Analysis of Emission Characteristics of Single Cylinder 4 Stroke DI Diesel Engine Fuelled with Biodiesel Blends with Diesel

By

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Abstract

Depleting oil reserves, rising oil costs, a lack of fossil fuel oil supply, and the issues of pollution have motivated worldwide researchers for alternative fuels for diesel engines. Vegetable edible and non-edible oil-based fuels have been shown to be a viable greener energy alternative to diesel fuels. Vegetable oils are non conventional and renewable fuels. These fuels have qualities that are equivalent to petro-diesel. These are biodegradable fuels, and produce fewer emissions while burning. It has been discovered that all of the gasoline blends, KB15 produce the least CO. When compared to other fuel mixes like KB5, KB10, KB20, and KB100, KB15 produces 8 to 9 percent less CO and CO2. For all load conditions, KB100 has a higher BSFC than diesel. KB15 had a lower BSFC than diesel, indicating that it was the best mix in terms of fuel efficiency. At full load, KB100 has a higher amount of unburned hydrocarbon as compared to diesel due to more fuel is injected, resulting in a richer mixture and incomplete combustion. However, KB15 produces 5% less unburned hydrocarbon than diesel under all loading conditions. Because the quantity of mixed fuel grew as the concentration of biodiesel increased, the amount of NOx emitted increased, resulting in a higher temperature during fuel combustion. KB100 increases NOx emissions by up to 25% under all load conditions.

Keywords: Karanja oil; Biodiesel; Diesel; DI engine.

1. Introduction

Due to increased industrialization and motorization, energy has become a fundamental demand in today's globe. The lifeblood of modern civilization is abundant and cost-effective energy. Energy is one of the most important building blocks in human growth, and as such, it is a major determinant of all countries economic progress. Due to limited stocks of fossil fuels and emission issues and due to heavy utilization of petro-diesel fuel there is a major concern for need of alternative and green fuels. Worldwide environmental concerns and energy security issues have led to legislation and regulatory actions that create a need for other fuels such as biodiesel. However, several studies have been conducted regarding production of biodiesel and emission testing over the last two decades. So there is huge need of renewable fuel, which can be produce in endless manner. There are too many studies have been done on different sources for alternative of diesel fuel. Biodiesel is most suitable alternative fuel due to its physical properties and chemical properties comparable with conventional diesel fuel. Biodiesel can be produced from a non conventional and regenerative source of energy mainly biomass of both waste from agriculture, animal fats and vegetable oils. Biodiesel can be produce mainly by vegetable oils like edible and non-edible oils. We do not create biodiesel from edible oil at lager scale because the production of edible oils does not meet the needs of food. Non-edible oils along with moringa, jatropha, neem oil, babassu, safflower oil, and tobacco seed oil may be found in many countries, including India, where they can be used as a cheaper substitute for edible oils. Numerous studies have looked at the non-edible Karanja oil's numerous potential applications as a gasoline replacement because to its wide range of qualities. "Methyl ester of Karanja oil" and diesel combinations ranging from 20% by volume to 80% by volume were evaluated for their fuel properties by Reheman et al [1]. Reheman et al. evaluated the efficiency and emissions of "karanja methyl ester" and its mixes in a "single-cylinder, four-stroke, direct-injection, liquid-cooled diesel engine" operating at 3000 rpm with a compression ratio of 16:1. The feasibility of making biofuel using karanja oil through the methylation and ethyl substance pathways as a replacement gasoline for fuel was studied by Baiju et al. [2]. Using pure karanja oil in a compression ignition drivetrain is not recommended due to the oil's exceptional fluidity. Additional properties had been evaluated and contrasted to conventional diesel, including the fuel's ability to had its fluidity reduced by alcoholic trans-esterification. The operational attributes of direct injection internal compustion diesel engines are said to be affected by fuel injector force, as observed by Bakar et al. [3]. A two-stroke, four-cylinder, direct injection diesel engine was used for the tests. "Indicated power, indicated pressure, brake power, break mean effective pressure, and brake specific fuel consumption" (BSFC) were examined when fuel injector pressure was increased from 180 to 220 bar under both constant and dynamic conditions. The effects of liquid level on gasoline engine operation have been studied by Kalbandeet. et. al. [4], who also looked at the efficiency of diesel engines running on biofuels and biofuel blends with regular fuel and biofuel made from non-edible oils in a biofuel processor (transesterification). This processor was capable of producing oil esters of a high enough quality to power typical farm engines. According to them, in transesterification, the stirring speed was kept between 500 and 700 rpm, the temperature inside the reactor was kept between 55 and 600^{o}C, 200 ml/kg of vegetable oil methanol was used, KOH/NaOH varies between 0.5 and 1.0 gm/liter of vegetable oil and 1.0 ml/liter of vegetable oil (for pre-treatment) was used to make biodiesel from the vegetable oil. Thiruvengadaraviet et.al.[5] investigated that there is a large annual production of a variety of non-edible oils in India, which might be used to make biodiesel to supplement other conventional energy sources. Biodiesel production in India from non-edible oils would help down the cost of petroleum-based gasoline imports. In order to examine the efficiency of a "single-cylinder 4 stroke direct injection diesel engine", Kadu and Sarda [6] warmed neat karanja oil from 30 to 100 degrees Celsius. The effectiveness of the motor was studied between 1500 and 4000 revolutions per minute. 3 distinct combustion temp ranges and 2 injecting pressures were used in the experiments by Verma et al. [7] to evaluate 4 distinct blends of karanja methyl ester Biodiesel oil in diesel. The blends ranged in volume from 20 percent to 100 percent. Pure diesel was utilised at 300°C and 180 kg/cm2 for the controlling trial. Several authors, including Yadav, [8] Thus as per studies, biodiesel is among the best diesel fuel alternatives available worldwide. In India, there are a variety of plants and trees that might assist to meet the increasing energy needs. Different methods like trans-esterification process can be used to extract the oil from different plants; however, their conversion to biodiesel may consume the power at numerous steps, from the growth from initial stage to the final use as fuel in a CI engine. Saifuddin et. al [9] worked on reduction of the production costs, as biodiesel costs are much higher than petro-diesel. This opens up a good opportunity to use waste or recycled oil as a stock for their production.

