A Review on the Performance, Emission and Combustion Characteristics of Karanja, Jatropha and Polanga Biodiesel and its Blends in a Diesel Engine

Feyisola Idowu Nana[1], Haeng Muk Cho[1]*

[1]Department of Mechanical Engineering,
Kongju National University, Cheonan, Republic of Korea,

Abstract:

Energy is an essential factor for improving the quality of life, human welfare, socio-economic growth, and development. As the world's energy demand increases , the need for energy security as a result of rapid depletion of fossil fuels has been an issue of concern.Hence, an alternative source of energy needs to be established. Biodiesel, which is biodegradable, renewable, non-toxic, and has similar properties to conventional diesel fuel could serve as an alternative source of fuel. When compared to mineral diesel, biodiesel has lower CO, CO_2, HC, and smoke opacity emissions.In terms of brake thermal efficiency (BTE), brake specific energy consumption (BSEC), smoke opacity, and exhaust emissions, biodiesel-fueled engines performed slightly better than diesel-fueled engines. This paper reviews the performance, emission, and combustion characteristics of some non-edible oils of karanja, polanga, and jatropha-based biodiesel obtained from experiments performed at different conditions.

Keywords: Karanja oil, Polanga oil, Jatropha oil, engine performance, engine emission, combustion analysis

1. Introduction

Energy is regarded as a necessary part in improving the quality of living, human welfare, and socioeconomic growth and development.The world energy demand is growing at a much faster rate with an increasing rise in industrialization and modernization[1],[2]. As a result of this development, the number of vehicles on the road is increasing, bolstering demand for fossil fuels.The heavy dependence on the use of non-renewable fossil fuels leads to over-exploitation and ultimate depletion of the fossil fuel reserve. Petroleum fuels degrade the environment and pose health risks, prompting a quest for alternative renewable fuels to provide environmental protection and energy security[3].Some unfavorable physical qualities constrain the use of straight vegetable oils, most importantly viscosity, which is higher than mineral diesel. Vegetable oil's high viscosity causes poor fuel atomization, partial combustion, and carbon buildup on injectors and valve seats, causing major engine fouling. [4]. Transesterification is a chemical reaction that produces fatty acid alkyl esters and glycerol by reacting oil or fats with monohydric alcohol in the presence of a catalyst.It is one among the most widely used process of producing biodiesel from vegetable oil and has proven over the years to be an effective method[5],[6],[7]. The trans-esterified vegetable oils gives cleaner emission properties and give hope for their wider use without modification in diesel engines. Aside from the issue of biodiesel's high viscosity, another barrier to its usage is its thermal and oxidative instability, since it is prone to oxidation at ambient temperature[8],[9],[10].Biodieselsare mono-alkyl esters of long-chain fatty acids derived from a renewable lipid feedstock, such as vegetable or animal oil, and are popularly known as the esters of vegetable oils [11].Biodiesel is a promising alternative to fossil fuels such as gasoline and diesel fuel used in an internal combustion engine.It's renewable, biodegradable, sustainable, non-toxic, and healthier to breathe because it produces less greenhouse emissions.Biodiesel hasenvironmental benefits with physicochemicalfeatures comparable to diesel fuel and can be used as an alternative fuel source[12],[13],[14],[15].Vegetable oils from food crops including soybean, palm, coconut, rapeseed, corn, sunflower, and others, as well as non-edible crops such as jatropha, rubber seed, sea mango, castor, pongamia pinnata, karanja, algae, mahua, and others, can be used to make biofuels [16], [17].Non-edible vegetable oil is also preferable as it is quite affordable and a better substitute than edible vegetable oil. The study review the Karanja, Polanga, and Jatropha biodiesel's engine performance, combustion, and emissionsfor proving its suitability as a substitute fuel in diesel engines without any modification.

