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Experimental investigations of effect of Karanja biodiesel on tribological properties of lubricating oil in a compression ignition engine

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HIGHLIGHTS

- Comparison of lube oil degradation for diesel & KOME20 in 200 h test.
- Resinous material content in lube oil increased for biodiesel fuelling.
- Comparatively higher oxidation of lube oil from biodiesel engine.
- Higher wear trace metals in lube oil from biodiesel engine after 100 h.
- Copper corrosiveness of lube oil of biodiesel engine similar to diesel.

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ABSTRACT

For large-scale implementation of biodiesel in transportation engines, its effect on lubricating oil degradation needs to be experimentally investigated. Due to differences in chemical composition of biodiesel and mineral diesel, the comparative effects on lubricating oil degradation and residual useful life for long-term application will be different. In this study, effect of 20% Karanja biodiesel blend on lubricating oil tribology was studied vis-à-vis mineral diesel in a 200 h long endurance test. Higher increase in density, carbon residue and ash content was observed for biodiesel blend fuelled engine's lubricating oil in comparison to diesel. Higher amount of resinous polymerized material in the lubricating oil of biodiesel fuelled engine indicated possibility of higher oxidation and polymerization of base-stock of lubricating oil of the biodiesel fuelled engine. After 100 h, higher increase in concentration of wear trace metals such as iron, aluminum, copper, chromium and magnesium in the lubricating oil of biodiesel fuelled engine in comparison to mineral diesel indicated significant deterioration of lubricating oil.

1. Introduction

Due to depletion of petroleum resources and resulting environmental degradation and global warming, alternative transportation fuels are getting worldwide consideration. Biodiesel is the most readily considered renewable alternative to mineral diesel at current stage of technology development, which remains the most widely used transportation fuel. Before large scale implementation of biodiesel, its effects on engine performance, emissions, durability and lubricating oil degradation needs to be investigated. Some studies have experimentally evaluated the lubricating oil degradation during long duration tests on static engines experiments and field trials [1–10]. Verhaeven et al. investigated the effect of rapeseed oil methyl ester (RME) and used vegetable oil methyl ester (UVOME) on engine durability in a demonstration study using ten vehicles operated over a distance of 100,000 km [2]. Analysis of the lubricating oil samples taken at an interval of 7500 km vehicle run confirmed that no special degradation of the engine or lubricating oil took place [2]. Lin et al. compared the effect of fuels on lubricating oil degradation over 300 h (18,000 km equivalent) operation of heavy duty diesel engine fuelled with palm biodiesel blends [11]. They reported that viscosity (@ 40 °C) of the lubricating oil for diesel fuelled engine after 300 h reduced to 95.1 cSt from the initial viscosity of 107 cSt and total alkaline number increased to 8.24 mg KOH g^{-1} from the initial value of 7.89 mg KOH g^{-1}. For biodiesel, the corresponding values of viscosity and total alkaline number after 300 h were 96.8 cST and 8.26 mg KOH g^{-1} respectively [11]. Staat and Gateau reported the results of 3 years long investigations on 2000 vehicles in France using rapeseed methyl ester (RME) as fuel [1]. For more than 50% concentration of RME in the fuel, slight reduction in lubricating oil viscosity with usage

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was observed but it was not significant enough to alter the lubricating oil change interval [1]. Agarwal investigated the effect of 20% biodiesel blend (B20) of linseed oil methyl ester on the tribological properties of lubricating oil in 512 h endurance test [7]. He reported that the fuel dilution was lower for the lubricating oil from the biodiesel fuelled engine in comparison to diesel fuelled engine by measuring viscosity and flash point [7]. Sinha and Agarwal observed lower wear trace metal concentration of Fe, Cr, Cu, Zn, Ni and Mg in the used lubricating oil from B20 fuelled engine in comparison to mineral diesel fuelled engine. Pb and Al were found in slightly higher concentration in the lubricating oil from B20 fuelled engine, which might be due to the attack of biodiesel on paints and bearings [3,6]. Agarwal et al. reported lower concentrations of trace metals such as Fe, Cu, Zn, Mg, Cr, Pb, and Co in the lubricating oil from B20 fuelled engine in comparison to mineral diesel fuelled engine [12–13].

Fuel chemistry plays an important role in the performance and useful life of lubricating oil [7,14]. Properties of lubricating oil change with its usage due to fuel dilution and addition of contaminants from the engine due to wear, carbonaceous materials and impurities entering with intake air [14]. Biodiesel is comparatively more chemically reactive than mineral diesel due to presence of oxygen in the molecular structure of biodiesel [15]. Differences in physical properties of biodiesel and mineral diesel cause different levels of fuel dilution of the lubricating oil. Hence, the effect of biodiesel on the lubricating oil degradation needs to be evaluated in long-duration engine tests before taking decision about their large-scale usage. There are very few studies reporting the long-term effects of biodiesel on the lubricating oil degradation in the open literature. Karanja oil is being considered as an important feedstock with a potential of producing biodiesel on large scale because it is well adapted to climatic conditions and is available in surplus quantities throughout South Asian region [9,10]. In this study, effect of 20% (v/v) blend of Karanja biodiesel with mineral diesel (KOME20) on the lubricating oil degradation was experimentally investigated during 200 h long endurance test vis-à-vis baseline mineral diesel. Various tribological studies on the lubricating oil samples drawn at a regular interval from mineral diesel and KOME20 fuelled engines were conducted in order to correlate the effect of fuel properties on lubricant degradation and its residual useful life.

