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Experimental Investigation of Preheated Jatropha Oil Fuelled Direct Injection Compression Ignition Engine—Part 2: Engine Durability and Effect on Lubricating Oil

ABSTRACT: Straight vegetable oil utilization as diesel engine fuel has the advantage of eliminating the energy, time, and cost involved in biodiesel production. Since straight vegetable oils have relatively higher viscosity compared to mineral diesel, they have to be modified to bring their combustion related properties closer to mineral diesel. In this study, a heat exchanger was used to utilize the waste heat of engine exhaust gas for reducing the viscosity of jatropha oil, and the performance, emission, and combustion characteristics are described in the first part of the paper. Carbon deposits, wear of vital engine parts, and the effect of jatropha oil on lubricating oil properties were analyzed in long-term endurance test for 512 h. The effect on lubricating oil of heated jatropha oil (J100) as well as 50 % blend of jatropha oil (J50) were compared with mineral diesel by comparing the lubricant's density, viscosity, flash point, carbon residue, ash content, copper corrosion, and pentane and benzene insoluble measurements after an interval of every 128 h. Wear of the cylinder liner, diameter of piston, piston rings, gudgeon pin, and small and big-end bearings for J100 and J50 were measured vis-à-vis mineral diesel. Jatropha oil fuelled engine first undergoes lowering of lubricating oil viscosity followed by severe vegetable oil initiated oxidation of lubricating oil base-stock and thus the life of the lubricating oil gets depleted in approximately 400 h. The wear of J50 fuelled engine liner is found to be relatively lower compared to mineral diesel fuelled engine.

KEYWORDS: jatropha, oil tribology, engine deposits, insolubles, kinematic viscosity, lubricating oil

Introduction

In India, there is a massive movement underway toward commercial implementation of biodiesel as fuel; however this involves chemical processing, input of fossil energy in chemical processing, and use of primary alcohols. Instead of this, the possibility is being explored for using straight vegetable oils in direct injection (DI) compression ignition engines without substantial hardware modification for applications in the rural agricultural sector, where these vegetable oils are produced locally, thus avoiding transport and fuel processing related costs. Vegetable oils can be used directly or blended with mineral diesel to operate diesel engines in a variety of applications. It has been proved that use of 100 % vegetable oils is also possible with some minor modifications in the fuel handling system [1–8].

In India, there is a tremendous interest to utilize non-edible vegetable oils and their derivatives as fuels in diesel engines [9,10]. Vegetable oils as an alternative fuel have numerous advantages [11,12] because they are available locally, they strengthen the rural agricultural economy, they are biodegradable and non-toxic, etc.

Plenty of experimental work has been carried out in various countries for utilization of vegetable oils in compression ignition engines. Vegetable oils and their derivatives in diesel engines lead to substantial reductions in sulfur, carbon monoxide (CO), polycyclic aromatic hydrocarbons, smoke, noise, and particulate emissions. Vegetable oils have about 10 % lower heating value than mineral diesel due to its oxygen content. Higher viscosity of vegetable oils (35–45 cSt at 40°C) as against diesel (3–4 cSt at 40°C) leads to problems in pumping and atomization, ring-sticking, carbon deposits on the piston, cylinder head, ring grooves, etc. Since straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to mineral diesel.

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Several researchers investigated long-term usage of vegetable oil in engines for various durability aspects. Injector coking was investigated on a diesel engine running with cold pressed rapeseed oil by considering various engine load conditions [13]. The results showed that coking of the injection nozzles depend on the engine performance. The injector nozzles that operated on neat rapeseed oil were coated to a higher degree by carbonaceous deposits compared to the injector nozzles, which are operated on mineral diesel. Controlled studies of valve lift opening pressure and visual evaluation of fuel sprays confirmed that all injector deposits were still within the norm, suitable for further operation. Carbon deposits related to the usage of rubber seed oil blend were investigated by Ramadhas [11]. It was found out that the deposits on the cylinder head were higher than mineral diesel. A quick build-up of carbon deposits on the injector nozzles was observed. Higher carbon deposits occurred due to the incomplete combustion of the vegetable oil blends. Because of the gum forming tendency of the rubber oil, the carbon particles were deposited on the walls of the combustion chamber. It was established by experiment that 50–80 % of rubber seed oil could substitute for diesel without any major engine modification and operational difficulties.

Carbon deposit accumulations in the injectors of a diesel generator fuelled with palm oil were investigated by de Almeida et al. [2]. It turned out that deposit accumulations in the injectors could lead to higher exhaust gas temperatures. The deposits on the cylinder head reached high levels when the engine was operated with palm oil heated at 50°C and to acceptable levels when the oil was heated to 100°C (almost similar to the operation with mineral diesel). However, adequate engine modifications (increase of injection pressure, installation of a turbo-charger in order to increase the temperature and pressure inside the cylinders, usage of special lubricants with convenient additives, and adaptation of the injecting system to the particular use) were required to improve lubricating oil degradation, performance, and emissions and achieved an efficient combustion [14]. The present long-term study has been performed to evaluate the effect of pre-heated jatropha oil and its 50 % blend on engine wear and lubricating oil degradation.

Experimental Method

Nearly all tractors, agricultural pump sets, farm machinery, and transport vehicles use DI diesel engines. Keeping the specific features of diesel engines in mind, a typical engine system widely used in the agricultural sector in developing countries has been selected for present experimental investigations.

Engine

Four-stroke, single-cylinder, constant speed, water-cooled, DI diesel engines fitted with ac alternators of 7.4 kW (10 HP) rating (make: Kirloskar Oil Engines Ltd., India; model: DM-10) were procured to study the effect of pre-heating the vegetable oils on performance and emissions of different fuels. The engines operated at a constant speed of 1500 r/min. The fuel injection pressure recommended by the manufacturer is in the range of 200–205 bars at 1500 r/min. Fresh lubricating oil was filled in the lubricating oil sump before initiating the experiment.

Fuel Conditioning System

Fuel conditioning is essential because vegetable oils are highly viscous and contain impurities including dust particles, gums, etc. Therefore, it is necessary to filter the vegetable oils adequately before they are fed to the engine. If vegetable oil of poor quality is supplied to the engine, then it will lead to the generation of higher particulate matter and increased engine wear apart from chocking of the fuel lines, fuel pumps, etc. In the experimental setup, two filters are provided (in parallel) after the exit of the fuel from the fuel tank, and another filter is provided before the fuel pump (Fig. 1). These filters have to be changed once they get clogged. Two fuel filters are provided next to the fuel tank because if one filter gets clogged, the supply of fuel can be switched over to the other filter, while the clogged filter can be cleaned/replaced and engine operation during this procedure is not affected.