2. Literature review

Nagarhalli M. V et al[3]studied the engine emission and performance characteristics of a karanja biodiesel in a 3.67 kW single-cylinder 4-stroke, constant speed CI diesel engine. The engine, coupled with an eddy current galvanometer, was fueled with mineral diesel and diesel-biodiesel blends at an injection pressure of 200 bar. Thetests were conducted using diesel and biodiesel-diesel blends at no load, 33.3% load, 66.6% load, and 100% load of the engine at the constant speed of 1500 rpm. A blend of 20% biodiesel and 80% diesel denoted by B20 and 40% biodiesel and 60% diesel denoted by B40 was used in this study. The performance parameters such as the brake thermal efficiency (BTE) and brake specific energy consumption (BSEC) and emission were measured and compared. A non-dispersive infrared gas analyzer (NDIR) was used in the measurement of the exhaust gases of carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC),and oxides of nitrogen (NO_X) present. The experimental analysis from this study shows that with an injection pressure of 200 bar, the HC emissions decreased by 12.8 % and 3 % for B20 and B40, respectively at full load. Similarly, the NO_x decreased by 39 % and 28 % for B20 and B40, respectively at full load. CO emission was slightly higher whereas the efficiency decreased for the blends in comparison with diesel fuel. The BSEC increased by 7 % for B20 and 1.9 % for B40 at full load and was observed to be slightly more at these blends. The studyrecommended a blend of B20 and B40 as there was no significant change in inefficiency. Avinash Kumar Agarwal et al[18]investigated and analyzed the performance and emission characteristics of a CI engine fueled with karanja oil (K100) and its blend K10, K20, K50, and K75. A four-stroke, constant speed (1500 rpm), single-cylinder, water-cooled direct injection (DI) diesel engine was used for theexperimentation. The alternator was calibrated at no-load (0%), 20%, 40%, 50%, 60%, 80%, and 100% loads, and conducted for all fuel type. A smoke opacimeter was used to measure the smoke opacity while an NDIR gas analyzer was used to measure the exhaust gas emissions of CO_2, CO, HC, NO, and O_2. Performance parameter such as brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and brake specific energy consumption (BSEC) was also measured.To assess the influence temperature has on the viscosity of karanja biodiesel, a specifically built exhaust gas heat exchanger was employed in engine testing with and without preheating.The thermal efficiency increases with the increase in the concentration of the blend and was higher than mineral diesel. The BSFC obtained for the unheated and preheated karanja oil of 10% to 50% was lower than that of mineral diesel. The BSEC of the karanja oil blends were lower than mineral diesel either unheated or preheated. The performance result of the karanja oil blend with and without preheating is shown inFigure 1. Lower HC emission was obtained at lower engine loads and higher HC emission was obtained at higher engine load for all karanja oil and blends. The nitrogen oxide (NO) emitted was found to be relatively lower for karanja oil and its blend at lower engine load when the fuel sample was unheated and preheated. The emission of NO also reduces as the engine load increases. Smoke opacity increases with an increase in engine loads.The study showed that karanja oil blended with diesel up to 50% by volume with and without preheating replaced diesel for operating a CI engine for improved performance and lower emissions.Avinash Kumar Agarwal et al[8]studied the performance, emission, and combustion characteristics of karanja oil and its blend with mineral diesel in an unheated condition in adirect-injection compression ignition(DICI)engine. A constant fuel injection pressure of 200 bar was used in the test. The karanja oil blend by volume used in the study consists of 10% biodiesel and 90% diesel (K10), 20% biodiesel and 80% diesel (K20), 50% biodiesel, 50% diesel (K50), and 100% biodiesel (K100). The sample fuels were carried out at six different engine loads of 0%, 20%, 40%, 60%, 80%, and 100%. A four-stroke single-cylinder CI engine operated at a constant engine speed of 1500 rpm was used in the study. The result obtained from the study showed that the BSFC increased with ahigher concentration of karanja oil in the blend. The **c**alorific value of karanja oil was lower when compared to mineral diesel. The thermal efficiency of karanja blends was found to be lower than mineral diesel. The CO_2 emitted for the karanja oil, and its blends were significantly higher than mineral diesel. With the increase in the concentration of karanja oil in the blends, the CO emission also increases. When compared to conventional diesel, karanja oil and its blends resulted in a mass reduction in HC emissions, with the lowest levels for K20 and K50 at all engine operating conditions.Figure 2 shows a comparison of the different emissions of a karanja oil blend fueled diesel engine. Combustion duration was significantly higher for Karanja oil blends compared to mineral diesel. The study suggested that a higher concentration of karanja oil blends was not appropriate as an alternative fuel in an unmodified diesel engine. Injectiontiming optimization with unheated blends, as well as preheating the karanja oil was considered a potential and feasible method in the use of karanja oil as fuel in adiesel engine. Atul Dhar et al[19]investigated the performance, emissions, and combustion characteristics of karanja oil. The karanja biodiesel blends of 10% (KOME10), 20% KOME20, and 50% KOME20 were analyzed in the study. For the different biodiesel blends, the effect of injection timing, and injection pressure was studied. The experiment was conducted using a single-cylinder common rail direct injection (CRDI) diesel engine in various injection mode at 500 and 1000 bar fuel injection pressure (FIP).At a constant engine speed of 1500 rpm, the start of main injection (SOMI) and the start of pilot injection (SOPI) were varied.The input fuel energy was fixed at all operating conditions. The conventional diesel had a slightly higher BTE than karanja oil and its blends.With 1000 bar FIPs, the maximum BTE was achieved at SOPI timings of -21 ^{0}CA and SOMI timings of -9 ^{0}CA.

