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Influence of temperature on tribological performance of dual biofuel

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A R T I C L E I N F O

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A B S T R A C T

The consciousness of deteriorating fossil fuels and the adverse impact of its consumption on human health have diverted the research towards alternate energy sources. Biodiesel seems to be the best promising alternate fuel for diesel engines as it has potential to partially or completely eliminate diesel from compression ignition (CI) engine. Several investigations on performance and emissions had shown that use of double biofuels (biodiesel-oil blends) have ability to completely replace diesel. But, the lubricating properties of fuel also affect the performance of engine as some engine parts are lubricated by the fuel itself. In the present study, effects of concentration of biodiesel in blend, temperature and load on friction and wear are investigated with the help of four ball tester. As biodiesel is subjected to oxidation and has highly affected lubricity at higher temperature and load, so the effect of oxidation was also studied. The operating loads and temperatures were 147–392 N and 45–60–75 °C respectively. During operation of four ball wear monitor, frictional torque was recorded with the help of data acquisition system. The scars on the balls are investigated with the help of microscope. An analytical ferrography was also done to analyze the wear debris in the used oil after each test. It was found out from the present investigation that the operating parameters collectively affect the lubricity.

1. Introduction

Given the need for energy, the discovery of numerous energy sources is as old as mankind. Since the 19th century, research on the machines which can convert energy to power has increased to a great extent. In the beginning, feedstocks derived from fossil sources were extensively used in CI engines. But in due course of time, the biogenic material also getting some interest, mainly vegetable oil or their derived fuels in the case of CI engines [1–3]. As, transportation sector which is primarily based on CI engines is the main consumer of diesel [4] therefore, it is necessary to find out an alternative for diesel fuel. To select an alternative for diesel, it should have better combustion and performance, chemically stable, better tribological characteristics, produce less harmful emissions (regulated and unregulated) in the environment, etc [5,6]. Therefore in this context, biodiesel for CI engines is recognized as a leading choice due to its availability, renewability, sustainability, low aromatics, eco-friendliness and resemblance of its properties with diesel [7–10]. Along with the combustion, emission and performance characteristics of engine and lubricity of fuels also plays a vital role in engine's life as it reduces the wear and friction between the moving parts of engine and also minimizes the fuel consumption [11,12]. Due to pressure of international authority's competition and expectations of customer; it is necessary to reduce fuel consumption and increase lubricity between sliding components to reduce friction and wear on the surfaces of engine to increase engine's life. To fulfill these escalating demands, various feasible solutions are proposed by the researchers to minimize friction and wear between the moving parts [13]. These additives affect the lubricity positively, but it is destructive for the environment to use more additive through hydro treatment. It is very imperative to study the lubricity characteristics of biodiesel before using it as a fuel in CI engines. It has been investigated by many researchers that biodiesel provides better lubricity to the moving parts as compared to diesel but increases the tribo-corrosion [14,15]. The tribological characteristics are also influenced by the raw material and alcohols (edible oil, non-edible oil, fats, micro-algae) used for the production of methyl ester [16]. The combined impact of biodiesel degradation and the subsequent impact of corrosion and wear on automotive materials could be critical and hence, it is necessary to be studied.

The reason for the adoption of methodology to conduct bench tests for investigating tribological performance is that the cost and time reduces which is associated with the testing of the fuel in engine. There are number of bench tests conducted by the researchers i.e. high frequency reciprocating rig (HFRR), pin on disc, ball on cylinder lubricity evaluation, four ball tester, etc. for

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Nomenclature

AB	Aamla biodiesel	HFRR	high frequency reciprocating ring
ASTM	American society of testing and materials	r	distance between axis of rotation and centre of fixed balls (mm)
CI	compression ignition	T	torque (kg.mm)
COF (μ)	coefficient of friction	W	load applied (N)
EU	eucalyptus oil	WSD	wear scar diameter (mm)
FTP	flash temperature parameter		

the primary acquaintance about the tribological behaviour of the fuel [17]. Among all the evaluators, four ball tester has its own importance as it endows the convenient basic information about the fuel lubricity behaviour. Four ball tester is used to evaluate the wear scar diameter (WSD) of the grease and oils which are used in lubrication [18]. It measures the scar as it traverses a particular value.