1.1 Feedstock for biodiesel Production

Biofuels are the sustainable fuel that may be made from many materials, including organic waste, agricultural debris, and vegetable oils. Pugazhvadivu et. al [10] founded that there are more than 250 oil-producing crops of edible and non-edible vegetable oil. These vegetable oil crops can be utilized for generation of biodiesel. Palm oil, waste cocking oil, sunflower oil, mustered oil are some commonly used edible oil for biodiesel production. Saifuddin et. al.[11] told that currently, approximately more than 80% of biodiesel production is from edible vegetable oils. There are many issues have generated due to the consumption of vegetable oils for the generation of biodiesel (Ghosha et. al. [12]), It raise the debate of food versus oil because there are huge demands of vegetables oils for human consumption. So, non-edible oils should be used for production of biodiesel for overcome this issue. Vegetable oil biodiesel is a best suitable option for biodiesel production but there are various problems associated with uses of it directly for compression ignition engines (Meher et. al.[15]). These problems are as follows:

(i) Injector coking is major problem due to direct use of vegetable oil biodiesel.
(ii) It affects the atomization phenomenon.
(iii) More carbon deposition.
(iv) Sticking of oil rings.
(v) Plug orifice extension due to high firing point of biodiesel.

Everywhere you look today, the tide of protectionist sentiment is flowing because limited stocks of fossil fuels increase the demands of alternative fuel like biodiesel. Moreover, another big challenge is the physiochemical properties of biodiesel of non-edible oils. These physiochemical properties compared with conventional diesel fuel for uses as alternative fuel source.

2. Literature Review

Nair et al., 2021 [1] studied the large surface concentration of nanoparticles means that they enhance the catalytic process that occurs when biodiesel is burned. The presence of nanoparticles in fuel improves its radiative mass transition capabilities and shortens the time it takes to ignite. Karanja biodiesel was tested in a low duty diesel machine. Researchers looked at how adding "graphene nanoparticles to a Karanja methyl ester" mix altered the operation and pollutants of a diesel vehicle. Using an ultrasonicator, B20 and graphene nanoparticles were blended together. Some of the samples used for testing include B20, B20G25, B20G50, and B20G75. As far as functionality and pollutants concerned, graphene nanoparticle mixes were found to be on par with gasoline fuel. Pollutants including CO, HC, and NOx were cut down significantly when graphene nano molecules were added in comparison to diesel. Significant reductions in CO, NOx, and HC pollutants were seen at greater loads in the B20G75.

Bedar et al., 2021 [3] investigated a dual chamber four stroke CRDI engine is employed in conjunction with various cooler emission gases recirculating (EGR) rates and "Jatropha curcas biodiesel blends" made using the "Trans-esterification" method. Researchers examined the burning parameters of a consistent speed engine by measuring things including chamber compression, NHRR, MGT, and CHRR. It was determined via investigation that the JB20 fuel mix had the highest maximum burning force, heat, and NHRR. Since fuel-air combination is enhanced with increasing FIP, peak chamber force and peak gas temperature both rise with FIP. Increased EGR levels may result in the development of low-temperature flames, and the increasing amount of CO_2 and H_2O in the combination would result in delayed response times, both of which reduce the NHRR.

Krishna et al., 2019 [9] discussed that the engine operation and pollution levels are profoundly affected by the blend's fuel mix qualities, which in turn are tightly associated with the blend's constitution. Hence, it is necessary to determine the optimum mix proportion for "biodiesel-diesel-ethanol" (BDE) mixes to obtain the same specifications and functionality as gasoline. Unfortunately, the majority of quantitative computing approaches to optimizing a refineries prioritise economical limitations above practical engine function, leading to approaches that are impractical. In order to predict the ideal compositions for BDE blending, a complex optimized technique was developed. The goal was to achieve the highest possible gross thermal potential within a set of restrictions imposed by the properties of the fuels themselves. DBE blend qualities may be predicted using acceptable fuel blending methods. B y varying the ethanol percentage from 5% to 10%, researchers had seen how the diesel and biodiesel mix ratios change in response to these changes. The attributes of BDE blends that are found to fulfil superior diesel fuel grade criteria are next evaluated experimentally. An ideal ratio was found to be 78% diesel, 17% biodiesel, and 5% ethanol, with this combination satisfying all important fuel property requirements and showing the smallest net heating value divergence above diesel (4.3%). Researchers found that BDE mixes with the right proportions produced diesel-like fuel qualities, engine operation, and pollutant characteristics.

Samuel et al., 2022 [10] studied the lack of relationships for estimating biodiesel's boiling temperature prohibits fuel consumers from optimising engine operation. Boiling temperature is an essential qualitative controller of fundamental fuel qualities that is seldom discussed in the research, which in turn hinders fuel processors from achieving optimal function of the engine. "Response Surface Methodology" (RSM) and "Particle Swarm Optimization" (PSO) were used to delve into the process of "sunflower oil methanolysis". T he biodiesel MBP was modelled against the biodiesel percentage and the biodiesel MBP was modelled against the kinematic viscosity using analytical modelling methods. When compared to the RSM approach, the PSO framework had a lower value of "root mean squared errors" and a higher "coefficient of determination". PSO's anticipated values, in comparison to RSM's expected yield, demonstrate its reliability and convenience for prediction without stringent testing. Effective methods for investigating the creation of methylic biodiesel from WSO have been shown using RSM with PSO. Both the MBP and the kinematic viscosity were shown to be associated with the bio-diesel percentage using "least square regression" and the "parabolic equation", respectively.

Okoro and Ezeakacha 2021 [16] discussed that Biodiesel is viewed as the nearest substitute to gasoline because to its price, ecological effect, and renewable energy concerns. Rubber oil, which is not consumable, was utilised to generate biodiesel, and its "cetane number, kinematic viscosity, and yield were optimised". Â Biodiesel synthesis modelling and optimisation utilising RSM. 30 trans-esterification studies through CCD were conducted in the laboratory. A parameterized investigation of the trans-esterification reactive characteristics indicated that yields, dynamic viscosity, and cetane number depended more on methanol to oil ratio, reaction duration, and reactivity temperature than on catalyst quantity. Maximum performance predictions utilising computational optimisation approaches were found at 151 min, 48, 8.2:1 methanol-to-oil ratio, and 1.2% catalyst concentration. Verification trials employing ideal settings indicated a tight relationship between expected and real results. Laboratory-produced rubber oil biodiesel was analysed for its physiochemical and fuel characteristics. Findings showed that biodiesel may be blended with Conventional diesel.

3. Experimental Setup

The objectives of this work is to find out the possibility of using biodiesel made from the seeds of Karanja trees in different proportions with conventional diesel by evaluating the discharge features of a "single cylinder, 4- stroke DI diesel engine". Moreover, it is also aimed to find out the optimal concentration of biodiesel blend, to observe whether there is any specific combustion related problem of biodiesel fuel with unmodified C.I engine. The various stages of experimentation are planned out as shown in figure.

