material constraint. Literatures [27-30] indicate that the inner diameter of a copper coil tube should be in the range of 6-10 mm. The outer diameter of copper coil tube (do), helix diameter (D), outer and inner diameter of HE shell and pitch (space between each helix turn) (p) were kept as10 mm, 120 mm, 160 mm, 140 mm, and 20 mm respectively [27-30].

The density of USKO was taken as 933 kg/m3 (refer to Table 2) for designing of heat exchanger. The preheating temperature of Karanja oil was considered as 105℃ (Table 3). The kinematic viscosity (υ = 4.8 cSt at 105℃), EGT and NOx emission level found comparable with DF at preheating temperature of 105℃ [19, 31]. Additionally, literature also reported that the fuel preheating temperature of vegetable oils above 105℃, EGT, and NOx significantly increased, and below 105℃, Karanja oil gets significantly thicker [19, 22-21, 24, 31]. Considering the above, the number of turns of the helical coil (N) and the length of the coil needed to make N turns (L) are calculated.

The cross sectional area of the heating helical coil (A_c), and mass flow rate of vegetable oil flowing into the helical coil ($\dot{m}$) were estimated using relation [29]

$$A_c = \pi d^2/4 \tag{1}$$

and

$$\dot{m} = M/\rho \tag{2}$$

Here, ‘M’ is the specific fuel consumption of fuel in kg/h and ρ is the density in kg/ $m^3$of USKO (Table 2). The velocity of vegetable oil (s) was determined as per the relation suggested by Raheman and Pradhan [29] ($s = m/A_c$).

Considering the non-linear flow of vegetable oil inside the helical coil, the Reynolds and dynamic viscosity (μ) were calculated using the relation in the following equations 3 and 4 respectively [27-30]

$$N_{Re} = \rho s d/\mu \tag{3}$$

and

$$\mu = \upsilon \text{ x } \rho \tag{4}$$

Similarly, the Prandtl number for vegetable oil was calculated using equation following equation 5 [27-28, 32]

$$N_{Pr} = \mu \text{ x } C_p/ k \tag{5}$$

Here, k and C_p are thermal conductivity (0.024 W/m/K) and heat capacity of engine exhaust gas (1.15 kJ/kg/ K) [29].

Similarly, the coefficient of heat transfer was estimated as per the empirical relation suggested by Alimoradi and Farzad [27-28], Raheman and Pradhan [29] and Cengel and Ghajar [33].

$$h_i = 0.6\, {N_{Re}}^{0.5}\, {N_{Pr}}^{0.31}\, k / d \tag{6}$$

(for the value of N_{Re} < 10,000)

and

$$h_{ic} = h_i[1+ 3.5(d/D)] \tag{7}$$

The coefficient of heat transfer inner side of the coiled tube based on an outside diameter (h_{io}) was estimated through [29, 33]

$$h_{io} = h_i(d/d_o) \tag{8}$$

The length of the coil needed to make N turns (L), the volume occupied by the coil (V_c) and the volume of the HE shell were evaluated by relation (V_a), and were calculated using equations 9, 10 and 11 [27-29]

$$L=\sqrt{(2\pi \text{ x } D/2)^2 + p^2} \text{ x } N \tag{9}$$

$$V_c = \frac{\pi}{4} \text{ x } d_o^2 \text{ x } L \tag{10}$$

and

$$V_a = \frac{\pi}{4} \text{ x } C^2 \text{ x } p \text{ x } N \tag{11}$$

The Volume available for the flow of exhaust gas in the annulus ($V_f = V_a - V_c$) and the Mass velocity of exhaust gas (v_m) = $\frac{M}{\frac{\pi}{4} \text{ x } (C^2 - d_o)}$ were determined considering mass flow rate of exhaust gas ($\dot{M}$) as 109.278 kg/h [27,29].

