Experimental Investigations on Effect of Karanja Biodiesel on Engine Performance, Combustion and Durability in Collaboration with Shell Technology India Private Limited

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Introduction

Domestic consumption of mineral diesel in India accounted for approximately 16% of the total imports valued about INR 3.4 lakh crores in 2011-12 [1]. This indicates the economic stress on the country due to diesel consumption. With depletion of fossil fuels in the foreseeable future, this pressure will certainly increase. Utilization of fossil transportation fuels has significant contribution to the global warming and urban air pollution. Therefore, alternative fuels, which promise sustainable development with security of supply and lesser environmental implications, are required. Fuels for transport sector require additional challenges of sufficient energy density and lower pollutant emission potential because their exhaust products are emitted directly into the ambient air, which affects human health. Biodiesel, which can be produced from edible and non-edible straight vegetable oils, recycled waste vegetable oils and animal fat through transesterification by converting triglycerides into fatty acid alkyl esters is one such alternative fuel, which can be used as partial substitute of fossil based diesel [2-5]. Biodiesel is the name of a clean burning mono-alkyl ester based oxygenated fuel made from natural, renewable resources such as raw/ used vegetable oils and animal fats. Edible and non-edible straight vegetable oils are converted into biodiesel by using the process of transesterification. Transesterification is the reaction of triglycerides present in the vegetable oils with primary alcohols in presence of a catalyst, which produces primary esters (referred as "biodiesel") and glycerol [6]. Properly planned implementation of major program for promotion of biodiesel in India may result into following advantages.

- Biodiesel has CI engine compatible fuel characteristics, indicating a possibility of it being used as a diesel substitute with none or minor hardware modifications in the engine system. It will not put any significant extra cost on existing engine power-trains.
- Blending biodiesel with mineral diesel can compensate for the loss of fuel lubricity in low sulfur diesel because sulfur content is being reduced in diesel fuels, in order to make them compatible with EURO-IV or higher emission standards [7].
- Utilization of biodiesel is helpful in reducing greenhouse gas (GHG) emissions because vegetable oil production consumes large part of carbon dioxide, which is produced during combustion of these fuels in the engines. Blends of diesel and biodiesel may also be helpful in reducing harmful gaseous and particulate emissions from the engine, which will help in meeting stringent automotive emission norms.
- Biodiesel is a safer fuel in comparison to mineral diesel, for storage and handling, because its flash point is approximately 100°C higher than mineral diesel [7].
- It is compatible with the existing mineral diesel infrastructure for fuel delivery and transportation as in pure or blended form.
- Biodiesel may be produced from locally available feedstock resources. Hence development of biodiesel industry would strengthen domestic industrialisation, in particular, rural agricultural economy of developing countries like India and would generate significant rural employment.
- Biodiesel production using presently under-utilized high salinity lands and waste-lands will be helpful in checking soil erosion thus preventing land degradation. In the process, it would also provide resources for livelihood of rural poor living in areas with highly degraded lands.

For large-scale implementation of biodiesel, key areas for improvement include more efficient catalyst recovery, improved purification of the co-product glycerol for cost reduction, planning large-scale use of glycerol (because production volume of glycerol will increase with increasing production of biodiesel), increasing shelf life of biodiesel and enhanced feedstock flexibility [8]. With the development of technology, production of biodiesel from micro-algae based oil may reduce stress on land and water and make the large scale implementation of biodiesel feasible [8-9, 10].

Background

In view of these advantages and the unique position India enjoys as far as biodiesel is concerned, a collaborative research project by Shell Technology India Private Limited and Engine Research Laboratory (ERL), IIT Kanpur was started in year 2007 with major focus on issues like characterization and standardization of biodiesel production process for optimum yield and quality, effect of biodiesel on fuel injection system, and wear of engine components upon long-term usage, and effect of biodiesel on lubricating oil life during an engine durability test etc.

Project Objectives

Following project objectives were identified for this project sponsored by Shell:

- Characterization of fuel properties of biodiesel produced from Karanja oil and mineral diesel.
- Determination of the effect of biodiesel and its blends on the performance and emission characteristics of a medium duty transportation engine vis-à-vis mineral diesel.
- Analysis of the in-cylinder combustion parameters for understanding the behavior of biodiesel.
- Determination of the effect of biodiesel on engine wear upon long-term usage vis-à-vis mineral diesel.
- Determination of the effect of new fuel on the lubricating oil vis-à-vis mineral diesel.