Two fuel tanks are given in the setup. One fuel tank is for mineral diesel and the other one is for vegetable oil. The engine is initially started with mineral diesel, and once the engine warms up (after about 5 min), it is switched over to vegetable oil. After concluding the tests with vegetable oil, the engine is

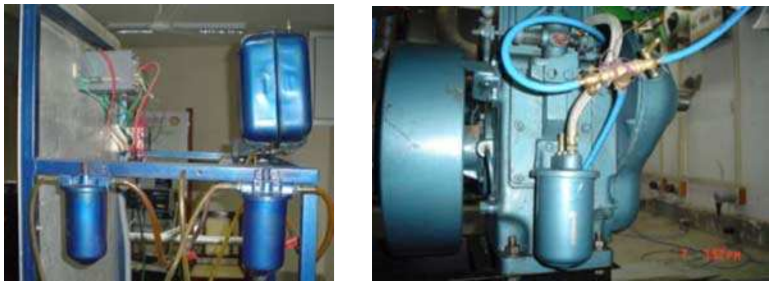


FIG. 1—*Fuel filters.*

again switched back to diesel until the vegetable oil is purged from the fuel line, injection pump, and injector in order to prevent deposits and avoid cold starting problems when the engine needs to be started next time around.

A shell and tube type heat exchanger is designed to preheat the vegetable oils using waste heat of the exhaust gases. One supply pipe connection is provided at each side plate of the heat exchanger as an inlet and outlet for vegetable oil. A thermocouple is provided in the heat exchanger to measure the temperature of the pre-heated vegetable oil close to the exit.

In the long-term endurance test, the effect of jatropha oil and its 50 % blend on various engine parts vis-à-vis mineral diesel fuel was studied. For this purpose, three new identical engines were subjected to similar loading cycles and operating conditions with different fuels. The assessment of wear of various parts of 50 % and 100 % jatropha and diesel fuelled engines was done in a long-term endurance test after dismantling various parts of the engine. Various tests on the engine systems are conducted as per the procedure specified in IS 10000, Part V [15], and IS 10000, Part IX [16].

After the completion of preliminary running-in and fuel consumption test, the engines were dismantled completely and examined physically for the conditions of the various critical parts before endurance test was initiated. After physical examination, the dimensions of various moving vital parts were recorded, e.g., cylinder head, cylinder bore/cylinder liner, piston, piston rings, gudgeon pin, valves (inlet and exhaust), valve seats (inserts), valve guide, valve springs, connecting rod, big-end bearing, small-end bush, connecting rod bolts and nuts, crankshaft, crankshaft bearings and journals, camshaft, etc. The engines were re-assembled and mounted on suitable test beds and again run-in for 12 h as recommended by the manufacturer. This test was carried out to take care of any misalignments occurring during dismantling and re-assembling of the engine. This test included 11 h of continuous run at the rated full load at the rated speed followed by 1 h run at 10 % overload.

During the running-in period, none of the critical components listed above were replaced. The lubricating oil from the oil sump was drained off, and the engine was refilled with SAE30 grade fresh lubricating oil as specified by the manufacturer. The engines were operated for 32 cycles (each of 16 h continuous running) at the rated speed. The test cycle followed is specified in Table 1. After completing this test, the engines were dismantled for further investigations.

Carbon Deposits

Visual Inspection of Vital Engine Parts

Figure 2 shows the deposits on various in-cylinder parts after the completion of the long-term endurance test (i.e., after 512 h). An important observation during this test was that the injector tip of the J100 fuelled

TABLE 1—*Test cycle for long-term endurance test.*

Load (% of Rated Load)	Running Time (h)
100	4
50	4
110	1
No load (idling)	0.5
100	3
50	3.5