Shell-side equivalent diameter (D_e) is also calculated through the following relation equation suggested by Yousefi et al. [26] and Alimoradi and Farzad [27-28]

$$D_e = \frac{4 \text{ x } V_f}{(\pi \text{ x } 10 \text{ x } L)} \tag{12}$$

For calculating the Reynolds number and Prandtl number of the gas equations 13 and 14 were used

$$N_{Re} = D_e \text{ x } v_m / \mu_{ex} \tag{13}$$

and

$$N_{Pr} = \mu_{ex} \text{ x } C_{pe}/ k \tag{14}$$

The viscosity of exhaust gas flow (μ_{ex}= 0.0828 kg/m/h at temperature T = 400 K) [34] heat capacity of gas C_{pe} = 1.15 kJ/ kg/ K, Viscosity of gas, μ_{ex} = 0.230 x10^{-4} kg/m/s and thermal conductivity of gas, k = 0.024 W/m/K were used for calculation of Reynolds number and Prandtl number [26-28].

The heat transfer coefficient outside the coil (h_o) was estimated by equation 15 [27-30].

$$h_o = 0.36\, {N_{Re}}^{0.55}\, {N_{Pr}}^{0.33}\, k/D_e \text{ when } N_{Re}>10{,}000 \tag{15}$$

For the determination of the overall heat transfer coefficient of the heat exchanger, the relation given in the equation 16 was used [29, 33].

$$\frac{1}{U} = \frac{1}{h_o} + \frac{1}{h_{io}} + \frac{z}{k_c} + R_a + R_t \qquad (16)$$

Here coil wall thickness (z) was consider as 2 mm**,** Shell-side fouling factor, R_a = 0.00176 m^2 K/W**,** Tube-side fouling factor, R_t = 0.00053 m^2 K/W, Thermal conductivity of the copper coil, k_c = 401W/m/K was used to calculate above parameters [29, 33, 35].

2.3.1 *Determination of Required Area of Coil (A)*

The following parameters were assumed for designing the HE. It includes the intake temperature of exhaust gas (T_1) = 210℃, exit temperature of exhaust gas (T_2) =195℃, intake temperature of Karanja oil (t_1) = 30℃, and exit temperature of Karanja oil (t_2) =105℃ (Table.1.3). Raheman and Pradhan [29], Cengel and Ghajar [33] suggested the relation of the Log mean temperature difference (LMTD) Δ_{tm} [26-29,33].

$$\Delta_{tm} = \frac{(T1-t1)-(T2-t2)}{ln\frac{(T1-t1)}{(T2-t2)}} \qquad (17)$$

The Total Heat loads (Q) and required area (A) were estimated using the following equations 18 and 19 [29, 33].

$$Q = MC_p\Delta_t \qquad (18)$$

and

$$A = \frac{Q}{U\Delta_{tm}} \qquad (19)$$

However, for determination of the Theoretical Number of Turns of the Helical Coil (N) and the Horizontal Length (Y) of the HE Shell were estimated by equations 20 and 21 of the HE Shell which contains 'N' Turns of the Helical Coil [29]

$$N = \frac{A}{\pi d(\frac{L}{N})} \qquad (20)$$

and

$$Y = N\,(p+d) \qquad (21)$$

3. Experimental Setup and Procedure

A Kirloskar make diesel engine as per specification given in Table 4 was used for experimentation. The Experiment was performed at the School of Energy and Environmental Studies, Devi Ahilya Vishwavidayala, Indore, India. It was instrumented as shown Figure 2. Belt brake dynamometer was used for loading the engine.

Table 4. Engine Specifications

Particulars	Engine Specifications
Make and Model	Kirlosker AV1
Rated Output	3.7 kW /5 hp; constant speed (1500±5% rpm)
Type of Engine	Vertical, Direct Injection, VCR, naturally aspirated and manually started CI engine.
Number of Cylinder and Stroke	Single Cylinder and Four Strokes
Compression Ratio	Variable compression Ratio 12:1 to 20:1
Bore and Stroke	80 mm, 110 mm
Type of Loading and Cooling	Rope Brake Dynamometer, Water Cooled
Injection Timing	23 Degree bTDC
Injection Pressure	210 Bar
Torque at Full Load (kN-m)	0.024(2.387) @ 1500 rpm
Specific Fuel Consumption (gm/kW.h)	245