Implementation

All major engine fuel property characterization and biodiesel engine compatibility investigations were executed by ERL, IIT Kanpur with close involvement of Shell Global and Shell Technology India Private Limited. Inspiration from Prof. Gautam Kalghatgi, Shell, Chester, UK for starting the collaborative activities and his personnel involvement were very crucial for starting this project. He personally visited IIT Kanpur and several other Indian universities to start collaboration between Shell and Indian universities. With his constant involvement, project objectives and methodology were refined for making the project more fruitful and application oriented. During discussions with him, it emerged that production of Jatopha oil for making the biodiesel was not going to meet expected yield therefore it was decided to use Karanja oil for making biodiesel rather than Jatropha, as was mentioned in the beginning of the project proposal. Another reason for this choice was the indigenous origin of Karanja tree, which makes it well adapted to all soil types and climatic conditions in India. It resists drought very well and is moderately forest hardy and highly tolerant to salinity [11] therefore it emerged out to be the natural choice for implementation of the project. In the initial phase of this project, Ms. Usha Soni and Dr. Donald Reinalda were co-coordinating the activities from Shell Technology India Private Limited, Bangalore. Later on, Dr. Girish Rao and Mr. Kushan Biswas took charge from the side of Shell Technology India Private Limited, Bangalore. All project managers in Shell got actively involved and provided very important suggestions and inputs during execution of this project, by their personal visits to the institute from time to time. As an attempt to share the concerns of Shell regarding industrial and research environment safety, which is strongly emphasized and is a valuable part of Shell working culture globally, a safety seminar was organized in IITK. Shell HSE experts visited ERL and evaluated the safety measures in the ERL in general and experimental setup used for this project in particular. For increasing general awareness in the institute regarding safety, Shell also organized a one day workshop and an Institute lecture on safety issues in 2008. This effort from an industrial partner helped initiate many changes and improvements in the safety practices in ERL and other laboratories in the Institute. ERL now has almost all required safety measures and has extremely safe working environment. Students working on the project got an opportunity to visit Shell Technology Research Centre in Bangalore annually. This enabled them to understand the requirements and culture of industrial research. Final report and findings of this project were presented to Shell on February 19, 2012 during one day visit by the principal project investigator from IITK and the research student to Shell Technology Research Center, Bangalore.

Effect of Karanja Biodiesel on Engine Performance

A typical medium-duty transportation engine (Mahindra and Mahindra, India; MDI 3000) was used for comprehensive experimental investigations of the effect of Karanja biodiesel blends on engine performance, emission, combustion and long-term utilization effects on engine durability and lubricating oil degradation (figure 1). KOMEXX indicates the XX percent of Karanja oil methyl ester (Karanja biodiesel) and (100-XX) percent mineral diesel in the test fuel blend. Comparative experimental investigations of engine performance parameters of Karanja biodiesel blends and mineral diesel indicated that maximum engine torque produced by KOME10 and KOME20 was higher than mineral diesel. Average 0.7% and 0.3% increase in torque were obtained for KOME10 and KOME20 respectively in comparison to mineral diesel. Maximum torque for KOME05 fuelled engine was almost similar to mineral diesel. Average reduction of 1.4% and 2.1% in torque was observed for KOME50 and KOME100 in comparison to mineral diesel. Higher biodiesel blends produced lower torque compared to mineral diesel.