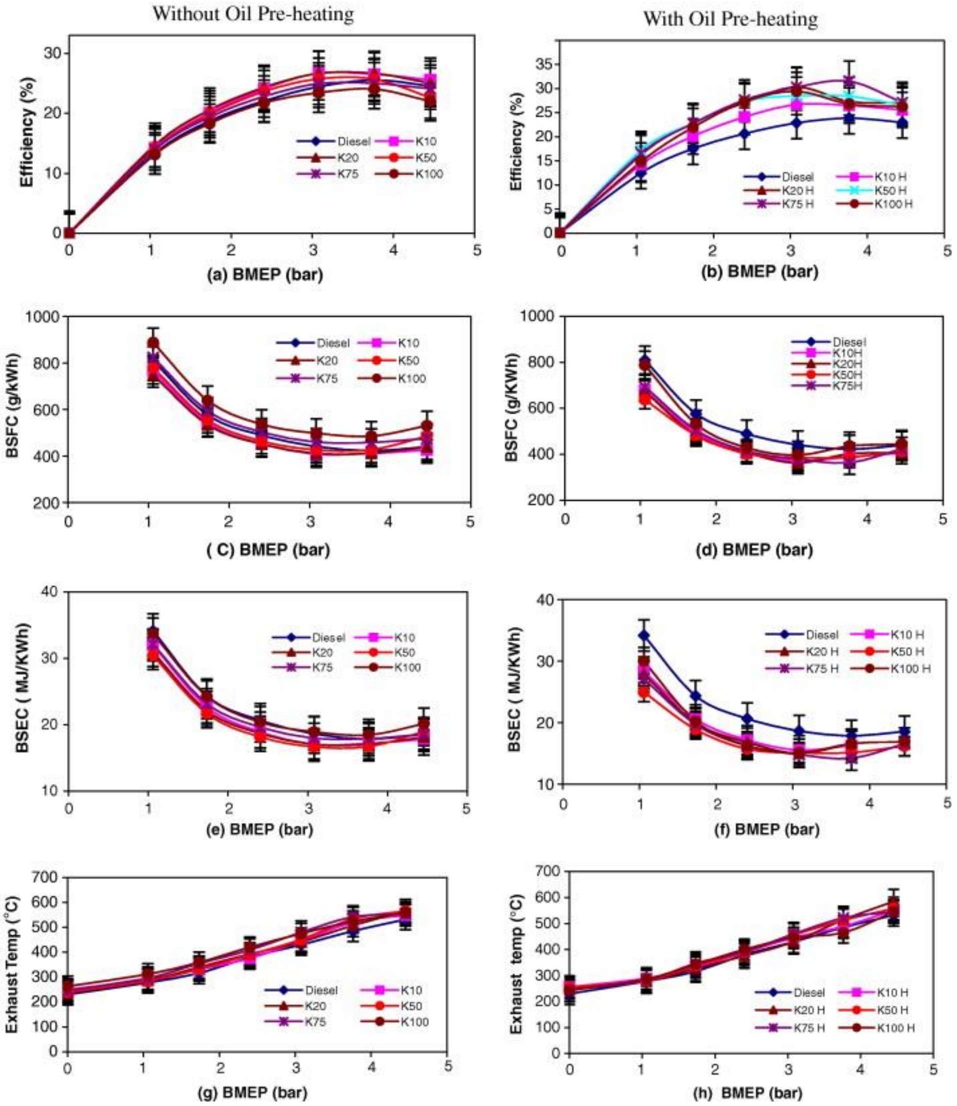

Figure 1: Performance results of karanja oil blend with and without preheating[18]