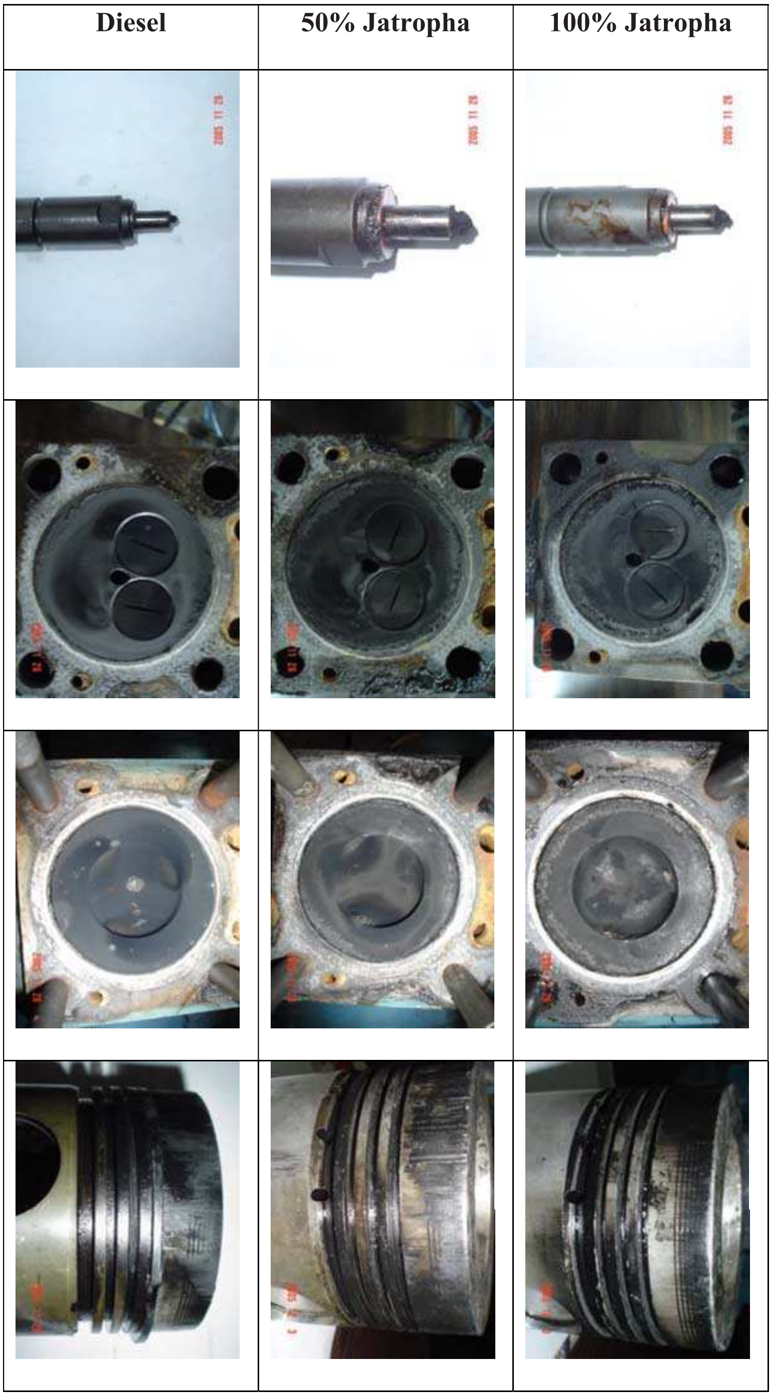


FIG. 2—*Comparison of carbon deposits of mineral diesel, J50, and J100.*

engine was cleaned three times during the 512 h test. During this period, mineral diesel as well as 50 % jatropha fuelled injector tips were not cleaned; hence no definite conclusion can be drawn from the injector tip deposit for J50. However it can be concluded that J100 is comparatively problematic from an injector tip deposit point of view. While comparing J50 and mineral diesel injectors, which were continuously in service for 512 h, relatively more deposits are observed to have formed on the J50 injector.

One can also clearly observe slightly higher amount of carbon deposits on the vegetable oil fuelled engine's cylinder head and piston top compared to the mineral diesel fuelled engine. However one can also notice that none of these engines demonstrated an order of magnitude higher amount of deposits, which are expected (and also reported in literature) from the straight vegetable oil (SVO) fuelled engine. This indicates that the pre-heating technology is successful in using SVO as an alternate diesel engine fuel; however a revised maintenance schedule needs to be devised for this purpose.

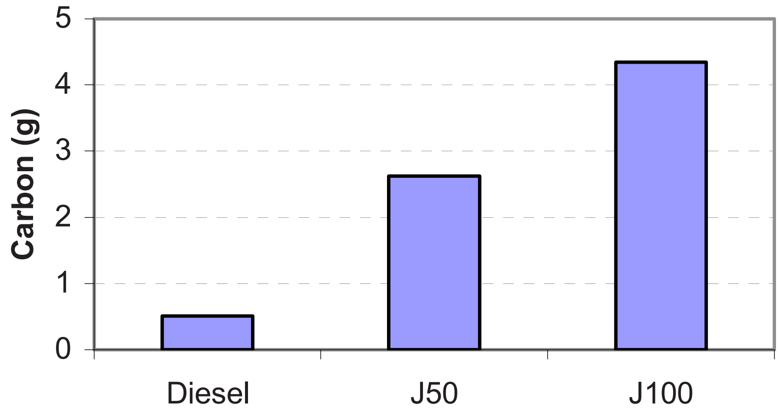


FIG. 3—*Piston top carbon deposits on engines.*

Carbon Deposit Rating

After completion of long-term endurance test, the carbon present on the top of the piston was scraped carefully, collected, and weighed for comparison (Fig. 3). Vegetable oil fuelled engines showed higher carbon deposits on the piston top, and it increased with the concentration of vegetable oil in the blend.

Piston Deposit Rating

The piston deposit rating is useful to rate the varnish of the piston skirt for estimation of the engine performance and quality of the lubricating oil. For exclusion of some defects, the rating includes an automatic quantitative varnish rating developed by using image processing. The varnished area of the piston was extracted from the developed color image by setting the two thresholds, the density, and the *x*-value of the chromaticity diagram [17]. The nomenclature used for piston rating is given in Fig. 4.

After completion of the long-term endurance test, diesel fuelled, J50, and J100 fuelled engine pistons ratings were carried out. The method of rating is IP/247/69 (merit rating system for engine cleanliness and wear) [17]. In this test, piston portions like skirt, ring groove, ring land, under-crown, under-skirt, etc. were analyzed by comparing the color of one square centimeter area of the piston using a chromaticity diagram. The color factors used for lacquer deposits are given below in Table 2.

Diesel, J50, and J100 fuelled engine pistons have 8.7, 8.7, and 7.94 merit points respectively (Fig. 5).

Each ring groove was divided into ten sectors using a transparent grid. The merit rating assigned to each groove is given in Table 2. This parameter estimates the top ring groove, i.e., the percentage of clearance volume between the back of the ring and back of the ring groove, assuming the ring to be constrained in the cylinder bore. All consolidated results are shown in Table 3.

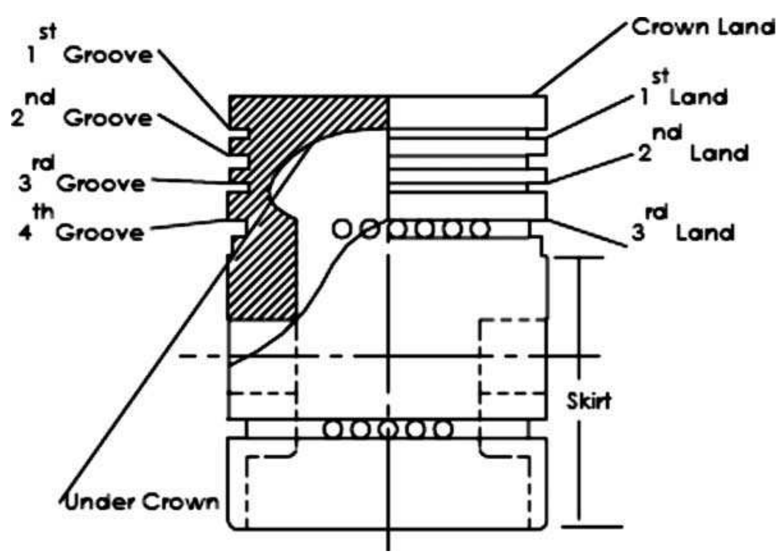


FIG. 4—*Nomenclature of various engine parts: used for piston rating.*

TABLE 2—*Color factors for lacquer deposits for piston rating.*

Clean	0.00
Discoloration	0.10
Light brown	0.25
Red brown	0.5
Dark brown	0.75
Black (carbon is to be considered as black lacquer)	1.00

The deposits on the vital engine parts were found to be higher on SVO fuelled engines. The piston rating carried out on the pistons of the three engines reflects that the SVO fuelled engines have reasonable long-term performance.