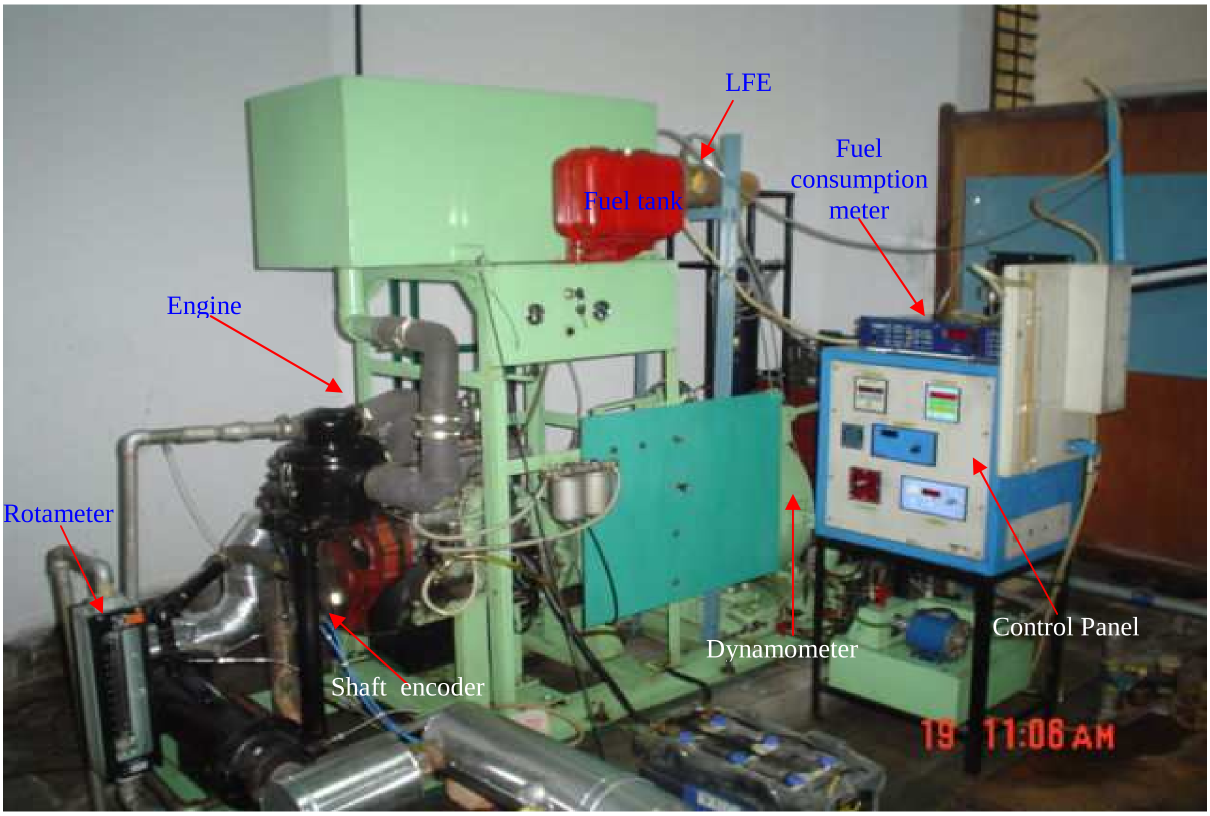

Figure 1: Experimental setup used in the project for engine tests on Karanja biodiesel and its blends

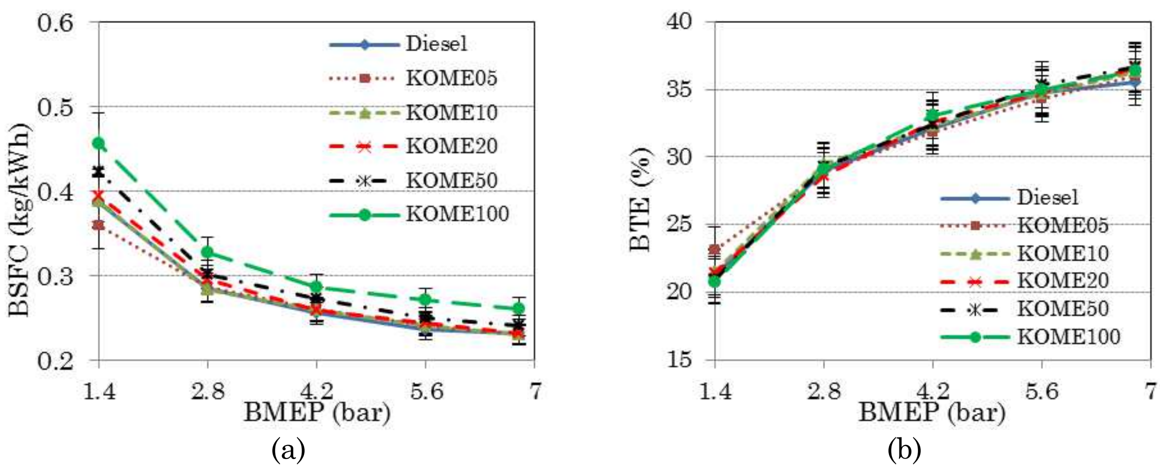

Figure 2: Variation of (a) BSFC and (b) thermal efficiency of Karanja biodiesel blends with engine load

Brake specific fuel consumption (BSFC) was higher for biodiesel blends due to lower calorific value of biodiesel (figure 2(a)). Differences in the BSFC of higher biodiesel blends and mineral diesel were higher at lower engine loads and they reduced at higher loads. The thermal efficiency was generally found to increase with engine load for all test fuels at all test speeds (figure 2(b)). At higher engine loads, brake thermal efficiency of biodiesel blends and mineral diesel were almost identical.