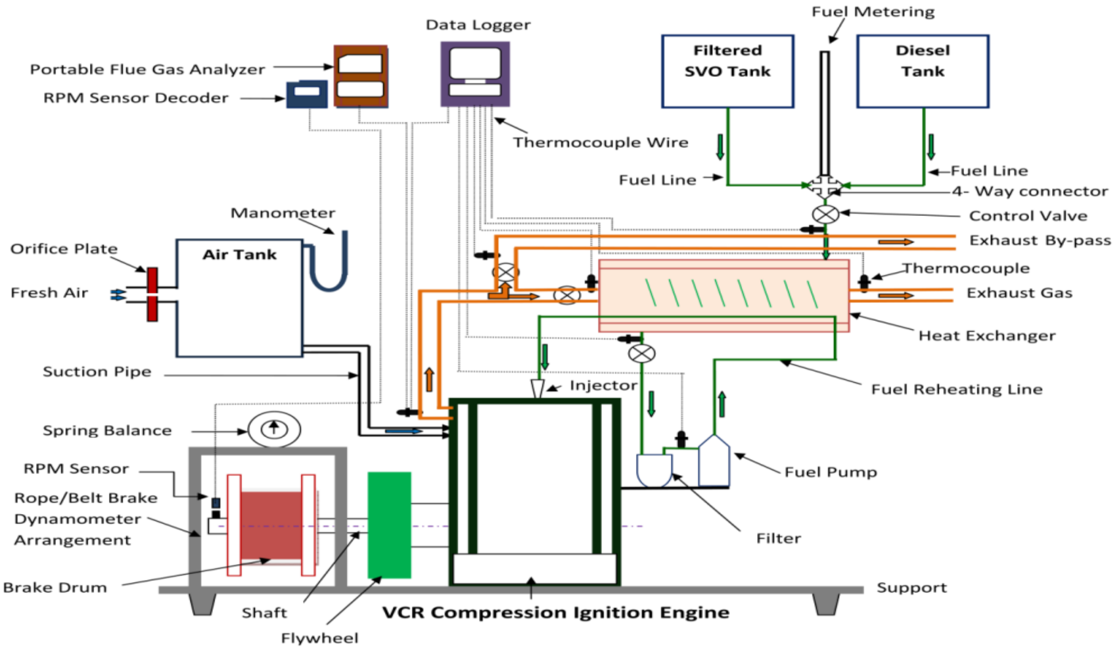

Fig. 2 Experimental setup of SVO based 4 stroke VCR diesel engine with modified fuel injection line

Separate fuel tanks, one for FD and another for Karanaj oil) with modified fuel supply lines (gravity-fed) were incorporated with the setup. A calibrated burette was equipped to measure the rate of fuel consumption. To know the temperature of Karanja oil and engine exhaust gas J and K-type thermocouples along a 16-channel data logger were used. A flue gas analyzer (TESTO-340) was used to record the emissions data. The engine performance parameters like fuel consumption rate, operating efficiency at different loads, engine exhaust temperature, and exhaust gas emissions were evaluated [36].

The fuel injection system was linked to a three-hole pumped injection system with a 0.25 mm needle lift and a 200–240 bar nozzle opening pressure. Cooling water was supplied from the main tank through gravity to cool the engine. Finally, a copper tube with an inner and outer diameter of 8 mm and 10 mm and a spiral coil with a length of 220 mm was designed and developed using mild steel. The engine was always started and closed with FD, and later it was shifted to Karanja oil (once Karanja oil gained temperature up to 65°C) by the four-way valve.