Similarly, the maximum BTE was obtained at -18 ^{0}CA SOPI and -12 ^{0}CA SOMI timing at 500 bar FIPs. The brake specific NOx emissions at a fixed SOMI and different SOPI timing were similar for all fuel test fuel. The maximum in-cylinder pressure at 500 bar FIP was lower in comparison to 1000 bar FIP at the same SOMI and SOPI. The study showed that the utilization of 10% or 20% in volume of karanja biodiesel blends in a CRDI engine with a pilot engine was useful in reducing emission and improving engine efficiency.The performance and emission characteristics of a single-cylinder direct injection diesel engine were studied by Sahoo Bajpai et al[10]The physicochemical properties of karanja oil in neat mineral diesel of 5% by volume of karanja vegetable oil (KVO) in diesel denoted by KVO 5 and subsequently, KVO 10, KVO 15, and KVO 20 were determined. The experiment was performed at different load conditions at no load (0%), 20%, 40%, 60%, 80% and 100% for the test fuel blends.The result as shown in Figure **3**revealed that when the temperature rises to 100 ^{0}C, the kinematic viscosity of karanja oil decreases.The viscosity of the preheated neat karanja oil at 90 ^{0}C was found to be very closeto that of petroleum diesel oil.

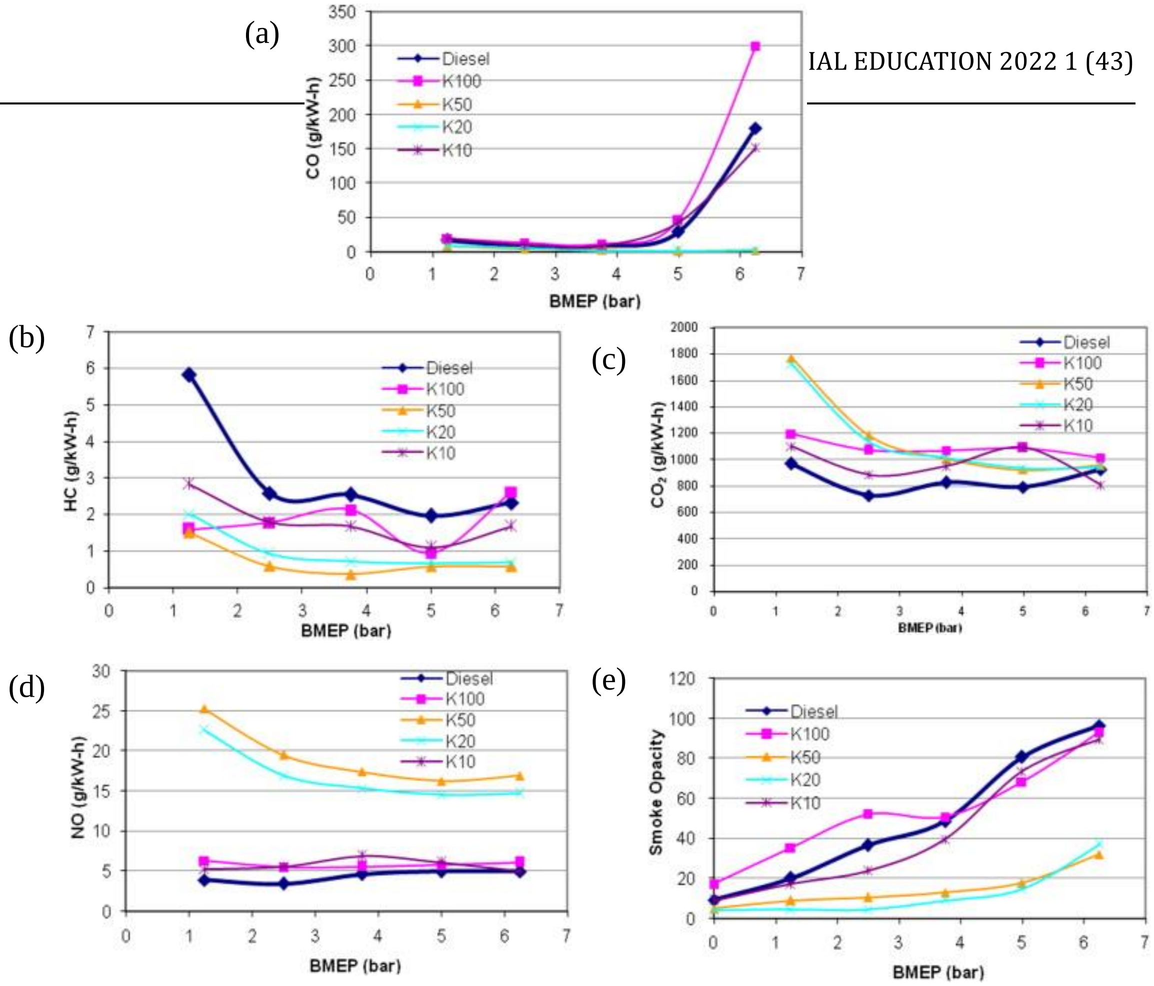

Figure 2: Comparison of the emissions of (a) CO (b) HC (c) CO_2(d) NO (e) Smoke opacity karanja oil blend fueled engine[8]