At higher engine speeds and loads, biodiesel blends produced lower CO emissions in comparison to mineral diesel (figure 3(a)). But at lower engine loads, CO emissions of higher biodiesel blends were found to be higher than mineral diesel. It was observed that total hydrocarbon (THC) emissions of Karanja biodiesel blends were lower than mineral diesel (figure 3(b)). THC emissions for all test fuels were higher at lower engine loads and quantity of THC emissions decreased with increasing engine load. It was observed that NOx emissions were higher for Karanja biodiesel blends in comparison to mineral diesel, particularly at higher engine speed and loads (figure 3(c)).

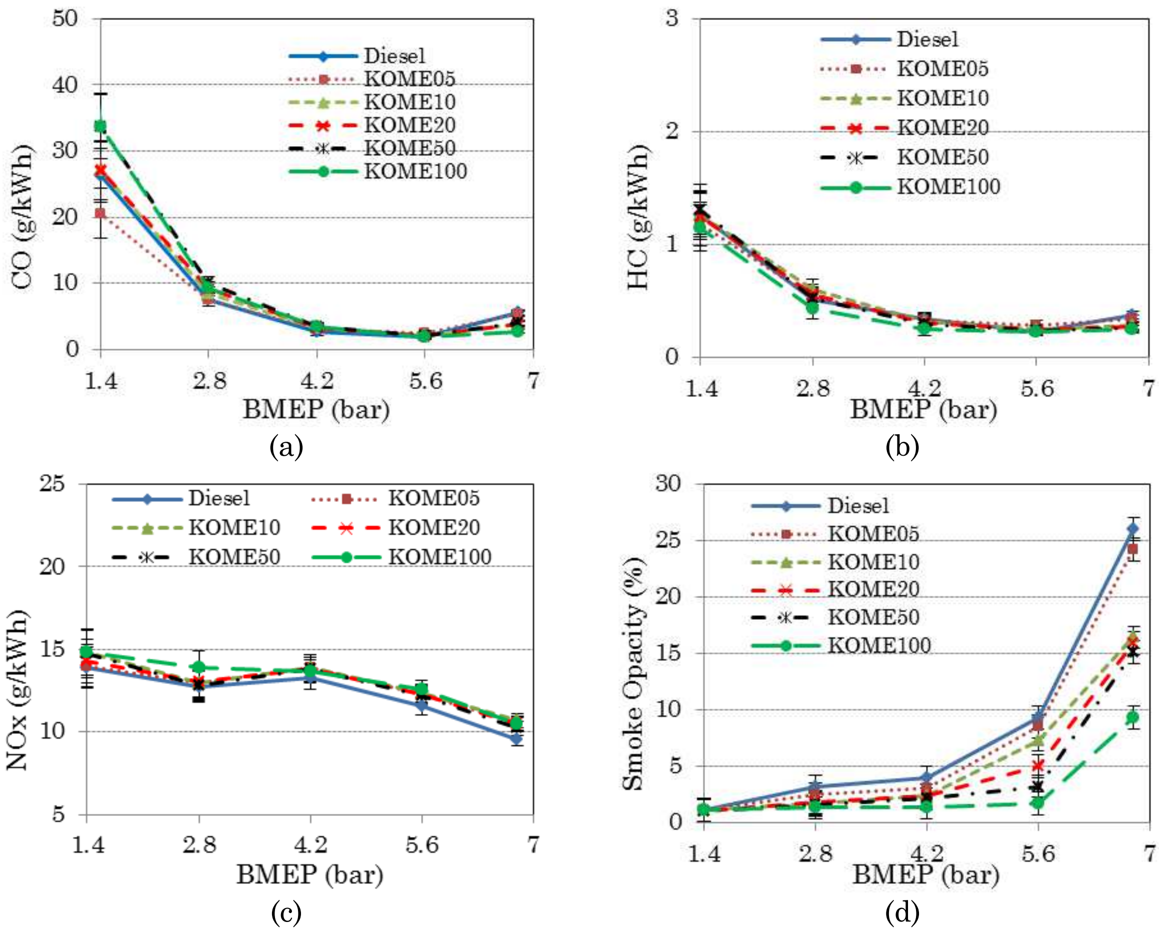

Figure 3: Variation of (a) BSCO, (b) BSHC, (c) BSNOx and (d) smoke opacity of Karanja biodiesel blends with engine load