Karanja oil was heated with a designed and developed shell and helical coiled heat exchanger, which was attached to the exhaust line. Two gate valves (one valve for regulation of flow rate to HE and the other for bypassing the exhaust gas) were installed in the exhaust gas line prior to the HE to regulate the temperature (40-120°C) of the Karanja oil. To maintain the temperature of Karanja oil, the injection line is passed from the heat exchanger. Before beginning the test run, the engine oil sump was filled with fresh lubricating oil (20 W 40) and filtered Karanja oil was filled in a separate fuel tank. The performance of the engine was evaluated at ten different engine-rated loads (varied from 0% to 100%) with FD, USKO, and PSKO as per the specifications of the engine supplier (Table 4).

4. Results and Discussion

4.1 Fuel Properties

Thermo-physical properties of pure Karanja oil and FD are summarized in Table 2. Table 2 indicates that at 40°C, the kinematic viscosity of neat Karanja oil (34.5 cSt) is about 10 times larger than FD, which creates problems during application in diesel engine.

4.2 Effect of Temperature on Viscosity

Studies indicate that heating of VO reduces its viscosity, making the fuel's spray characteristics more similar to those of FD [37]. Considering that Karanja oil was heated at different temperatures (40 to 140˚C) (Fig. 3). Karanja oil Preheated at 40 to 120˚C temperatures are abbreviated as KOP40, KOP50, KOP60, KOP70, KOP80, KOP90, KOP100, KOP105, KOP110 and KOP120. A close look at Figure 3 indicates that heating of Karanja oil at 105˚C makes the oil at par with the FD. This finding is also supported by Acharya et al. (2011 and 2014). They reported that preheating the VO to a temperature of 105°C improves the engine performance and emission control.

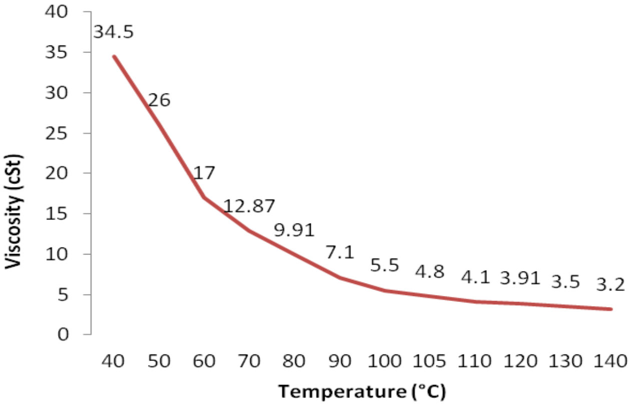

Fig. 3: Variation of kinematic viscosity of straight Karanja oil with temperature.

4.3 Development of Heat Exchanger

A heat exchanger having a heat carrying capacity of 523.62W was designed, and fabricated (Figure 4a and 4b). Detailed dimensions of the designed and developed heat exchanger are summarized in Table 6. For a better heat transfer rate, coil of the heat exchanger was made up of copper however, other components of the heat exchanger were made of mild steel to provide strength and make it economical [26-30].

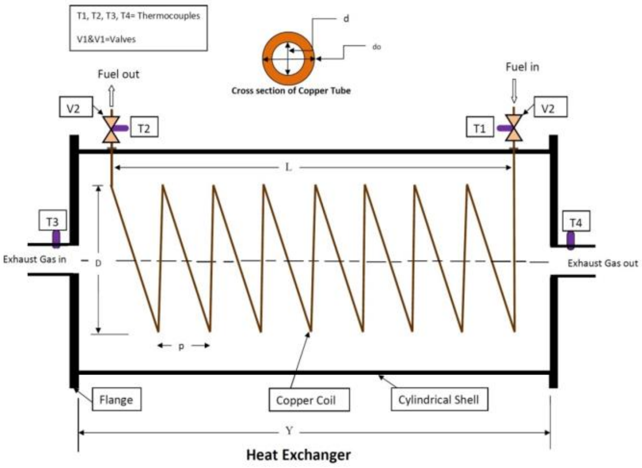

Fig. 4(a) Schematic diagram of helical coiled type heat exchanger

Fig.4 (b) Development of H E

Table 6: Specification of Designed Waste Heat Recovery HE

Designed Parameters	Dimension (mm)
Heat Exchanger Shell	
Outer & Inner diameter	160 and140 respectively
Horizontal Length (Y)	224
Helical Coil	
Inner (d) and Outer (d_o) diameter of tube	8 and 10 respectively
Thickness of tube (z)	2
Pitch (p)	20
Helix diameter (D)	120
Spiral coil length (L)	220
Number of Turns of Helical Coil (N)	8
Total tube length	3010