The KVO10 was deemed the best blend and improved the thermal efficiency of the engine. The KVO10 could be employed as a replacement fuel for existing conventional diesel engines without requiring any significant hardware modifications.The performance of the KVO-fueled engine was slightly better than the diesel-fueled engine in terms of thermal efficiency, BSEC, smoke opacity, and exhaust emissions, including NOx emission, for the whole operations.The fuel qualities of karanja methyl ester (KME) and its blend with diesel in operating a diesel engine were investigated by Hifjur Raheman et al[20]. The karanja biodiesel and its blends (B20, B40, B60, B80, and B100) were used as the test fuel. The karanja oil was esterified using the esterification process. A single-cylinder, four-stroke, water-cooled DI diesel engine with a compression ratio of 16:1 and a rated output of 7.5 kW at 3000 rpm was used in the study. The emissions from the engine were studied at different engine loads (10%, 25%, 50%, 75%, 85%, and 100% of the load corresponding to the load at maximum power) at an average engine speed of 2525 (62%) rpmreduced emissions such as CO, smoke density, and NOx on an average of 80 %, 50 %, and 26 %, respectively. The brake power output increased by an average of 6% up to biodiesel blend B40, and as the amount of biodiesel in the blend increases, the brake power output decreases.

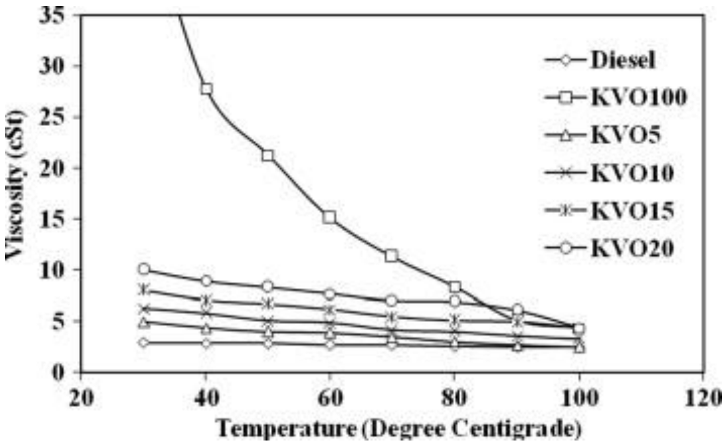

Figure 3: Effect of temperature on the viscosity of karanja oil and its blends with diesel[10]