Effect of Preheated Jatropha Oil on Lubricating Oil

Density measurements are important since they provide information on the addition of wear metals and fuel dilution to the lubricating oil. The density of lubricating oil from engines shows an increasing trend with usage. It can be observed from Fig. 6 that the density of lubricating oil from a diesel fuelled engine increases at the slowest rate.

The density of the lubricating oil increases mainly due to the addition of wear debris, fuel dilution, and an increase in moisture content. Initially, the wear of engine parts is faster and fuel dilution also starts. Due

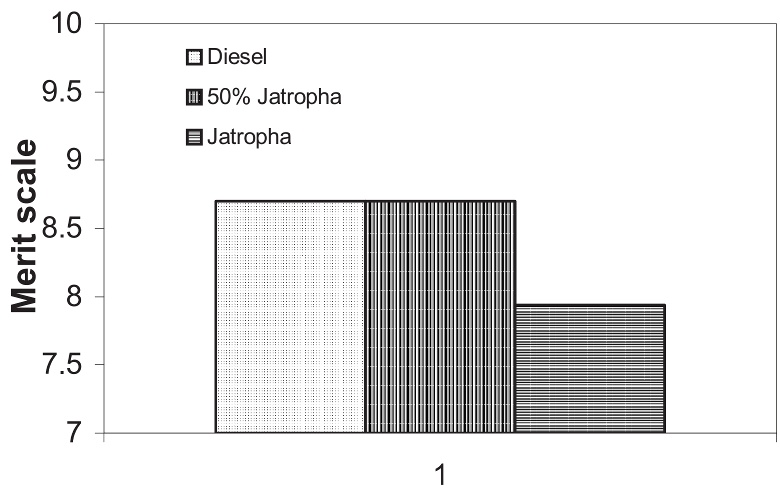


FIG. 5—*Merit scale for piston skirt.*

TABLE 3—*Consolidated results of piston rating for the four engines.*

Parameters	Diesel	J50	J100
Skirt	8.70	8.70	7.94
Ring groove (overall)	(1) [a]	(1) 0.00	(1) 0.00
	(2) 0.00	(2) 0.00	(2) 0.00
	(3) 0.00	(3) 0.00	(3) 0.00
	(4) 2.75	(4) 0.75	(4) 0.00
Top groove carbon-filling (%)	[a]	90	95
Ring land	(1) 0.18	(1) 1.68	(1) 0.72
	(2) 4.01	(2) 3.62	(2) 0.78
	(3) 5.51	(3) 0.00	(3) 0.00
Under-crown	1.25	0.00	0.00
Under-skirt	6.00	5.77	6.80
Ring-sticking	Top ring merit rating=3.00	···	···

[a]Ring stuck in the groove; this ring was not removed, so no rating was assigned.

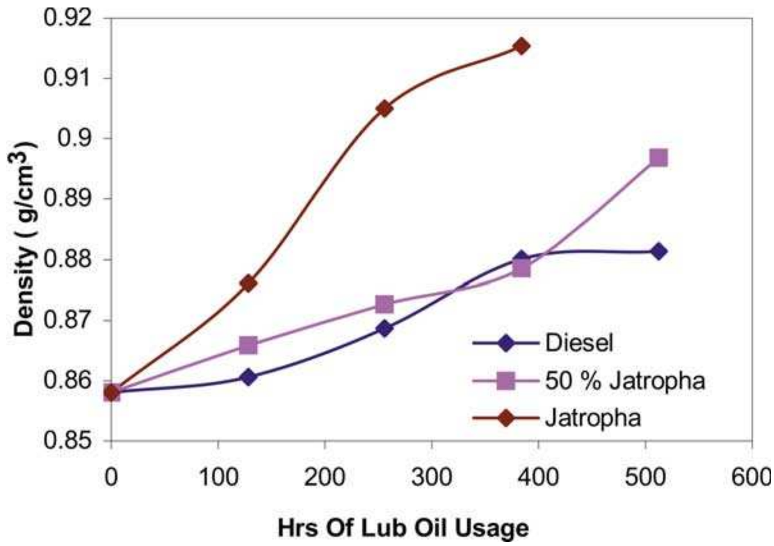


FIG. 6—*Change in density of lubricating oil with usage.*

to the combined effect of these factors, the density of the jatropha oil fuelled engine's lubricating oil increases faster as compared to diesel and J50 fuelled engines. The rate of increase in lubricating oil density decreases after 384 h of engine operation in a diesel fuelled engine.

Ash content reflects non-carbonaceous material in the lubricating oil since carbonaceous materials such as oil, soot, fuel, and non-metallic parts of organo-metallic additives get converted into CO_2 after thermal decomposition. Ash content mainly indicates metallic wear debris and abrasive foreign particles like dust entering the system from the environment. Since all engines were operated under similar conditions, the contribution of foreign particles was assumed to be similar hence variation in ash content of lubricating oils drawn from the engines primarily reflected wear debris. Ash content is measured according to ASTM D482 [18]. Ash can be present as either solid or oil/water soluble metallic compounds. These particles are often designated as sediments.

Approximately 5 g of an oil sample, contained in a silica crucible, was kept in the muffle furnace at 450°C for 4 h and 650°C for 2 h and allowed to burn until only ash was left. The ash was finally cooled and weighed.

Figure 7 indicates that the ash content initially decreases for SVO fuelled engines, suggesting a higher amount of fuel dilution and moisture addition. Thereafter the ash content steadily increases suggesting the addition of wear debris progressively.