2. Materials and methods

Effect of KOME20 on lubricating oil degradation was studied in a four stroke, four cylinder, variable speed, medium duty, transportation compression ignition (CI) engine (Mahindra & Mahindra, MDI 3000) during 200 h long endurance test in two phases. 200 h endurance test duration is equivalent to 20,000 km field trial of the vehicle. Recommended oil change interval by the manufacturer was 20,000 km. Hence 200 h endurance test duration was conducted. Technical specifications of the test engine are given in Table 1.

Table 1
Technical specifications of the test engine.

Engine type	Four stroke, naturally aspirated, water cooled
Number of cylinders	Four, in-line
Compression ratio	18
Combustion system	Direct injection, re-entrant bowl
Bore/stroke	88.9/101.6 mm
Swept volume	2520 cc
Liner type	Cast iron replaceable wet liners
Fuel injection timing	(SOI) 17 ± 1° BTDC
Max. torque	152 N m @ 1800 rpm
Oil sump capacity	7.0 l

In the first phase, engine was operated for 200 h on mineral diesel for generating baseline data under severe loading according to IS: 10,000 (Part IX) specifications [16]. In the second phase, KOME20 was used as a fuel in place of mineral diesel, keeping all other test conditions identical to the first phase. At the start of the second phase, new set of liners, pistons, piston rings, gudgeon pins and bearings were installed. Table 2 shows a 2 h engine loading cycle, which was followed during the long-term endurance test. Engine was subjected to 100 such loading cycles in each phase. For comparing the effect of KOME20 and mineral diesel on the lubricating oil, samples were drawn from the oil sump during the endurance test after a regular interval of every 20 h engine operation.

A large number of tests were conducted on the lubricating oil samples in order to evaluate the comparative performance of fuels such as measurement of density, viscosity, flash point, moisture content, pentane and benzene insoluble. Density of the lubricating oil samples was measured using a portable density meter (Kyoto Electronics, DA-130N). Viscosity of the lubricating oil samples was determined at 40 °C and 100 °C temperatures using kinematic viscometer (Stanhope-Seta, Setavis 83541-3). Flash point of the lubricating oils was measured by flash point apparatus (Sanhope-Seta, 33000-0) according to relevant ASTM procedures applicable.

For determination of ash content, lubricating oil sample taken in a silica crucible was ignited and was allowed to burn until only ash and carbon remained. The carbonaceous residue was reduced to ash by heating in a muffle furnace at 775 °C for four hours then it was cooled and weighed. TBN measurement apparatus (Kittiwake, DIGI cell) and "Reagent C" were used for determining the total base number of the lubricating oil samples. The copper corrosion bath (Stanhope Seta, Setavis 11300) was used for determining the copper corrosion potential of test fuels and lubricating oil samples. Freshly polished copper strip was immersed in lubricating oil sample for 3 h and maintained at 100 °C temperature. For determination of resinous material and oxidation of lubricating oil, pentane, benzene and toluene insolubles were measured separately. These tests were conducted using an oil centrifuge (Remi Instruments, R-19). 10 grams of lubricating oil sample was put in preweighed conical centrifuge tube and filled up to 100 ml mark with pentane. The tube was shaken until the mixture became homogeneous. Pairs of tubes were placed in the centrifuge on opposite sides of the rotating head in order to maintain balance and centrifuge was then operated at 1500 rpm to maintain relative centrifugal force (ratio of centrifugal and gravitational accelerations) between 600 and 700 for 20 min duration. The insolubles get deposited at the bottom of the tubes. Supernatant liquid was thrown without disturbing the precipitate formed in the bottom of the conical tube. This insoluble was again centrifuged with 50 ml pentane, twice 20 min each time. This precipitate was then dried for 30 min in an oven at 105 °C temperature and then the centrifuge tube was weighed to find the mass of pentane insolubles. For determining toluene insolubles, lubricating oil sample was first dissolved in pentane and centrifuged as described above. After washing the precipitate second time with pentane, toluene–ethanol solution was added up to 50 ml mark and samples were subjected to centrifugation for 20 min at 1500 rpm. This procedure was repeated again by substituting toluene–ethanol mixture with toluene. For benzene insoluble determination, toluene was

Table 2
Engine loading cycle for the endurance test (IS 10,000 Part IX [14]).

Speed (rev/m)	Load (N m)	Running time (min)
2600	105	50
1800	135	45
750	No load	5
2600	135	20