Many investigations had been carried out by the researchers to evaluate the tribological performance using various biogenic materials with or without additives. Masjuki et al. [19] has investigated the tribological performance of palm oil methyl ester with the help of four ball tester. They found out that the wear characteristics are improved with palm oil methyl ester. They suggested that palm oil methyl ester can be used as an additive to enhance the lubrication properties of the fuel. Haseeb et al. [20] has investigated the effect of temperature (30° to 75 °C) on tribological properties of palm biodiesel using four ball tester. Result shows that the biodiesel-diesel blends (B10, B20 and B50) show lower WSD as compared to diesel. At higher temperature, wear and friction increases due to fall in viscosity and hence degradation of boundary lubrication. Additionally, wear and friction decreases with the increase in biodiesel content in blend. Fazal et al. [21] has studied wear and friction characteristics of palm biodiesel on four ball tester. They have investigated the characteristics at varying speed (600, 900, 1200 and 1500 rpm) at a constant load and temperature of 40 kg and 75 °C respectively. At 1500 rpm, they observed that 10 and 20% drop in wear for B20 and B100 blends respectively. Kumar et al. [22] has also investigated tribological performance by using four ball tester. Jatropha biodiesel, Jatropha biodiesel-diesel blends and oxidized biodiesel is used at varying load (40, 50 and 60 kg) and temperature (45, 60 and 75 °C). Habibullah et al. [23] has evaluated the tribological performance of *Calophyllum inophyllum* biodiesel at constant speed of 1800 rpm with varying load (40, 50, 63 and 83 kg) conditions. They found out that biodiesel shows better result as compared to diesel as it reduces the WSD and flash temperature parameter (FTP). The WSD for neat biodiesel is approximately 41.02% lower than the diesel. Mosarof et al. [24] has compared the tribological properties of *Calophyllum inophyllum* biodiesel with palm biodiesel. Result shows that 20% palm biodiesel with diesel blends show the improved results as compared to other tested blends.

Some of the engine parts are lubricated by the fuel itself i.e. fuel pump and fuel injectors. The lubricity of the feedstock is dependent upon the dynamic viscosity. As, the inlet temperature at fuel inlet seems to be more than 60 °C and dynamic viscosity is also changing, so the, tribological characteristics of fuel also varies accordingly. Moreover, the authors have studied the combustion, performance and emission characteristics of biodiesel-oil blends for the purpose of total elimination of diesel from CI engine. But there is no literature available on their tribological performance in engine.

The objective of the study is to investigate the tribological performance of dual biofuel i.e. different concentration of *Phyllanthus emblica* (Aamla) biodiesel (AB) in eucalyptus oil (EU) and to compare the results with conventional diesel fuel on varying temperature and load conditions. The effects of oxidation stability of biodiesel on wear and friction characteristics are also discussed.

2. Materials and methods

2.1. Test oil

In this study, new non-edible *Phyllanthus emblica* (aamla) seed oil was used for making biodiesel which is most capable feedstock for production of biodiesel as; it is renewable, sustainable, biodegradable, etc. Phyllanthus emblica is a perennial tree found in the Himalayan region in India [25]. The methyl ester used in the present study was produced by the commonly used process ‘ transesterification’. Initially, the raw oil was filtered by using filter paper. Then, this oil was heated at 120 °C for removing moisture from oil for one hour. After that, the oil was cooled down at room temperature. The chemical reaction for the methyl ester production was done by taking methanol to an oil molar ratio of 6:1 and potassium hydroxide as a catalyst (0.75% by weight of oil). The mixture was heated at 60 °C at 600 rpm stirring speed for 120 min. Then the mixture was settled down for 24 h in separating funnel. The glycerol got settled down in the bottom layer and biodiesel in upper phase and hence was separated by decantation process. The biodiesel was heated at 65 °C for removing the excess methanol and then washed with hot distilled water to remove the impurities. By taking these conditions, the yield of AB was approximately 84%.

The biodiesel having blend of 0, 10, 20 and 30% of EU by volume were used for the investigation. The effect on tribological performance of a quiescent aging biodiesel was also studied along with diesel fuel is used for comparison. The properties of AB, EU oil and diesel are shown in Table 1.

2.2. Ball specification

The balls used in this experiment consisted of chrome alloy steel ball. The balls were of standard diameter 12.7 mm. The steel ball consists of chromium, carbon and balanced iron. The specifications of ball were shown in Table 2. After each experiment, four new balls were taken. Initially, all the balls used for experimentation were properly cleaned with acetone. After that all these balls were cleaned and dried with the tissue paper.

2.3. Experimental setup

The tribological performance of the biodiesel-oil blends were evaluated on four ball tester (Ducom TR30L PNU). Fig. 1 shows schematic diagram of four ball tester set up. Four steel balls with standard diameter of 12.7 mm were placed in such a way that they make an equilateral tetrahedron. The lower three balls were fitted in cup with locking nut and clamping rings so that they remain in the position. The rest fourth ball which is rotated over three fixed