Any change in viscosity of the lubricating oil is undesirable in an engine as it affects the lubrication. The viscosity of lubricating oil may increase or decrease with usage. Inadequate oil viscosity affects

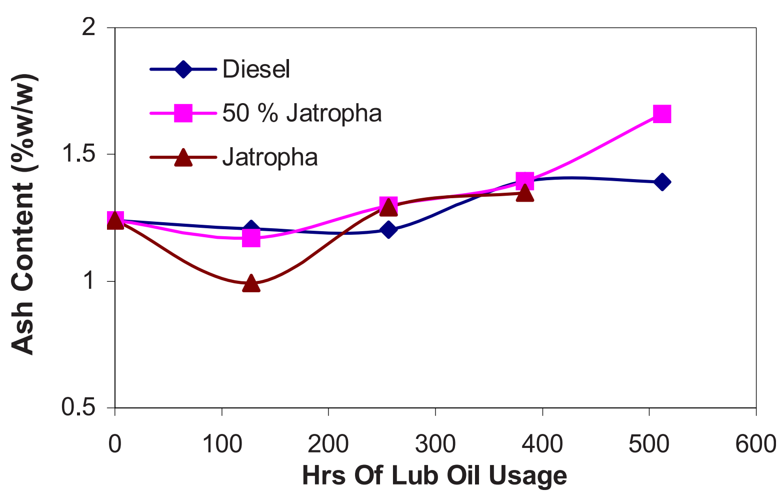


FIG. 7—*Change in ash content of lubricating oil with usage.*

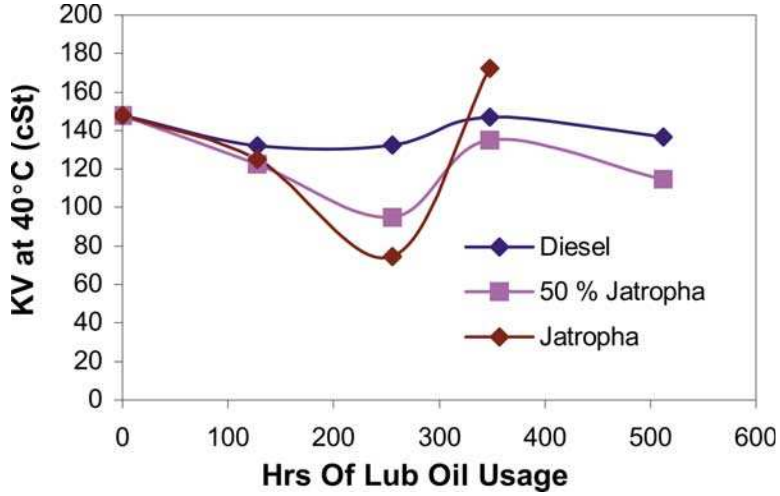


FIG. 8—*Change in the lubricating oil viscosity at 40°C with usage.*

lubricating oil film thickness separating the metallic parts and load bearing capacity leading to low oil pressure, poor oil efficiency, excessive wear of mating parts, bearings, and other moving components.

Two factors are mainly responsible for lubricating oil viscosity changes in opposite directions. The formation of resinous products because of oil oxidation, evaporation of lighter fractions, depletion of anti-wear additives, and contamination by insolubles tend to increase the oil viscosity, while moisture addition, fuel dilution, and shearing of viscosity index improvers tend to reduce oil viscosity. The extent of dominance of both mechanisms however differs from system to system. Hence, the net result can be reflected in either direction, e.g., oil viscosity can decrease, if fuel dilution is a more dominating mechanism. The viscosity of all lubricating oil samples was evaluated at 40 and 100°C using a kinematic viscometer (Figs. 8 and 9).

These figures show that the viscosity of an SVO fuelled engine first decreases and then increases rapidly, making the lubricating oil unfit for further use beyond 384 h.

The rate of change of viscosity is also controlled by oil oxidation. It is also possible that vegetable oils, which get into lubricating oil through fuel dilution (in the initial period), accelerate the oxidation rate of the lubricating oil's base-stock, leading to an initial reduction in viscosity (due to fuel dilution and shearing of lubricating oil), followed by an increase in viscosity due to oxidation of lubricating oil base-stock. In the initial phase, the decrease in viscosity due to fuel dilution could have slowed down due to base-stock oxidation.

Fuel dilution is a direct consequence of clearance between piston rings and cylinder liner. The more the piston rings wear, the more will be the clearance, and hence more fuel dilution.

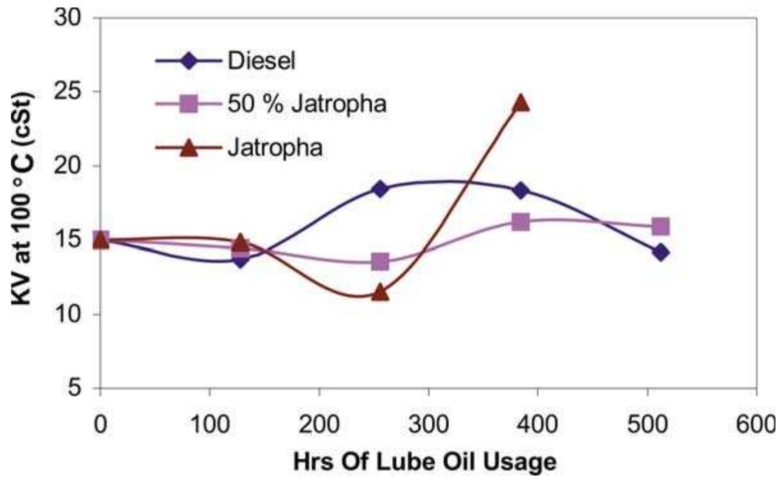


FIG. 9—*Change in the lubricating oil viscosity at 100°C with usage.*

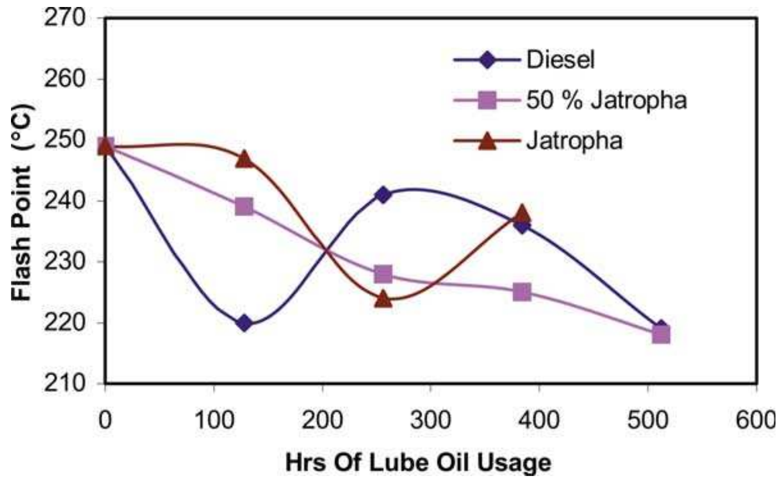


FIG. 10—*Change in flash point of lubricating oil with usage.*

The flash point temperature of all lubricating oil samples was evaluated using the Setaflash closed cup flash point apparatus. The higher the van der Waal's forces are, the higher will be the energy required for vaporizing and the higher will be the flash point. Fuel dilution of the lubricating oil is undesirable because it will reduce the van der Waal's forces to a greater extent, thus lowering the flash point.