The study found that blending KME with diesel up to 40% by volume could be used to substitute diesel in diesel engines, resulting in lower emissions without losing power output.The acid catalyzed esterification of high free fatty acid karanja oil (KO) in the synthesis of biodieselKO) was investigated by KadathurThiruvengadaravi et al[11].At a temperature of 60 ^{0}C, sulfated zirconia (SZ) was utilized as an acid catalyst with a 9:1 alcohol-to-oil ratio for two hours.The biodiesel was produced from the preheated KO by alkaline crystalline esterification. The conversion increase with an increase in catalyst quantity up to 1% of the catalyst. Beyond 1%, there is no significant improvement in conversion. The fuel properties of KO biodiesel were equivalent to those of diesel and were within the ASTM D6751-09 limitations, with an acid value of less than 2 mg KOH/g.The study also found SZ to be a promising strong solid acid catalyst for the esterification of KO with methanol. SZ showed high catalytic activity and significantly reduced the FFA value. The results proved that the catalyst was an attractive and less expensive alternate to treat oils with a high amount of free fatty acids. It also appears as a possible alternative catalyst for esterification of FFA, particularly in non-edible oils leading to higher final conversions.The performance, emissions, and combustion properties of biodiesel produced from non-edible Karanja oil and its blends with diesel fuel were compared by Bhupendra Singh Chauhanet al[21].A Kirloskar-made, single-cylinder, constant speed, air-cooled, direct injection in an unmodified diesel engine was used in the study. The engine was loaded at no load (0%), 20%, 40%, 60%, 80% and 100% load. Neat biodiesel of karanja methyl ester (KME100) and different blends of biodiesel of KME5, KME10, KME20, KME30 were evaluated and compared with diesel fuel (D100). A two-step process comprising of esterification and transesterification was carried out in biodiesel production. When compared to diesel fuel, KME and its blends had a higher flash point, higher density, reduced calorific value, and higher kinematic viscosity. The BTE was about 3-5% lower with karanja biodiesel and its blends to diesel. The peak cylinder pressure and heat release rate were lower for karanja biodiesel. At all loads, karanja biodiesel and its blends produced more nitrogen oxides than diesel fuel, which could be decreased by using an EGR (exhaust gas recirculation) system or other suitable techniques.When compared to diesel, CO, CO_2, smoke density, and HC emissions were reduced.Lalit Mohan Das et al[9]studied the stability of karanja oil methyl ester (KOME) during a 180-day storage period under various storage conditions.The stability of KOME was improved by adding different antioxidants of Tert-Butylated Hydroxytoluene (BHT), Tert-Butylated Hydroxyanisole (BHA), Pyrogallol (PY), Propyl gallate (PrG), and Tert-Butyl Hydroxyl Quinone (TBHQ). The induction period of KOME was determined without antioxidants at different temperatures (90 ^{0}C, 100 ^{0}C, 110 ^{0}C, and 120 ^{0}C) and with antioxidants of 100 ppm at 110 ^{0}C. The study showed that the antioxidant of PY gave the best improvement in the oxidation stability (OS) of karanja biodiesel followed by BHA and BHT while those of PrG and TBHQ have significantly lower oxidation periods.Peroxide value (PV) increases with the storage time of biodiesel and OS decrease with increased storage time. PV was also more at a lower concentration level and less at a higher antioxidant concentration level. The OS of KOME increased with a higher concentration of antioxidant levels.The effects of fuel inlet temperature (FIT) on engine performance and emissions were investigated by Bhupendra Singh Chauhan et al[22].In the study, a Kirloskar made with constant speed, one cylinder, air cooling DI diesel engine was employed in performing the experiment.To preheat the vegetable oil using heat from the exhaust fumes, a shell and tube counter-flow heat exchanger was developed. The setup is shown in Figure 4. The temperature of the jatropha oil was controlled from 40^{0}C-100^{0}C by adjusting the amount of exhaust gas. Preheated jatropha oil at 100^{0}C was denoted as (PJO 100), at 80^{0}C (PJO 80), 60^{0}C (PJO 60), and 40^{0}C (PJO 40). The result showed that the engine performance with unheated jatropha oil was slightly inferior to the performance with diesel fuel.The value of CO, HC, and smoke opacity reduced with preheated Jatropha oil, whereas CO_2 emissions increased slightly.For the safe operation of the brake thermal efficiency, brake specific energy consumption, gaseous emission, and engine durability, the research proposed an ideal fuel inlet temperature of 80 ^{0}C.The study of the performance, combustion, and emission properties of biodiesel generated from pongamia oil was investigated by Varatharaju Perumal et al[23].Different blend ratio of 20% biodiesel, 80% diesel (B20), 40% biodiesel, 60% diesel (B40), 60% biodiesel, 40% diesel (B60), 80% biodiesel, 20% diesel (B80) and pure biodiesel (B100) was studied. A Kirloskar single-cylinder, four-stroke, direct injection diesel engine with an eddy current dynamometer was used at different load conditions. The result showed that the BSFC increased by 4.2%.

