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Effect of non-edible oil and its biodiesel on wear of fuel injection equipment components of a genset engine

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ABSTRACT

In this study, a fuel injection equipment (FIE) test rig was designed and fabricated to investigate the wear characteristics of FIE components used by a single cylinder diesel engine using Karanja oil (KO100), and Karanja biodiesel (KOME100) vis-a-vis baseline mineral diesel. A 250 h endurance test was performed in the FIE test rig to evaluate the wear, weight loss, dimensional loss and alterations to the surface texture at different locations in various components used in the FIE such as nozzle needle, plunger, valve and valve holder. Cam and follower mechanism was used for developing fuel injection pressure in the fuel pump of the test rig, which was operated at 1500 rpm. Karanja oil showed the lowest wear and mineral diesel showed the highest wear of the FIE components, except for plunger. The same was confirmed by surface texture images obtained by optical microscopy at magnifications of 100, 200 and 500×. Wear of FIE components took place primarily due to mechanical and thermal stresses, and chemical reactivity of test fuels with the FIE components. Overall, the wear of FIE components was relatively lower with biodiesel and SVO usage compared to baseline mineral diesel usage in the test rig.

1. Introduction

In the current energy scenario, petroleum derived fuels face immense challenges such as unpredictable and fluctuating prices, concerns related to security of supply and dependence on imports from few oil producing regions of different countries, which are under sectarian conflicts. Due to increasing demand and high cost of petroleum products, researchers globally are exploring low-cost alternative fuels, which can replace petroleum fuels. Alternative fuels such as biodiesel, straight vegetable oils (SVOs), primary alcohols, mixture of gasoline and primary alcohols (gasohols), natural gas (CNG/LNG), liquefied petroleum gas (LPG), hydrogen, unconventional fossil oils, electricity, ethers, etc. have emerged as potential alternative fuel candidates, which can potentially address some of these concerns. Non-edible vegetable oils such as Karanja and its biodiesel are one set of such promising alternative fuels in developing countries, since they offer potential benefits in reducing greenhouse gas (GHG) emissions, dependence on crude oil and engine out emissions of particulate matter. In this context, particulate emissions have been studied for SVOs and biodiesels by several researchers [1–5]. However there are some concerns related to their use in existing internal combustion (IC) engines. The fuel injection equipment (FIE) is normally designed for conventional mineral diesel, which has slightly different physical and chemical properties. This is a matter of concern because slightly different physical and chemical properties of any alternative fuel may have adverse impact on the performance and durability of the FIE system of the engine. This aspect needs to be investigated for different biodiesel/SVO blends.

Kumar et al. [6] conducted a 512 h endurance test to investigate carbon deposits on the cylinder, piston and injector in a diesel engine using B40 (40% v/v Jatropha biodiesel + 60% v/v mineral diesel). Optical microscopy was conducted on these engine components. Optical microscopy images showed that abrasive, adhesive, as well as corrosive wear occurred on the surface of the injector. Higher carbon deposits were seen on the surface of mineral diesel fuelled FIE components compared to biodiesel fuelled FIE components. FIE Plunger and injector needle wear were lower by ∼23–40% and ∼11.9–25% respectively in the engine fuelled by biodiesel. In another study, 512 h engine endurance test was performed and relatively lower carbon deposits were reported for B20 than baseline mineral diesel [7]. There are several studies given in the open literature related to the use of biodiesel in IC engines [8–11], however very few cover the long-term

Abbreviations: SVO, straight vegetable oil; FIE, fuel injection equipment; B20, 20% (v/v) Karanja biodiesel blended with 80% (v/v) mineral diesel; KOME100, Karanja biodiesel; KO100, Karanja vegetable oil; CRDI, common rail direct injection; FFA, free fatty acid

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endurance tests and effect on FIE components. Dhar and Agarwal [12] conducted a 250 h endurance test and reported higher carbon deposits on engine components in case of B20 (Karanja) compared to baseline mineral diesel. Wo et al. [13] reported objectionable carbon deposits in the injector nozzles using emulsified bio-oil. Morphological studies of the pintle type nozzles were carried out to understand the mechanism of emulsified biomass oil derived deposit formation. Carbonaceous deposits formed primarily due to presence of oxygen in the test fuels. Oxygen leads to polymerization and condensation of fuel molecules, resulting in formation of higher viscosity liquids, which carbonize and forms deposits on the nozzle surfaces. In another study [14], a mechanical FIE system was investigated for the effect of Rapeseed biodiesel usage in a heavy-duty diesel engine (MAN-D2566 MUM). After 110 h of engine operation, fuel pump plunger surfaces, injector and injector nozzle holes were examined for carbon deposits and surface texture changes. With biodiesel, injector was found to be clear however deposits were non-uniformly distributed. On the other hand, surface roughness of the plunger surface increased with use of Karanja biodiesel (KOME100). Similar study was performed by Wander et al. [15], and they concluded that castor oil methyl ester (COME) and soya methyl ester (SME) were better fuels than baseline mineral diesel in terms of wear of the FIE components. Surface properties and type of fuel have profound influence on FIE wear characteristics [16,17]. In another endurance test [18] spanning 250 h, impact of B20 (20% v/v Jatropha biodiesel and 80% v/v mineral diesel) on injector deposits was investigated. Mineral diesel and biodiesel, both showed accumulation of carbonaceous deposits on the fuel injector. Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) showed dry, dark colored deposits around the injector, when the engine was fueled with biodiesel. Barker et al. [19] reported that internal deposits such as soaps may be formed due to presence of sodium (NaOH is a catalyst used in esterification process), calcium or other trace contaminants, which interfere with the functioning of fuel additives.