As observed from Fig. 10, the flash point of lubricating oil from diesel engine reduces first (possibly due to dilution by diesel, which has a flash point of approximately 70°C), whereas the flash point of SVO fuelled engines reduces to a lower extent because they have fuel dilution from a fuel that has a very high flash point (229°C).

Carbon residue was measured according to ASTM D189 [19]. Carbon residue was determined by placing a weighed sample in a silica crucible (Fig. 11). The crucible was heated in a muffle furnace at 500°C for 30 min in an inert (nitrogen) atmosphere. The crucible was then cooled and weighed. The weight of tar remaining in the crucible in comparison to original sample gives the carbon residue (% w/w). Carbon residue for preheated jatropha oil fuelled engine was almost identical to that of mineral diesel fuelled engine.

Atomic Absorption Spectroscopy

Atomic absorption spectroscopy was used for quantitative and qualitative analysis of wear debris of lubricating oils. The data was correlated with the extent of wear, the performance characteristics of either lubricating oils or diagnosis of failure of moving components.

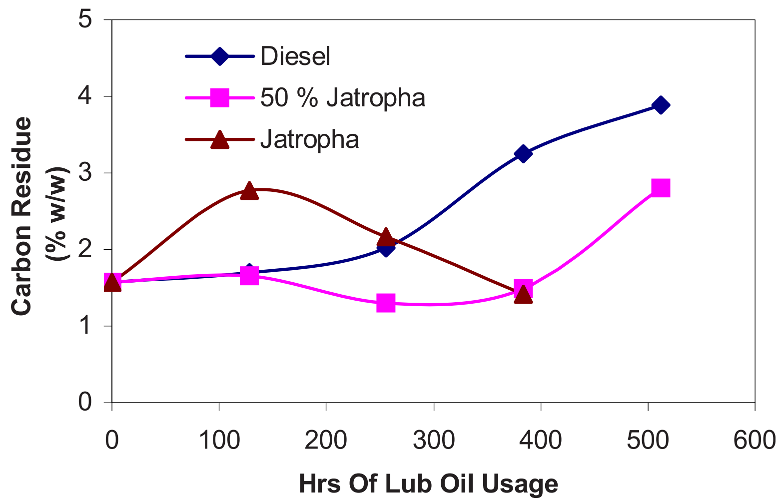


FIG. 11—*Carbon residue versus hours of lube oil usage.*

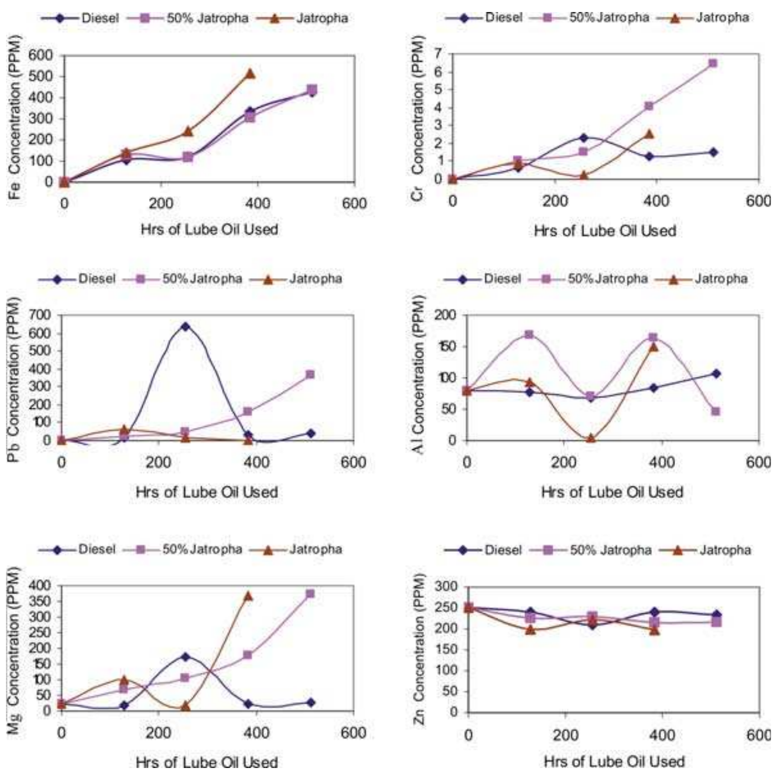


FIG. 12—*AAS results of lubricating oils from all four engines for various metals.*

The concentrations of various metals present in the lubricating oil samples from engines were evaluated to study the wear of different parts and material compatibility of the new fuels with the existing engines. Since many sliding components were involved, it was anticipated that the wear debris originating from different metallic parts appeared in the lubricating oil. The results of atomic absorption spectroscopy carried out on the lubricating oil samples for various metals are shown in Fig. 12.

Iron: The iron in wear debris could be because of wear of the cylinder liner, piston rings, valves, gears, shafts, bearing, rust, and crankshaft. For a J100 engine, iron wear is marginally higher than that for a diesel fuelled engine. In a J50 fuelled engine, iron wear is similar to that of a mineral diesel fuelled engine.

Zinc: The zinc in wear debris could be because of additive depletion, wear of bearings, brass components, and neoprene seals. Zn wear is almost same in SVO fueled engines as in diesel fuelled engines.

Chromium: The chromium in wear debris could be because of wear of cylinder liner, compression rings, gears, crankshaft, and bearings. Since chromium is found in a very small amount in the cylinder and its wear rate is very low, a very small amount is present in the lubricating oil of all engines. Comparatively, J50 fuelled engine has marginally higher Cr in the lubricating oil.

Magnesium: The magnesium in wear debris could be because of additive depletion, wear of bearings, and gear box housing. The wear performance of SVO and blend is similar to that of mineral diesel.

Lead: The lead in wear debris could be because of wear of bearings, paints, and grease addition. The wear performance of SVO and blend is similar to that of mineral diesel.