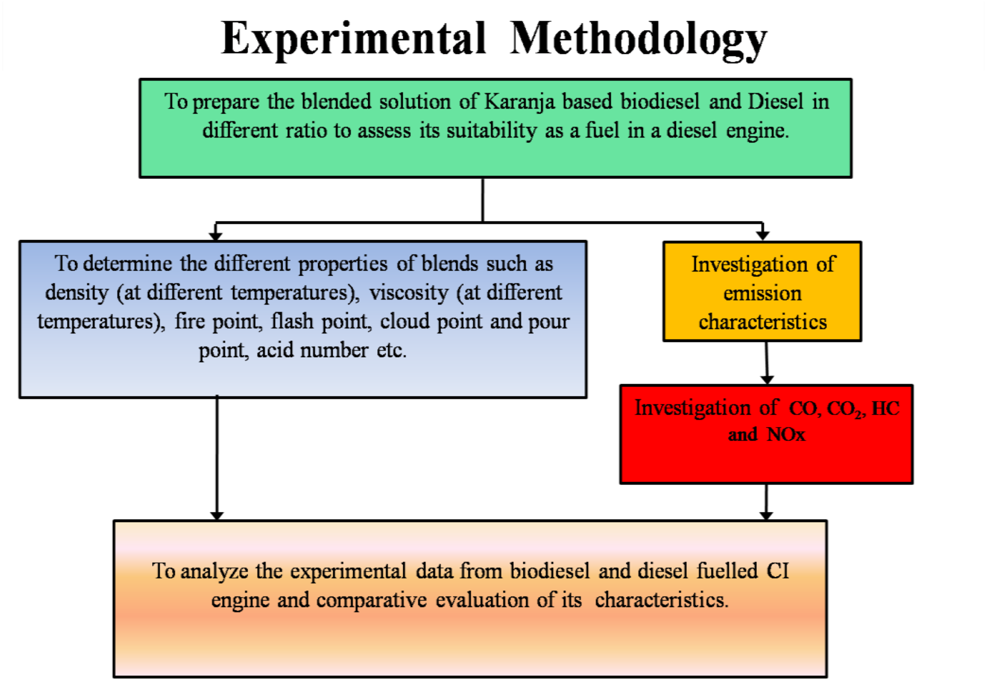

Figure 1. *Experimental Methodology steps*

3.1. Sample Preparation

In the present work, Karanja biodiesel is purchased from India mart seller and prepared the blends in different composition like KB5 means 5% biodiesel and 95 % diesel fuel, KB10, KB15, KB20 and KB100. Karanja oil and biodiesel at purest form is shown in figure 2 (a) and (b) respectively.

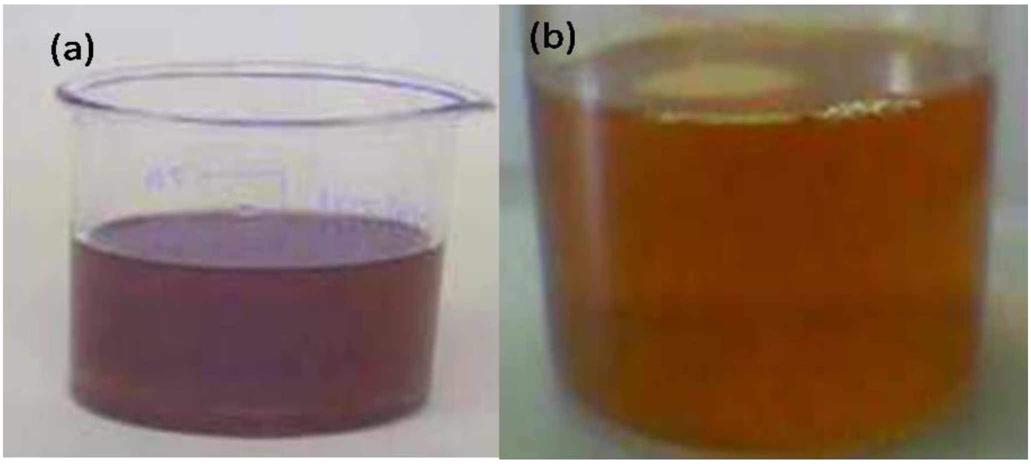

Figure 2. *(a) Karanja oil and (b) Karanja biodiesel*

3.2. Experimental Engine setup

In this engine setup, output shaft is attached with dynamometer to get different load conditions. Cooling water circulation must be ensured for eddy current dynamometer.

Parameters for the engine used in the assessment are shown in Table 1.

Table 1. *Engine Specifications*

Specification	Description
Details	Single Cylinder, DI, Four Stroke
Model	TV1
Manufacturer	Kirloskar
Bore and Stroke	87.5mm, 110mm
C R	17.5:1
CC	661
Brake Power	5.2KW @ 1500rpm
Orifice Diameter	20mm
Cooling	Water
Inlet Valve Opening and Closing	At 4.5^0 Before TDC and at 35.5^0 After BDC
Exhaust Valve Opening & Closing	35.5^0 Before BDC & $4.5\ ^0$After TDC
Injection of Fuel Start	23^0 Before TDC
"Eddy Current a Dynamometer"	"Model AG10, Saj Test Plant Pvt. Ltd."
Drum Brake Diameter	185mm
Load Sensor	Make Sensotronics SanmarLtd., Model 60001,Type S beam, Capacity 0-60 kg