In the IC engines, lubrication of FIE is essential however external lubrication leads to several issues such as injector coking, high viscosity lubricant mixing with fuel, and high density carbon particle deposition therefore it is not very practical to have external lubrication of FIE system. There is always a thin layer of fuel (boundary layer) present between the components of the FIE system, which helps lubricate the mating surfaces of FIE. Under such conditions, adhesion, corrosion, fatigue, or abrasive wear may possibly occur. However FIE component wear is mainly caused by abrasive action of debris/ solid contaminants in the fuel and corrosion. Wear by corrosion is relatively higher than wear by abrasive action in higher lubricity test fuels such as biodiesel.

India has surplus availability of Karanja oil due to large Karanja plantation in the length and breadth of the country and it is one of the main biodiesel feedstock for India's biodiesel program. Vital fuel properties such as density, heating value, cetane number, etc., of this oil are close to baseline mineral diesel. Major challenges in using SVOs as IC engine fuel are their higher viscosity, lower volatility and polyunsaturated character, compared to baseline mineral diesel. When biodiesel is used as an engine fuel, free methanol, dissolved and free water and glycerin, mono- and di-glycerides, free fatty acids (FFAs), total solid impurity levels, alkaline metal compounds, oxidation and thermal stability [20] are few characteristics, which are of concern for the FIE. Use of biodiesel and SVOs therefore creates operational issues in the FIE such as injector coking, higher wear and sludge formation, and can potentially block the nozzle holes.

There are few studies cited in the open literature related to wear of FIE with lower blends of SVOs and biodiesel. However, there is extremely limited information available on the long-term endurance of FIE components such as plunger, valve, valve holder and nozzle needle, while using SVOs and biodiesel (B100) as fuel. Use of test fuels with poor lubricity and SVOs can increase wear of fuel pump and injector components and in the extreme cases, it can even lead to catastrophic engine failure. Studies performed on SVO/biodiesel blends have

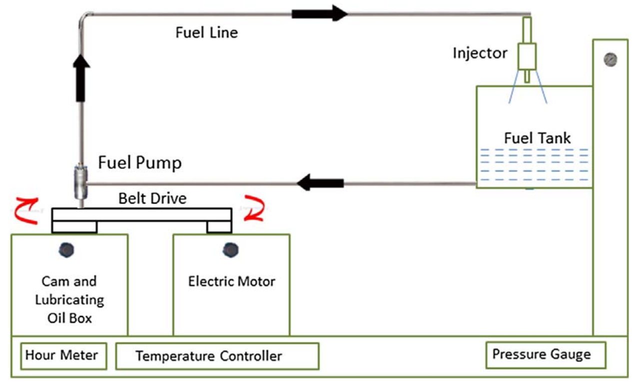

Fig. 1. FIE test rig.

Table 1
Technical specifications of the test engine.

No. of Cylinders	1
Bore × Stroke	102 × 116 (mm)
Engine capacity	0.948 (L)
Compression ratio	17.5:1
Rated output	7.4 kW
Rated speed	1500 rpm
Brake specific fuel consumption (SFC)	185 + 5% g/bhp
Type of fuel injection	Direct Injection

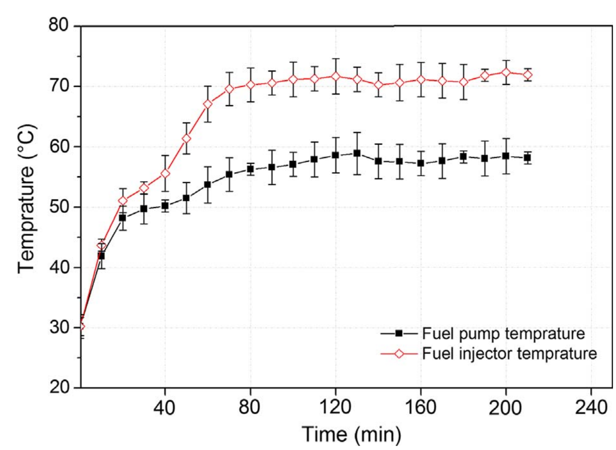

Fig. 2. Temperature vs. time history for fuel pump and fuel injector of a firing engine.

strongly suggested that there is a need to perform long-term endurance tests with SVOs or biodiesels [21], prior to their large scale implementation. The objective of this study includes developing a non-firing engine simulator, capable of simulating engine conditions as close as possible to the engine conditions that the FIE experiences. Thereafter, the compatibility of FIE system with Karanja oil and biodiesel in terms of wear and deposits formed on the injector tip were experimentally evaluated, and compared with baseline mineral diesel. The wear of FIE components in terms of weight and dimensional loss were evaluated. Optical microscopy images were captured to evaluate changes in the surface texture of the FIE components, while using different test fuels.

2. Experimental setup

FIE test-rig was designed and assembled to investigate the wear characteristics of the FIE system. Schematic of the test rig is shown in Fig. 1.

The test rig comprised of a fuel injector, fuel pump, fuel tank, camshaft, lubrication unit, two proportion-integral-derivative (PID)