Aluminum: The aluminum in wear debris could be because of wear of pistons, bearings, dirt, additives, and thrust washers. SVO fuelled engines show slightly higher Al wear as compared to diesel fuelled engines.

Copper Corrosion Test

The objective of the copper strip corrosion test was to find out the corrosiveness of lubricating oil to copper containing engine parts. This test monitors the presence of acids in the lubricating oil. The copper corrosion bath (make: Stanhope Seta, United Kingdom; model: Setavis 11300) is a constant temperature bath, which conforms to ASTM D130-IP154 [20], ASTM D4048 [21], BS 2000, Part 112 [22], and BS 2000, Part 154 [23]. This is used for determining the copper corrosion potential of various lubricating oil samples drawn from different engines.

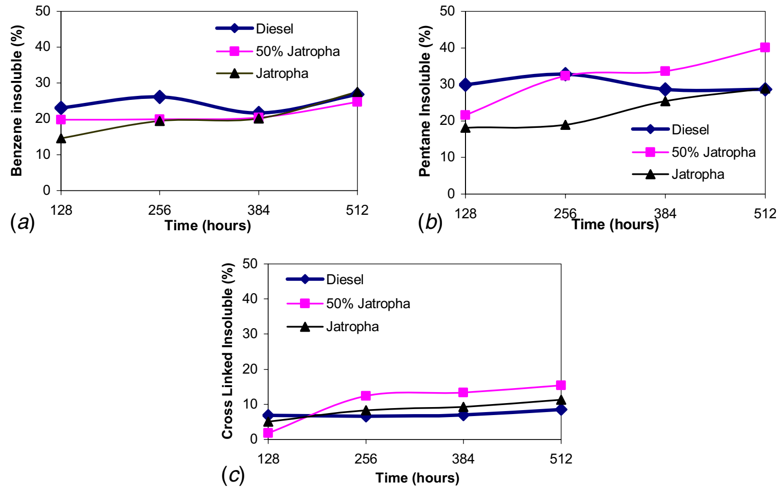


FIG. 13—*(a) Benzene insoluble versus hours of lubricating oil usage; (b) pentane insoluble versus hours of lubricating oil usage; and (c) cross-linked insoluble versus hours of lubricating oil usage.*

Fresh lubricating oil matches grade 1a, which is light orange, almost the same as freshly polished strip. Copper corrosiveness of all the lubricating oils is of grade 1a. Hence, it can be concluded that SVOs do not cause any harm to copper parts of the engine.

Pentane and Benzene Insoluble

The aim of the pentane and benzene insoluble test is to find out the suspended contaminants in lubricating oil. These suspended contaminations can be oil soluble resinous material formed as a result of the degradation of oil, additives or both, fuel carbon or highly carbonized material, corrosion and wear particles from the engine, and dust particles entering from the environment.

The weight of the insoluble in benzene is lower than that of pentane (Fig. 13(*a*)). The difference between pentane and benzene insoluble indicate the extent of oil oxidation. The higher the difference, higher will be the oil oxidation. A significant change in pentane insoluble, benzene insoluble, and insoluble resins indicates a change in oil properties, which could lead to lubrication system problems. Insoluble assessment can also assist in evaluating the performance characteristics of used oil or in determining the cause of equipment failure.

Formation of cross linked gels in J50 and J100 fuelled engines is higher as compared to a mineral diesel engine (Fig. 13(*c*)). This is expected because of the presence of oxygen in SVO, which causes oxidation of lubricating oil when it mixes with lubricating oil through fuel dilution.

Pentane insoluble with the diesel fuel remains almost constant with hours of lubricating oil usage, but it tends to increase in the case of 100 % jatropha and 50 % jatropha fuelled engines (Fig. 13(*b*)). At 128 h of lubricating oil usage, a comparatively small amount of pentane insoluble is formed in SVO fuelled engines, but with time, the content of the pentane insoluble becomes higher than mineral diesel fuelled engine in the case of a J50 fuelled engine. However in case of J100 fuelled engine, the pentane insoluble is always lesser than that for a mineral diesel fuelled engine.

Overall, it can be concluded that J50 and J100 show a higher tendency for polymerization (of lubricating oil) compared to mineral diesel.

Physical Wear Measurement of Vital Parts

The wear of various moving parts took place due to prolonged engine operation. All the engines were operated under identical conditions and the loading cycles of the engines were also similar. The only variation in the operation was that all engines were operated using different fuels so that the effect of each fuel on the life of engine hardware could be compared directly. The dimensions of the vital parts and physical condition were recorded before the commencement of and after the completion of the long-term endurance test (Fig. 14). The difference of these dimensions give the wear of these parts in the given

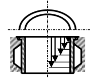
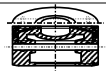
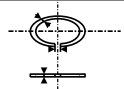
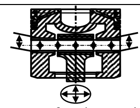
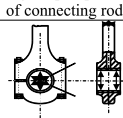
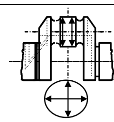
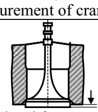
Component		operated engine	
		50% Jatropha	Jatropha
 Measurement of cylinder bore/ liner		19 ↑	29 ↑
 Measurement of diameter of the piston		37 ↓	85 ↓
 Measurement of piston rings	Ring 1	--	200 ↑
	Ring 2	38 ↓	17 ↑
	Ring 3	--	143 ↑
	Ring 4	33 ↓	148 ↑
 Measurement of gudgeon pin, pin bore, small end bush of connecting rod	gudgeon pin	30 ↑	122 ↑
	pin bore	40 ↓	131 ↑
	small end bush	20 ↓	17 ↓
 Measurement of big end bearing		102 ↑	450 ↑
 Measurement of crank pin		80 ↓	11 ↓
 Distance of valve head from mounting flange face		91.1 ↓	3.3 ↑

FIG. 14—*Comparison of wear of J50 and J100 with mineral diesel.*

period of engine operation. After completion of the long-term endurance test, the engines were again dismantled, and the physical condition of various parts inspected carefully.

Wear was estimated by accurate measurement of dimensions of various vital parts of the engine before and after the long-term endurance test. These observations of wear were useful to compare the performance of SVOs vis-à-vis mineral diesel oil on the wear of the vital engine parts. It is evident from Fig. 14 that the wear of vital moving parts of a J50 operated engine was substantially lower as compared to even a mineral diesel operated engine.