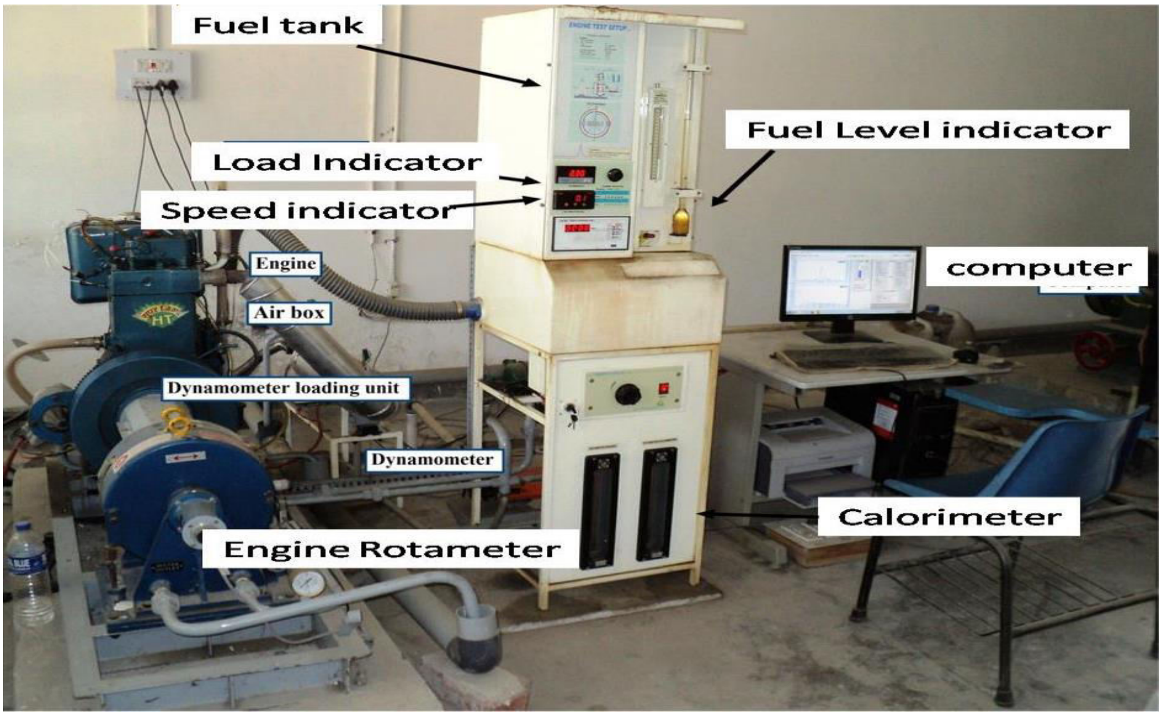

Figure 3. *Experimental Engine Setup*

There are some sensors used like injection pressure sensors for measuring the injection pressure and cylinder pressure, temperature sensors are utilised to calculate the temperature of different stages of combustion and exhaust gas temperature. Load sensor is also attached with this engine set up which is used for measuring the different loads at different stages of experimental investigation. Figure 3 depicts the experimental configuration, which of a single-cylinder, 4-stroke, DI Diesel.

3.3. emission measurement setup

2.3.1. Exhaust Gas Analyzer

All emissions like CO, CO2, unburned hydrocarbons, NO are found in exhaust gas emission analyzer. Both the analyzer's input and the emission gases outflow are linked to one endpoint of the line. In order for the analysis to function properly, it must be permanently connected to a power source. The Exhaust Gas Analyzer is shown in Figure 4 and is connected to the engine exhaust. EGA relies on the "Non-Dispersive Infrared Absorption Method," that is founded on the theory of wavelength acquisition in the infrared range. A container full with methane gas is exposed to the infrared light. An illumination source produces these rays. This methane vapor absorbs light at a certain spectrum, and scientists may use this fact to determine how much of each gas is present. At the exit of the container, a pyro-electric sensor is utilised to measure the light after a narrow spectrum optically filtering has eliminated all other spectrums.

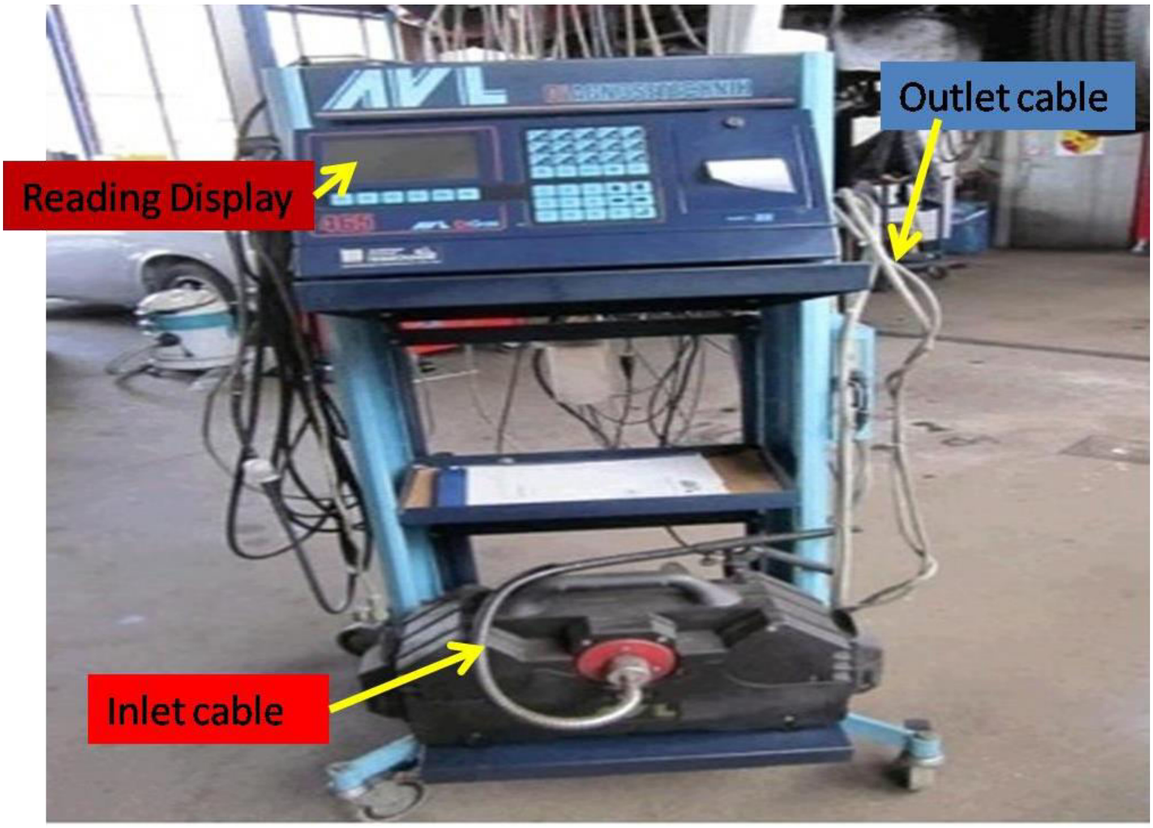

Figure 4. *Exhaust Gas Analyzer*

4. Results

4.1. Physico-Chemical Properties of Samples of Blends of Diesel and Karanja biodiesel

Karanja oil biodiesel is used in different proportion for preparing the blends in 5%, 10%, 15%, 20% by weight percentage with diesel fuel and the physicochemical properties were calculated by different methods which is specified by BIS and ASTM and the results were reported in table 2. These observations compared with conventional diesel and found that KB5 is show the better result as compare to other blends. Mohite et al., [24] reported that physical properties of Karanja biodiesel are similar to diesel fuel. Saleh et al. [25] reported that physical properties of karanja biodiesel have similarity at some points.