5. Performance Analysis of CI Engine

5.1 *Impact of Load and Fuel Temperature on Brake Thermal Efficiency (BTE)*

The variance in the BTE of the engine at different engine loads and different heating temperatures of Karanja oil along FD is plotted in Figure 5. A close look at Figure 5 indicates that although the BTE of the engine increases with load (up to 80% rated capacity) and Karanja oil temperature, however, temperature above 105˚C also increases the NOx in the flue gas.

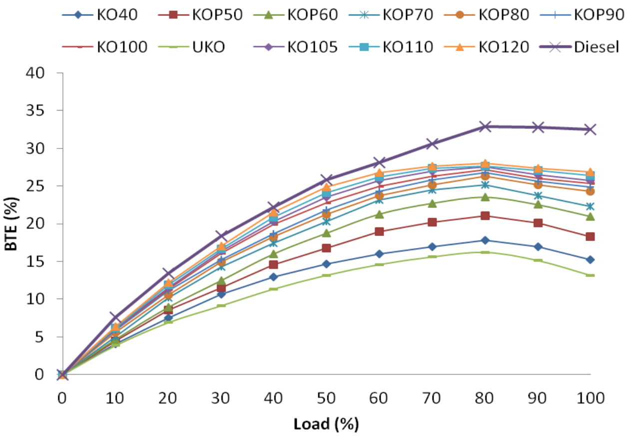

Fig.5: Variation of BTE with different loads and 105°C Karanja oil temperature

5.2 *Impact of Fuel Temperature and Load on BSFC*

The BSFC is used to compare the amount of fuel needed to produce one unit of energy. Variations in BSFC vs. loads for USKO, PSKO (40-120°C), and FD are shown in Figure 6. It is proven that the high density and low calorific value of Karanja oil causes increased BSFC than FD [38-39]. Lower BSFC was noted as the preheating temperature increased. This was because increasing fuel inlet temperature causes viscosity to decrease, improving atomization, combustion, and BSFC [19]. Critical analysis of Figure 6 revealed that there is a significant decrease in BSFC at high engine loads (up to 80%) for all the tested fuels. In the case of PSKO, there was no significant difference in BSFC for KOP105, KOP110, and KOP120 (0.333, 0.332, and 0.328 kg/kWh, respectively) at 80% load. The lowest and highest BSFC were recorded for FD (0.246 kg/kWh) and USKO (0.57 kg/kWh) at 80% brake load of rated engine capacity.

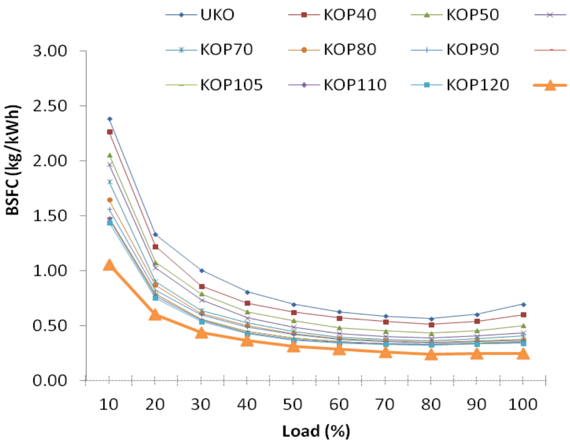

Fig. 6: Variation of BSFC with different load and fuel temperature of straight Karanja oil

5.3 *Impact of Fuel Temperature and Load on EGT*

Figure 7 depicts the variation EGT for different fuels with variable loads. The results demonstrate that for each fuel, the EGT rises as the brake load increases. In the case of the Karanja oil it is always higher to FD irrespective of engine loads. With higher loads, EGTs were unpredictable high for Karanja oil [22, 40]. Figure7 also depicts the sudden increase in EGTs (490 and 500°C) for POK110 and POK120 at full load. According to Agarwal and Dhar [22] and Chouhan et al. [41], the uncontrolled combustion of PSKO at higher temperatures may be the cause of this rise in EGTs.