Smoke opacity of exhaust is a qualitative indicator of amount of larger diameter particulates, which are large enough to scatter the incident light. It was observed that at lower engine loads for all test fuels, smoke opacity was almost identical at all engine speeds (figure 3(d)). At higher engine loads, smoke opacity decreased with concentration of Karanja biodiesel in the test fuel, indicating that Karanja biodiesel was helpful in reducing particulate emissions.

<u>Effect of Karanja Biodiesel on Engine wear and Lubricating Oil Degradation</u>

Effect of KOME20 on engine wear and durability was studied in 250 hour endurance test in two phases vis-à-vis baseline mineral diesel. In the first phase, new set of liners, pistons, piston rings, gudgeon pins and bearings were installed and engine fuelled with baseline mineral diesel was operated for 250 hours. After the endurance test, wear of vital engine parts were analysed. In the second phase, again, new set of components were installed in the engine and 250 hour endurance test was performed with KOME20 as fuel for comparing the effect of new fuel on the engine wear and durability vis-à-vis baseline mineral diesel. Higher amount for carbon deposits on the piston top, cylinder head and injector tip of KOME20 fuelled engine operation was observed (figure 4).

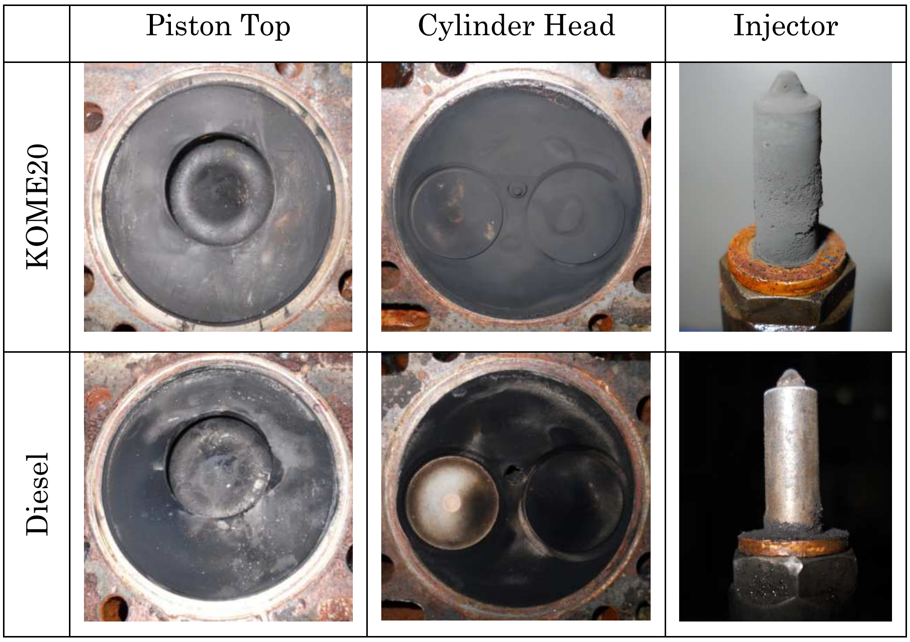

Figure 4: Carbon deposits on vital engine components after 250 hour endurance test

It was observed that wear of inlet valve was 10% lower for KOME20 fuelled engine in comparison to mineral diesel. Wear of exhaust valve was also lower for KOME20 possibly due to slightly lower exhaust gas temperature in case of KOME20 fuelled engine. Wear of cylinder liner, piston, and piston rings were lower for KOME20 fuelled engine, possibly due to higher lubricity of biodiesel and lower in-cylinder temperatures. Wear of small end of the connecting rod was also slightly lower for KOME20 fuelled engine. Higher wear of crank pin diameter, big end bearing and main bearing was observed for KOME20 fuelled engine. Bearings of these components are more directly affected by the quality of lubrication. Higher wear of these components indicated the possibility of adverse effect of KOME20 on the lubricating oil. Detailed analysis of surface texture of liner profiles indicated that for KOME20 fuelled engine, surface texture of cylinder liners was in acceptable condition after the 250 hour long endurance test.