Table 2. *The different properties of karanja biodiesel-diesel blend by volume*

S.NO.	Properties	Diesel	KB5	KB10	KB15	KB20	KB100
1	Flash Point (^{0}C)	52	54	61	74	86	168
2	Fire Point (^{0}C)	63	67	73	83	97	181
3	Cloud Point(^{0}C)	5	5	6	6.1	6.6	7
4	Pour Point(^{0}C)	3	4.1	4.7	5	6	6.2
5	K.Viscosity (cstat30 ^{0}C	2.71	2.95	3.23	3.48	3.69	7.67
6	Specific Gravity	0.829	0.836	0.841	0.848	0.852	0.878
7	Calorific Value (MJper kg	42	41.578	41.271	40.963	40.659	36.25

4.2. Effect of temperature on the kinematic viscosity

Kinematic viscosity plays an important role in case of biodiesel utilization as an alternative fuel of diesel. Pure Karanja biodiesel fuel has higher viscosity as compare to diesel so it is very difficult to directly use of it in diesel engine. So there is urgent need of reduction of viscosity. It is found that the kinematic viscosity changed with change in temperature. The kinematic viscosity decreased with increase in temperature of fuel (Figure 5).

Table 3. *The effect of temperature on the kinematic viscosity of different blends*

S.NO.	Fuel	Viscosity(cst) at 20 ^{0}C	Viscosity(cst) at 30^{0}C	Viscosity(cst) at 40^{0}C
1	Diesel	2.92	2.71	1.93
2	KB5	3.82	2.95	2.62
3	KB10	4.62	3.23	3.16
4	KB15	5.22	3.48	3.30
5	KB20	6.19	4.02	3.34
6	KB100	10.24	7.67	4.87

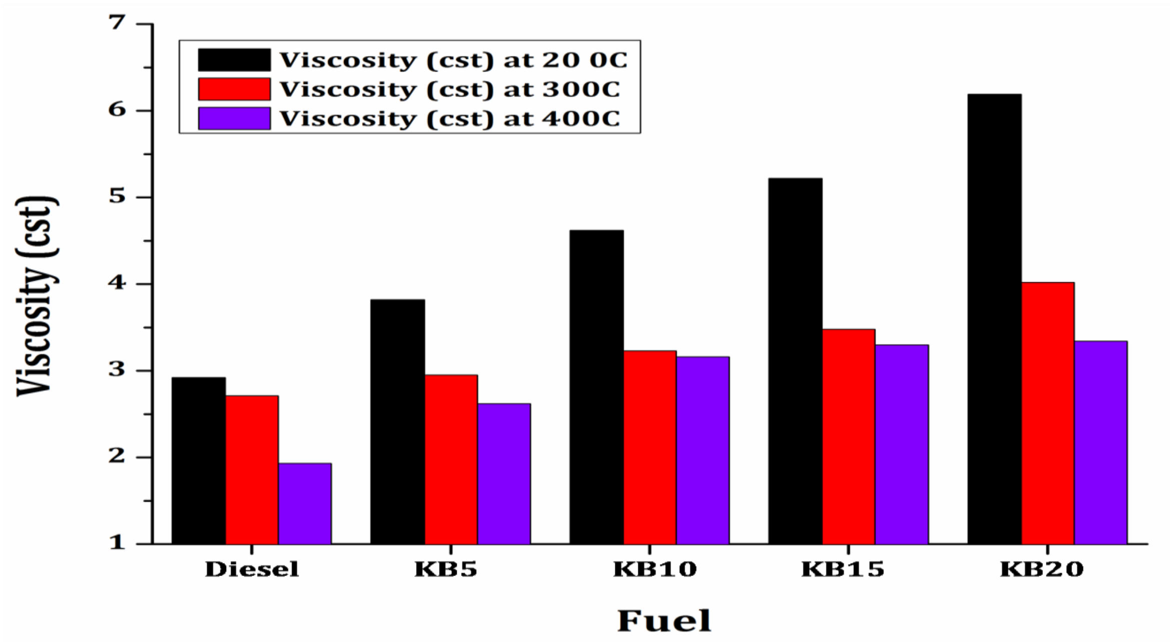

Figure 5. *Viscosity (cst) VS Temprerature*

4.3. Combustion Characterstics

4.3.1. Carbon Monoxide (CO)

The figures 6(a) and (b) show the CO emission at different load conditions. It is observed from figure that at no load condition diesel emited much more carbon monoxide as compare to other blends. It is observed that when load is increased then emission of CO decreased because of completed combustion is take place. But at all load fossil fuel diesel produce the more percentage of CO as compare to other blends because of improved combustion for all blends of biodiesel. Among all the blends KB15 produce less amount of carbon monoxide because it have 7% to 8% more oxygen as compare to other fuels. Singh et. al. [26] founded that CO emission percentage decreases with increased engine load and compression ratio because of complete combustion process takes place due to more amount of oxygen contents.

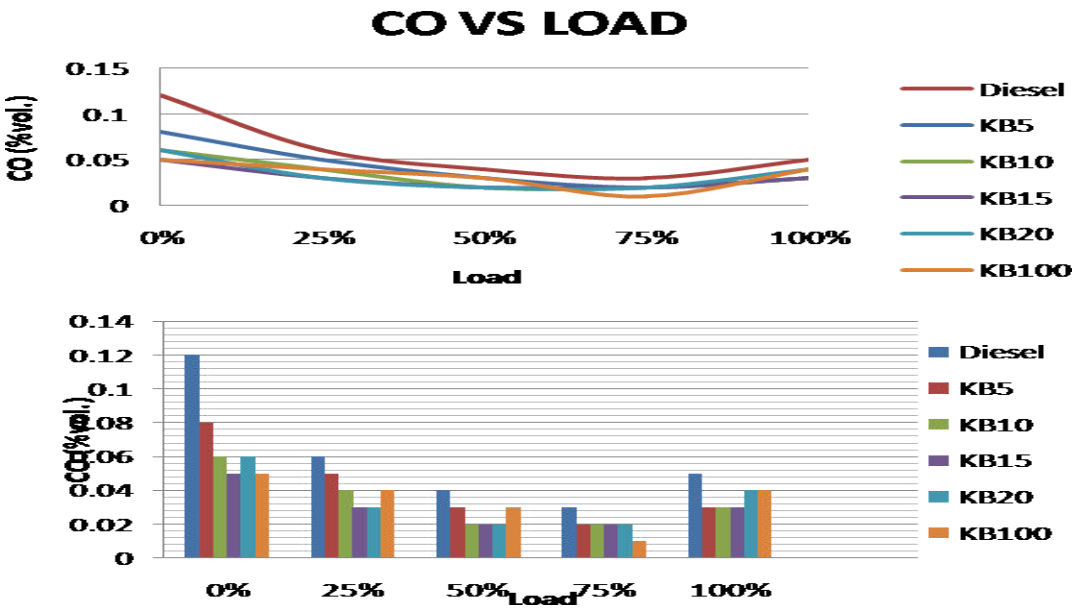

Figure 6. *(a- b) CO v/s Load*

4.3.2. Carbon Dioxide (CO2)

The figures 7 (a) and (b) show the CO_2 emissions at different load conditions. Initially, at no load condition, diesel and KB100 produce more CO_2 as compare to other fuel. It has been observed from the graph that on increasing the load, the percentage of carbon dioxide increased due to increased mass of fuel. At 50% and 100% load condition KB15 produce the less carbon dioxide. Sivaramakrishnan [27] also found that amount of carbon dioxide is increased with increased load which gives the sign of complete combustion of fuel.