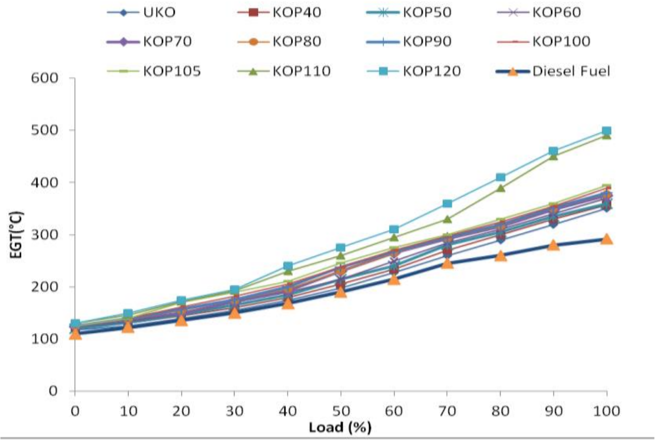

Fig. 7: Impact of fuel temperature and load on EGT

EGT is lower for an air-fuel mixture that is in a stoichiometric ratio. Due to the aforementioned factors, combustion is improved for PSKO. Higher EGTs while using Karanja oil are a sign of decreased engine BTE [41]. Less of the fuel's energy input is transferred to work when the BTE is lower. Pramanik also reported a similar result [38].

6. Exhaust Emissions Analysis

6.1 Impact of Fuel Temperature and Load on NOx Emission

When nitrogen and oxygen are combined during combustion, NOx is created, a function of high temperatures. A greater combustion temperature accompanied an increase in NOx emissions as engine load increased (Fig. 8). Figure 8 illustrates the variations in NOx emissions for all tested fuels (FD, USKO, and PSKO) [41]. Even though NOx emissions rise as fuel input temperature increases, FD produces more NOx emissions than USKO at all the test ranges. A close look at Figure 8 indicates that, at high loading conditions, the NOx output for KOP100 and KOP105 was comparable to that of FD. However, at low load (below 30%), NOx was discovered to be lower than FD for the same test fuel due to reduced engine cylinder pressure intensity in the same situation [40]. The temperature inside the combustion chamber rises due to preheating the Karanja oil, increasing the NOx emissions in the exhaust gases. An engine's NOx emissions can be reduced using either a pre or post-combustion technique [41, 42]. The maximum NOx emission for FD was noted as 410 ppm. The highest NOx emissions with unheated Karanja oil were 270 ppm. The maximum NOx values for KOP110 and KOP120 were 705 ppm and 1000 ppm, respectively, which were considerably higher than FD. At high load, NOx emission values (430 ppm) for KOP105 were found to be comparable to FD (410 ppm).