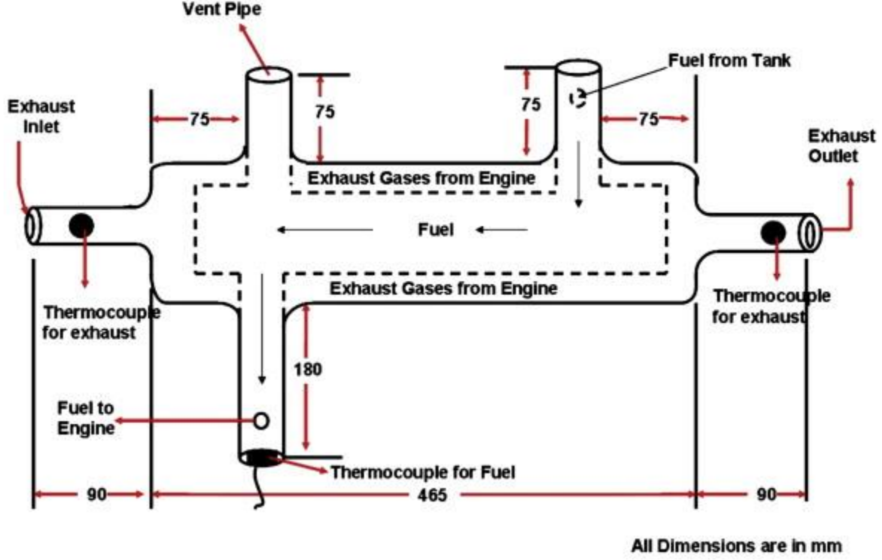

Figure 4: The schematic of the counter-flow heat exchanger[22]

At the same time, there was a decrease in BTE by 2.4% for the B20 blend of PME compared to that of diesel. There was an overall reduction in CO emission compared to diesel. The HC emission decreased with the increase in a blend ratio of biodiesel and decreased by around 8.9% for the B20 blend compared to diesel. The NOx emission increased with an increase in load. At all blend ratios, there was an increase in smoke emission.A negative value of heat release was obtained for the blend ratios of B20, B40, B60, B80, and B100 and was positive after the start of combustion.The B20 blend gave a high heat release and the higher blend ratios gave less heat release due to slow heat release and lower maximum pressure. The performance and exhaust emission characteristics of polanga oil methyl ester (POME) were studied by Pradeepta Sahoo et al [24]**.**The experiment was carried out in the laboratory with a single-cylinder diesel engine.A 20% POME + 80% diesel (B20 POME), B40 POME, B60 POME, B80 POME, andB100 POME was tested at different operating load of 0%, 20%, 40%, 60%, 80% and 100%. The density and viscosity of the polanga oil methyl ester produced following triple-step transesterification were found to be comparable to that of diesel.The flashpoint of all POME blends was greater than the flashpoint of diesel oil.The 100% biodiesel improved the thermal efficiency of the engine by 0.1% and was found to be the best.B60 also reduced smoke emissions by 35% when compared to conventional petrol-diesel.The performance of the biodiesel-fueled engine was slightly better than the diesel-fueled engine in terms of thermal efficiency, BSEC, smoke opacity, and exhaust emissions including NOx emission for the entire range of operations.Pradeepta Sahoo et al. [25] studied at the physicochemical properties of karanja, jatropha, and polanga oil, as well as the process of producing biodiesel from them.The production of fuel quality biodiesel from low-cost, high FFA feedstocks was also investigated. The biodiesels were produced in a laboratory setup.A two-step transesterification for jatropha and karanja; and a triple-stage transesterification for polanga oil are developed to convert the high FFA oils to its ester. The zero-catalyzed transesterification and acid-catalyzed transesterification reduce the FFA content of thejatropha,karanja, andpolanga oil to less than 2%. The result showed that the conversion efficiency was strongly affected by the amount of alcohol. The volumetric ratio of 11:1, 11.5:1, and 12:1 of alcohol favors the completion of alkaline catalyzed transesterification process within 2hr for the formation of JOME, KOME, and POME. A 93%, 91%, and 85% ester yield of JOME, KOME, and POMEwas obtained respectively. The density, kinematic viscosity, cetane number, high heat value, flash, and fire point of the blends increased with the increase of biodiesel concentration in diesel–biodiesel blends. The combustion characteristics of biodiesels made from the non-edible oil of karanja, jatropha, and polanga were studied by Pradeepta Sahoo et al [26].The suitability of these oils as a fuel in a diesel engine was also investigated. A small size 6 kW air-cooled single-cylinder four-stroke diesel engine fueled was used to prepare the test fuels.The result showed that the transesterification process improved the fuel properties of the oil with respect to density, calorific value, viscosity, flash point, cloud point and pour point. The comparison of these properties with diesel shows that the methyl esters of jatropha, karanja, and polanga oil have relatively closer fuel property values to that of diesel (HSD). Polanga biodiesel (PB100) had an 8.5% higher peak pressure than that of neat diesel followed by JB100 (7.6%) and KB100 (6.9%). The heat release rate showed that biodiesel and related blends had a shorter ignition delay than diesel.The heat released during the late combustion phase for biodiesel and their blends was slightly lower than that of diesel.As the difference in the increase in load increase, the ignition delay for JB100 was constantly shorter, spanning between 5.9^0 and 4.2^0 crank angle less than diesel. It was also shorter for KB100 (with a crank angle ranging from 6.3^0 to 4.5^0) and PB100 (varying between 5.7^0 and 4.2^0 crank angle).Lalit Mohan Das et al[1]optimized the biodiesel production process and assessed the comparative performance emission characteristics of the three-cylinder tractor engine. Ten test fuels of 100% neat diesel, JB20, JB50, JB100, KB20, KB50, KB100, PB20, PB50, and PB100 was studied. The experiments were conducted on a big-size water-cooled three-cylinder tractor diesel engine fueled with prepared test fuels. The BSFC, BTE, and brake mean effective pressure (BMEP) was measured at full/part throttle at three different engine speeds of 1200, 1800, and 2200 rev/min. A full-throttle and for all the biodiesel blends, no significant change in power was obtained for the three-cylinder tractor engine at lower speeds of 1200 and 1400 rpm.For all biodiesel-to-diesel blends, the BSFC improves with the blend and reduces with speed. During the full-throttle performance test, smoke emission decreases as the blends and speeds increase. When compared to diesel fuel, the fuel efficiency of JB20, PB20, and PB50 improved at part throttle.The blends with a higher percentage of biodiesel in diesel tend to decrease the exhaust smoke substantially. An observable reduction in HC and particulate matter (PM) was observed with biodiesel and its blends. However, the CO, NOx, and the combined HC and NOx were slightly increased at part throttle.