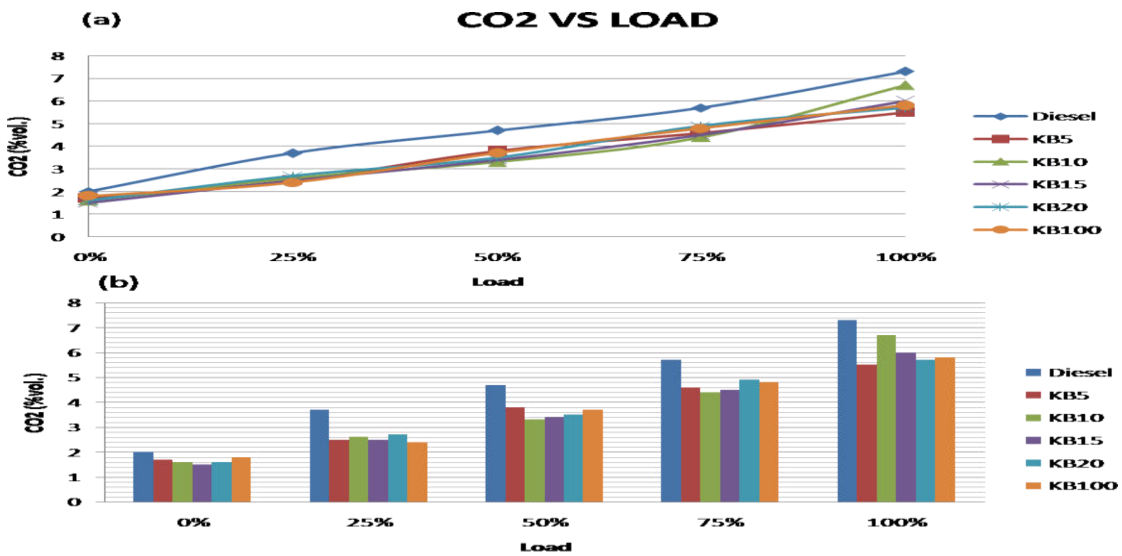

Figure 7. *(a-b) Carbon Dioxide v/s Load*

4.3.3. Hydrocarbon (HC)

The figures 8(a) and (b) show the hydrocarbon (HC) emission at different load conditions. At 0% load diesel, KB5, KB10, KB15, KB20 and KB100 emit 41, 38, 39, 40, 38 and 35 ppm hydrocarbon respectively. At 0% and 25% load condition KB100 produce the lower percentage of hydrocarbon because of good combustion of fuel as compare to other blends of biodiesel. It has been observed from the graph that up to 75% loading condition biodiesel blends produce fewer hydrocarbons because the component in blended fuel have greater molecular weight on average than those in diesel fuel and this results in higher boiling point and condensing temperature. At full loading condition biodiesel blends produce more hydrocarbons as compare to diesel because richer mixture formation due to more amounts of fuel injected and combustion process affected so that un-complete combustion takes place. Srivastava and Verma [28] also reported that HC amount increases as the load is increased on engine for biodiesel blends.