Investigations of the effects of any new alternative fuel on the tribological properties of the lubricating oil are very important for assessing the suitability of the new fuel for existing engines. For investigating the effect of KOME20 on the lubricating oil, lube samples were drawn from the oil sump during the endurance test for both phases at a regular interval of 20 hours of engine operation. A number of tests were conducted on lubricating oil samples in order to evaluate the comparative performance of fuels such as density, viscosity, flash point, moisture content, pentane and benzene insoluble, etc. All these tests were used for indirect interpretation of comparative performance of new fuel in the unmodified engine.

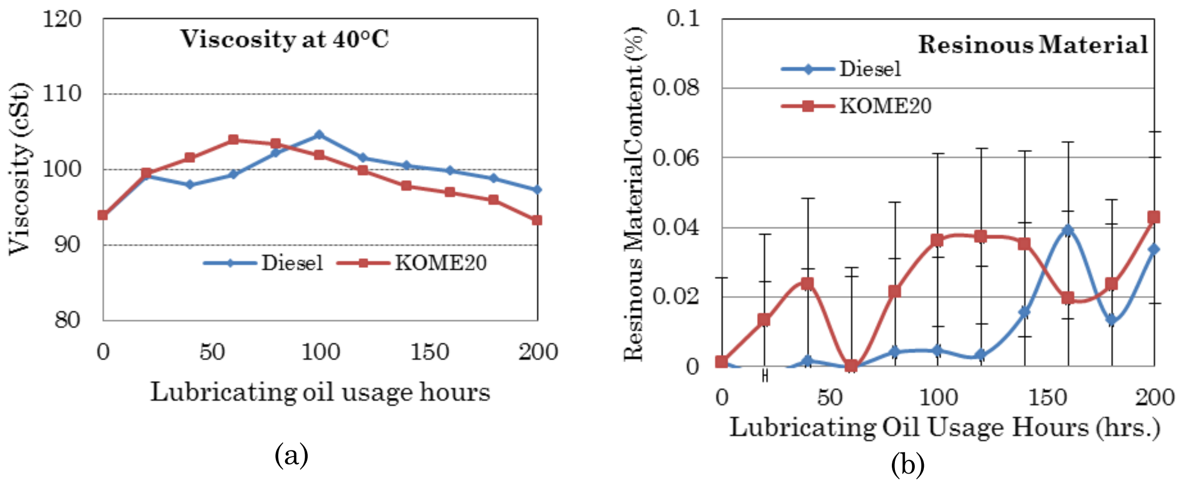

Figure 5: Variation of (a) viscosity and (b) resinous material content in the lubricating oil with usage

Figure 5 shows the variation of lubricating oil viscosity and resinous material content, which indicates extent of lubricating oil oxidation with usage for KOME20 and mineral diesel fuelled engine operation. Variation of lubricating oil viscosity, density and flash point indicated higher level of fuel dilution of lubricating oil in case of KOME20 fuelled engine operation in comparison to mineral diesel. Higher resinous material in the lubricating oil of KOME20 fuelled engine (figure 5 (b)) indicated higher extent of lubricating oil oxidation and polymerization of lubricating oil base-stock due to addition of Karanja biodiesel in the fuel (via fuel dilution).

Concentration of wear metals in the lubricating oil was used as an indicator of wear of components containing those metals. In the lubricating oil samples drawn upto 100 hours of engine usage, concentration of iron, aluminum, chromium, copper, manganese, magnesium were almost comparable for KOME20 and mineral diesel. After 100 hours of usage, concentration of these wear metals in the lubricating oil of KOME20 fuelled engine increased sharply indicating higher rate of degradation of lubricating oil with KOME20 fueling.

Concluding Remarks

Detailed investigation of performance and emission characteristics of Karanja biodiesel blends verified acceptable performance of biodiesel blends. Lower Karanja biodiesel blends (upto 20%) showed reduction in CO, HC and particulate emissions however slight increase in NOx emissions in an unmodified transportation engine. Rate of engine wear for most of the engine components for Karanja biodiesel blend fuelled engine operation was similar to mineral diesel. Karanja biodiesel led to higher rate of degradation of lubricating oil, which increased the wear of bearings hence some changes in the composition of the additive package of the lubricating oil will be worthwhile. Finally, Karanja biodiesel can be used as a partial substitute of diesel (upto 20%), with some modifications in the lubricating oil composition, without any major modification in the existing diesel engine hardware.

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