3. Conclusion

The paper focused on the performance, emission, and combustion characteristics of karanja, jatropha, and polanga oil and their blends when used in a diesel engine at different operating conditions. The following conclusions are derived from the experiment performed by different engineers and researchers:

- Injection timing optimization with unheated blends, as well as preheating the karanja oil, is a viable option for using karanja oil as a diesel engine fuel.With the increase in biodiesel concentration in the blends, the density, viscosity, cetane number, high heat value, flash, and fire point also increased.The ignition delay was shorter for the biodiesels of karanja, polanga, and jatropha, and was lower than diesel.
- The safe operation of the brake specific energy consumption, brake thermal efficiency, and gaseous emissions was determined to be at an ideal fuel input temperature of 80 %.
- NOx emissions from karanja and jatropha biodiesel were greater than diesel, although carbon dioxides, carbon monoxides and smoke emissions were lower.In terms of thermal efficiency, brake-specific energy consumption, smoke opacity, and NOx emissions, the pongamia-fueled engine performed slightly better than the diesel-fueled engine.
- The utilization of a 10% to 50% karanja oil blend with diesel, with and without preheating, proved effective in lowering emissions and enhancing engine efficiency and performance.In an unmodified diesel engine, a higher proportion of karanja oil was not suitable as an alternate fuel source.
- Sulfated zirconia (SZ) is a suitable alternative catalyst for treating oil that contains a lot of free fatty acids (FFA).

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Abbreviations

CO	carbon monoxide	CO_2	carbon dioxide
HC	hydrocarbon	NO_X	oxides of nitrogen
NO	nitrogen oxide	BTE	brake thermal efficiency
NDIR	non-dispersive infrared gas analyzer	CI	compression ignition
DI	direct injection	DICI	direct-injection compression ignition
BSFC	brake specific fuel consumption	BSEC	brake specific energy consumption
CRDI	common rail direct injection	FIP	fuel injection pressure
FIT	fuel inlet temperature	SOPI	start of pilot injection
SOMI	start of main injection	CA	crank angle
KVO	karanja vegetable oil	BMEP	brake mean effective pressure
KME	karanja methyl ester	KO	karanja oil
FFA	free fatty acid	SZ	sulfated zirconia
EGR	exhaust gas recirculation	BHT	tert-butylated hydroxytoluene
BHA	tert-butylated Hydroxyanisole	PY	Pyrogallol
PrG	propyl gallate	TBHQ	tert-butyl hydroxyl quinone
OS	oxidation stability	PV	peroxide value
PM	particulate matter		

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