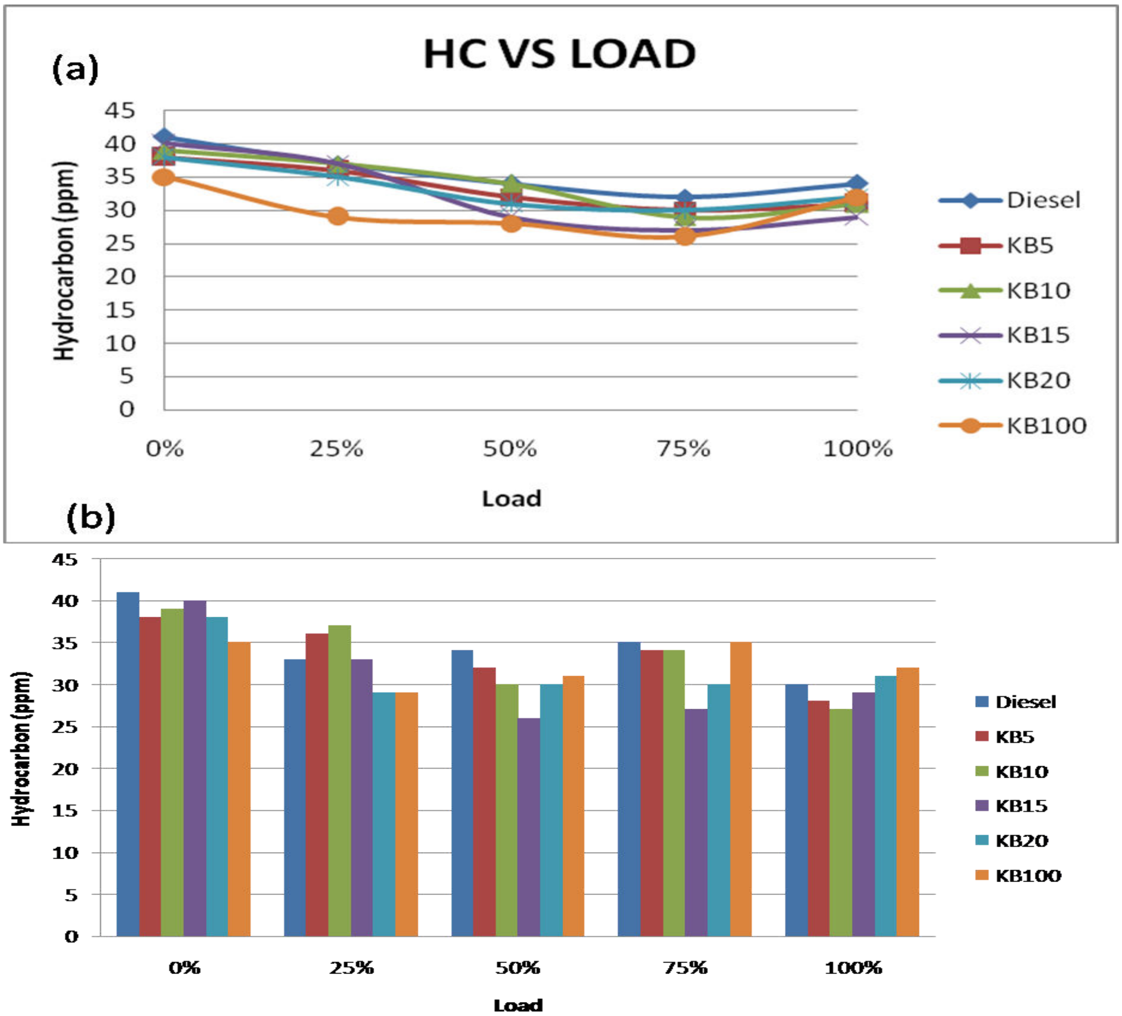

Figure 8. *(a-b) Hydrocarbon v/s Load*

4.3.4. Nitrogen Oxides (NO)

The variation in nitrogen oxides (NO) for different loads and fuel is shown in figures 9 (a) and (b). At 0% load condition KB100 produces the higher NO as compare to other blends. It is observed that as the concentration of biodiesel increases, the amount of NO increases in emission because mass of blended fuel increase which results in higher temperature produce on burning of fuel.

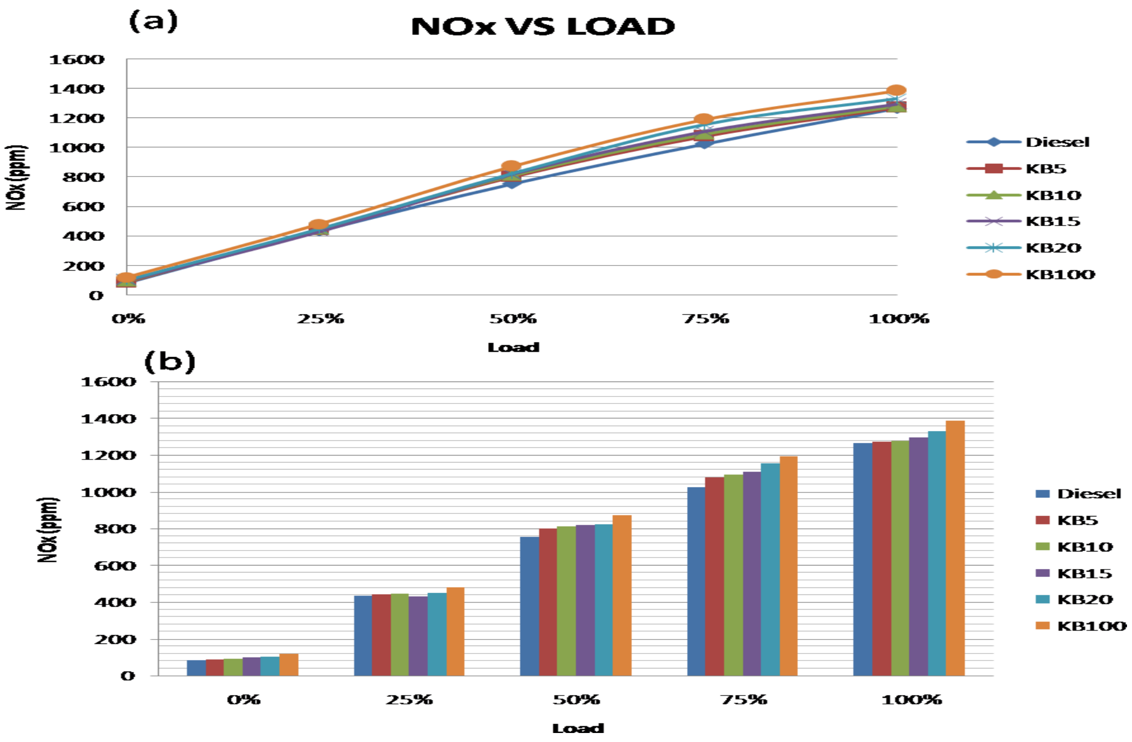

Figure 9. *(a-b) Nitrogen Oxides v/s Load*

It is also observed from the graph that NO concentration is increased along with increase in load percentage. At all load condition KB100 produce higher amount of NO in emission. Srivastava and Verma [28] also reported that biodiesel blends produce high amount of NO as compare to diesel and NO is directly proportional to the engine load.

5. Conclusions

Based on the findings of investigational data with a single-cylinder, four-stroke, direct-injection diesel engine using biodiesel-diesel mixes as fuel, it has been concluded that physical properties like fire point, cloud point, pour point, etc of Karanja biodiesel blends KB10 and KB15 have comparability and similarities as diesel but KB20 and KB100 have more difference in properties compared to diesel. On the viscosity point of view KB15 have nearly same value of kinematic viscosity at 40^0C compared to diesel but KB20 and KB100 have high value of viscosity than diesel fuel. It has also been concluded that Biodiesel and its blends with diesel have higher mean gas temperature than diesel because it have 8% to 9% excess oxygen composition which contribute to better combustion and density and bulk modulus of biodiesel is playing the role of another factor as compare to diesel. High mean gas temperature contributes more NO emission. Biodiesel blends have less CO and CO_2 than diesel at all load condition because it have 8% to 9% more oxygen compared to diesel due to this better combustion takes place. KB15 produce less CO among all the fuel blends. KB100 have higher amount of unburned hydrocarbon compare to diesel fuel at full load condition because more amount of fuel injected at full load condition due to which richer mixture form and un-complete combustion takes place. But at all loading condition, KB15 produce 5% less unburned hydrocarbon than diesel. Increase the concentration of biodiesel the amount of NOx increased in emission because mass of blended fuel increased this result is higher temperature on burning of fuel. At all load condition KB100 increase the NO up to 25% in emission.

Refrences

Nair, Jayashri, Putha Prasad Kumar, Amit Kumar Thakur, Samhita, and Aravinda. "Influence on emissions and performance of CI engine with graphene nanoparticles blended with Karanja biodiesel." In AIP Conference Proceedings, vol. 2317, no. 1, p. 020017. AIP Publishing LLC, 2021.

Baiju, B., Naik, M.K. and Das, L.M., 2009. A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of Karanja oil. Renewable energy, 34(6), pp.1616-1621.