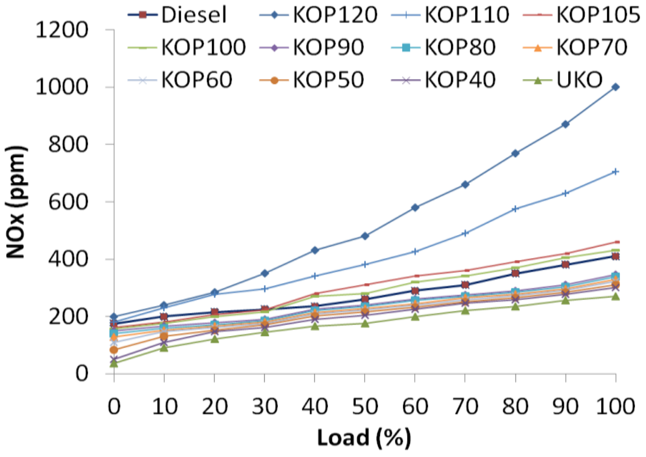

Fig.8: Impact of fuel temperature and load on NOx emission

6.2 Impact of Fuel Temperature and Load on Carbon Monoxide (CO) Emission

USKO has a higher CO emission than FD and PSKO. It may be due to the high viscosity of VO (Fig. 9). When VO is being used as a fuel in the diesel engine, incomplete combustion happens because it is more difficult to atomise VO having higher viscosities, resulting in improper combustion. As a result, more CO was produced during combustion; the poor mixing that resulted from the local shortage of oxygen prevented the temperature from rising at lower loads. Low CO emissions are produced when the fuel's input temperature is raised. As temperature rises, Karanja oil's viscosity reduces, resulting in proper fuel atomization and reduced CO percentage in exhaust emissions [41].

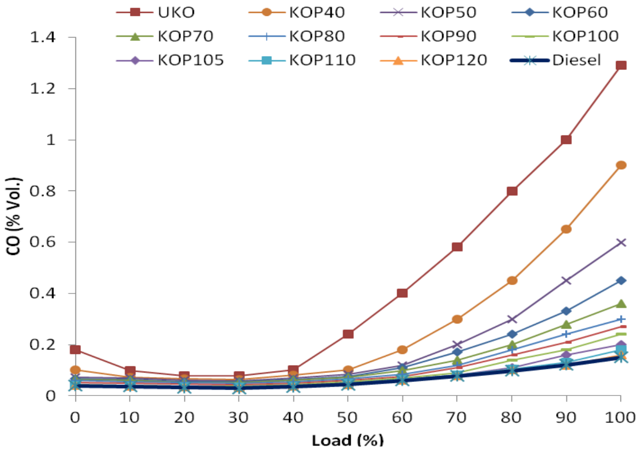

Fig. 9: Impact of fuel temperature and load on engine CO emission

7. Limitations

The following are the constraints of research work:

1. Due to a scarcity of edible oil, non-edible vegetable oil must be used as fuel for the CI engine
2. Vegetable oil must be preheated before injection due to its high viscosity.
3. To avoid a large rise in NOx emissions, preheat vegetable oil to no more than 105^{o}C.

8. Conclusion

The study concludes that as the temperature of Karanja oil rises between 105°C and 110°C, its viscosity reduces significantly and becomes closer to FD. To recover the waste heat lost from engine exhaust, a coil-type heat exchanger was developed to decrease the viscosity of Karanja oil. Results indicate that the performance of diesel engines using unheated Karanja oil is at par with FD. Engine performance could be enhanced by heated (105˚C) Karanja oil as a result of reduction in viscosity. The highest BTEs were recorded at 80% rated load of the engine. The unheated Karanja oil had lower nitrogen oxide (NOx) than FD. However, NOx emissions can be enhanced for heated Karanja oil. Although CO emissions from unheated Karanja oil were higher than those from FD, it could be decreased when heated Karanja oil is used. At a temperature of 105°C, Karanja oil gives the best performance and lowest emissions.

Abbreviations

BSFC	: Brake-specific fuel consumption
BTE	: Brake thermal efficiency
CI	: Compression ignition
DE	: Diesel engine
EGT	: Exhaust gas temperature

FD : Fossil diesel
KO : Karanja oil
PSKO : Preheated Straight Karanja oil
USKO : Unheated Straight Karanja oil
SVO : Straight vegetable oil
VO : Vegetable oil

Nomenclature and Symbol

MJ/kg : Mega Joule / Kilogram,
cSt : Centi-stoke,
kg/m^3 : Kilogram/ Cubic Meter,
w/w : Weight/ Weight,
MPa : Mega Pascal,
rpm : Revolution Per Minute,
ppm : Part Per Million, K: Kelvin,
°C : Degree Celsius,
bTDC : Before Top Dead Centre

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