Surface Roughness Parameters

In this experiment, new cylinder liners were used for all four engines for each phase of the experiment. To check the wear of cylinder liner material during the course of the engine test, the surface profiles of the liners were taken before and after 512 h of engine operation on a given fuel (Fig. 15). The surface profiles were taken at three locations, top dead center (TDC, 30 mm from the top of the cylinder liner), mid stroke (78 mm from the top of the cylinder liner), and bottom dead center (BDC, 128 mm from the top of the cylinder liner) on the thrust and anti-thrust sides. TDC and BDC are the most important locations of the cylinder liner where maximum wear is expected to take place. The piston skirt touches the liner surface in the intake stroke toward the thrust side and for the rest of the three strokes it touches the anti-thrust side. Hence these sides are chosen to study the wear pattern of the cylinder liners.

Scuffing and abrasion take place in the liners due to the three body relative motion of liner, piston rings, and soot particles. The major reasons for liner wear are high thrust due to high pressure and high temperature gases, abrasion due to soot and dust particles, poor lubrication, etc.

The evaluation length of the surface profile was kept at 2.4 mm. The profiles were taken with 10× magnification in the horizontal direction and 2000× magnification in the vertical direction [24].

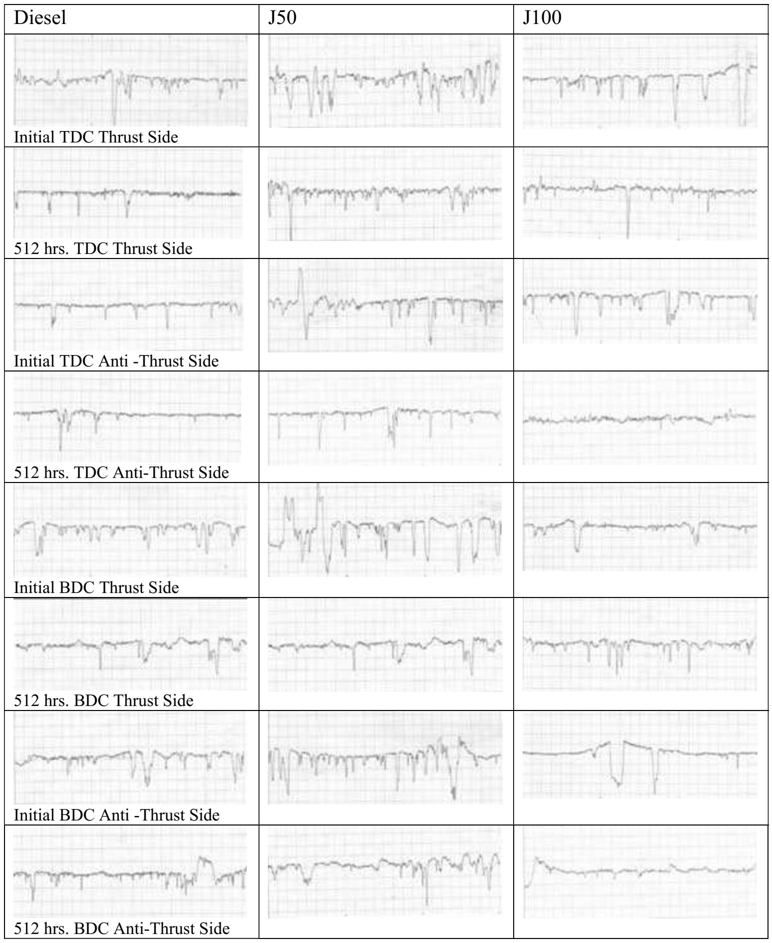


FIG. 15—*Comparison of liner roughness profile of J50 and J100 with mineral diesel.*

From these roughness parameters, it was observed that the wear of the liner at TDC is consistently higher than BDC and mid stroke positions. The wear at TDC is more because this zone of cylinder liner faces the highest temperature due to combustion gases. TDC faces high load, and relatively slower piston speeds due to which boundary layer lubrication at the TDC location breaks down. At the TDC position, the lubricating oil film thickness is less than 0.025 μm, which is less than the normal size of soot particles, which act as abrasives and increase the wear of the liner surface at the TDC location.

It was also observed that wear of the cylinder liner is higher on the anti-thrust side compared to the thrust side. The possible reason for this may be that the piston touches the thrust side of the cylinder liner surface during intake strokes only, while the piston touches the anti-thrust side of the cylinder liner surface during the remaining three strokes; hence the wear at the anti-thrust side is higher than the thrust side.

Conclusions

In the long-term endurance test, the effect of the use of heated jatropha oil on various engine parts and lubricating oil vis-à-vis mineral diesel was evaluated. The assessment of wear of various parts of J50, J100, and diesel fuelled engines was done where the vegetable oils and blends were preheated using waste heat of the engine exhaust. The deposits on the vital engine parts were found to be relatively higher on heated J50 and J100 fuelled engines. The piston rating carried out on the pistons of the three engines reflects that the J50 fuelled engine demonstrated reasonable long-term performance in comparison to the mineral diesel fuelled engine. The heated jatropha oil fuelled engine first underwent a lowering of lubricating oil viscosity followed by severe vegetable oil initiated oxidation on the lubricating oil base-stock, and thus the life of the lubricating oil was over in approximately 400 h. Viscosity, density, and carbon residue of the preheated J50 fuelled engine's lubricating oil were almost comparable to mineral diesel of up to 400 h of usage. Heated J50 and J100 were as good as mineral diesel fuel for copper parts of the engine in terms of copper corrosion behavior. Fe, Mg, Pb, Cr, and Zn metal debris in the lubricating oil were comparable to mineral diesel for heated J50 up to 384 h; however Al content in the lubricating oil was slightly higher than mineral diesel for J50.

It was found that the wear of J100 engine liners was substantially higher compared to that of a mineral diesel fuelled engine. The wear of a J50 fuelled engine liner was found to be relatively lower compared to that of a mineral diesel fuelled engine. According to the 512 h endurance test performed, J50 seems to be a promising substitute for mineral diesel in a stationary CI engine by utilizing waste heat of the exhaust with an objective of lowering the kinematic viscosity of the fuel blend, but for modern high pressure injection system engines, field trial studies are essential. The engines are expected to operate successfully after modification in their maintenance schedule and modified formulations of lubricating oils.

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