Bedar, Parashuram, K. Santosh, and G. N. Kumar. "Combustion analysis of cylinder pressure, NHRR, MGT and CHRR of twin cylinder CRDI engine." In AIP Conference Proceedings, vol. 2316, no. 1, p. 030033. AIP Publishing LLC, 2021.

Surendra R. Kalbande, Subhash D. Vikhe, “Jatropha and karanja biofuel: An alternative fuel for diesel engine”, ARPN journal of engineering and applied sciences, 2008, 3 (1).

K.V. Thiruvengadaravi, J. Nandagopal, V. SathyaSelvaBala, S. Dinesh Kirupha, P. Vijayalakshmi and S. Sivanesan, “Kinetic study of the esterification of free fatty acids in non-edible Pongamiapinnata oil using acid catalyst”, Indian journal of science and technology, 2009, 2 (12).

Sagar PramodraoKadu, Rajendra H. Sarda, “Experimental Investigations on the use of preheated neat karanja oil as fuel in a compression ignition engine”, International journal of mechanical and materials engineering, 2010,1 (3).

Dilip Kumar Bora, L M Das and M K G Babu , “Wear and tear analysis of single cylinder diesel engine using karanja biodiesel (B20) after 512 hours”, Journal of scientific & industrial research,2010, 69, 639-642.

Yadav, A., Singh, O. and Kumar, N., 2010. Evaluation of Energy Ratios for Karanja and Neem Biodiesel Life Cycles. SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology, 1(01), pp.55-59.

Krishna, Sachin Muralee, P. Abdul Salam, Manida Tongroon, and Nuwong Chollacoop. "Performance and emission assessment of optimally blended biodiesel-diesel-ethanol in diesel engine generator." Applied Thermal Engineering 155 (2019): 525-533.

Samuel, Olusegun D., Mohammad Kaveh, Oluwayomi J. Oyejide, P. V. Elumalai, Tikendra Nath Verma, Kottakkaran Sooppy Nisar, C. Ahamed Saleel et al. "Performance comparison of empirical model and Particle Swarm Optimization & its boiling point prediction models for waste sunflower oil biodiesel." Case Studies in Thermal Engineering 33 (2022): 101947.

Fathi, M., Saray, R.K. and Checkel, M.D., 2010. Detailed approach for apparent heat release analysis in HCCI engines. Fuel, 89(9), pp.2323-2330.

Ozsezen, A.N. and Canakci, M., 2011. Determination of performance and combustion characteristics of a diesel engine fueled with canola and waste palm oil methyl esters. Energy Conversion and Management, 52(1), pp.108-116.

Ghosha, B., Haldar, S.K. and Nag, A., 2008. Synthesis of biodiesel from oils of Jatropha, karanja and putranjiva to utilize in engine and its performance and emission measurement, proceedings of the 4th BSME-ASME. In International Conference on Thermal Engineering (pp. 27-9).

Stalin, N. and Prabhu, H.J., 2007. Performance test of IC engine using karanja biodiesel blending with diesel. ARPN Journal of Engineering and Applied Sciences, 2(5), pp.32-34.

Nagarhalli, M.V., Nandedkar, V.M. and Mohite, K.C., 2010. Emission and performance characteristics of karanja biodiesel and its blends in a CI engine and it’s economics. ARPN Journal of Engineering and Applied Sciences, 5(2), pp.52-56.

Okoro, Gideon Onyekachi, and Samuel Ikechukwu Ezeakacha. "Validation of Optimal Conditions of the Functional Properties of Rubber Seed Oil-Derived Biodiesel." International Journal of Renewable Energy Research (IJRER) 11, no. 1 (2021): 332-343.

El Sherbiny, S.A., Refaat, A.A. and El Sheltawy, S.T., 2010. Production of biodiesel using the microwave technique. Journal of Advanced Research, 1(4), pp.309-314.

Pandey, A.K. and Nandgaonkar, M.R., 2011, July. Experimental investigation of the effect of Esterified Karanja oil biodiesel on performance, emission and engine wear of a military 160hp Turbocharged CIDI engine. In Proceedings of the world congress on engineering (Vol. 3, pp. 6-8).

Yadav, A., Singh, O. and Kumar, N., 2010. Evaluation of Energy Ratios for Karanja and Neem Biodiesel Life Cycles. SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology, 1(01), pp.55-59.

Agarwal, A.K. and Rajamanoharan, K., 2009. Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine. Applied energy, 86(1), pp.106-112.

Di Blasio, G., Beatrice, C., Dijkstra, R. and Boot, M., 2012. Low cetane number renewable oxy-fuels for premixed combustion concept application: experimental investigation on a light duty diesel engine (No. 2012-01-1310). SAE Technical Paper.

El-Seesy, A.I. and Hassan, H., 2019. Investigation of the effect of adding graphene oxide, graphene nanoplatelet, and multiwalled carbon nanotube additives with n-butanol-Jatropha methyl ester on a diesel engine performance. Renewable Energy, 132, pp.558-574.

Nour, M., El-Seesy, A.I., Abdel-Rahman, A.K. and Bady, M., 2018. Influence of adding aluminum oxide nanoparticles to diesterol blends on the combustion and exhaust emission characteristics of a diesel engine. Experimental Thermal and Fluid Science, 98, pp.634-644.

Harreh, D., Saleh, A.A., Reddy, A.N.R. and Hamdan, S., 2018. An experimental investigation of karanja biodiesel production in Sarawak, Malaysia. Journal of Engineering, 2018.

Harreh, D., Saleh, A.A., Reddy, A.N.R. and Hamdan, S., 2018. An experimental investigation of karanja biodiesel production in Sarawak, Malaysia. Journal of Engineering, 2018.

Singh, A., Sinha, S., Choudhary, A.K., Sharma, D., Panchal, H. and Sadasivuni, K.K., 2021. An experimental investigation of emission performance of heterogenous catalyst jatropha biodiesel using RSM. Case Studies in Thermal Engineering, 25, p.100876.

Sivaramakrishnan, K., 2018. Investigation on performance and emission characteristics of a variable compression multi fuel engine fuelled with Karanja biodiesel–diesel blend. Egyptian Journal of Petroleum, 27(2), pp.177-186.

Srivastava, P.K. and Verma, M., 2008. Methyl ester of karanja oil as an alternative renewable source energy. Fuel, 87(8-9), pp.1673-1677.

Prakash, N., Jose, A.A., Devanesan, M.G. and Viruthagiri, T., 2006. Optimization of Karanja oil transesterification.

Kalbande, S.R. and Vikhe, S.D., 2008. Jatropha and Karanj bio-fuel: an alternate fuel for diesel engine. ARPN J Eng Appl Sci, 3(1), pp.7-13.