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Effect of straight vegetable oil blends and biodiesel blends on wear of mechanical fuel injection equipment of a constant speed diesel engine

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A B S T R A C T

Vegetable oils and biodiesel have emerged as strong alternative fuels worldwide. However use of new fuels in existing engines leads to issues such as wear of vital moving components, and fuel injection equipment (FIE). It is important to ensure that new alternative fuel does not affect the FIE adversely. In this experimental study, a non-firing engine FIE simulator test rig prototype was developed and 250 h endurance test of FIE was performed with an objective to ensure the long-term compatibility and durability of biofuel blends. The components of FIE such as plunger, nozzle needle, valve, and valve holder were investigated for wear. Test fuels used in this study were Karanja blends (K20, K5), Jatropha blends (J20, J5), Biodiesel blends (B20, B5) and baseline mineral diesel in a non-firing engine FIE simulator. The compatibility of FIE with test fuels in terms of dimensional loss, weight loss and surface texture variations using optical microscopy before and after the endurance test was compared. Biodiesel blends showed relatively lower wear compared to mineral diesel however SVO blends showed no definite trend of the wear results compared to baseline mineral diesel.

1. Introduction

Due to limited energy reserves, there is a need to investigate non-polluting, renewable and efficient fuels for transport sector for future needs. Renewable resources, green energy, and environmental friendly processes have emerged as fascinating areas of research in transportation sector to help ascertain energy security and global environmental preservation. Dependence of humans on machines has increased exponentially with time since industrial revolution in 1850. It has increased individual productivity but has also increased per capita energy consumption, which requires various types of fuels to be utilised. Scientists are now working on developing alternative fuels, which can help quench ever increasing global energy thirst. Energy consumption is leading to environmental pollution therefore stringent emission legislations for controlling NOx, CO, PM and HC emissions are being adopted worldwide. Several biofuel feedstock's are readily available in surplus quantities in various parts of the world. It is certain that biofuels would play an important role in meeting the global energy demand in near future. Biodiesel, which is one of the most important biofuels has almost similar physical, chemical and thermal properties as that of mineral diesel. Chemically speaking, biodiesel consists of mono-alkyl esters (C_{14} to C_{18}) derived from triglycerides present in straight vegetable oils and animal fats [1]. Biodiesel has to comply with international biodiesel fuel specifications such as ASTM D-6751 before it can be sold as a fuel in the market [2]. Biodiesel derived from non-edible feedstocks such as Karanja, Polanga, Mahua, Rubberseed, Cottonseed, Jojoba, Tobacco, Linseed, Jatropha, etc. have been investigated for engine use by researchers [3–10]. Karanja and Jatropha are two main biodiesel feedstocks found in abundance across South East Asia, Sub-Saharan Africa and India which are of immense interest as biodiesel feedstocks in these regions. Some of the advantages of biodiesel derived from these species include, (i) non-edible nature, (ii) growth in less fertile lands, (iii) large scale availability, (iv) faster growth, (v) survival in various environmental conditions and (vi) high energy content of the oil etc. The non-edible nature of Karanja and Jatropha oil has made them a primary biodiesel feedstock because they do not conflict with food chain and steer clear of food v/s fuel debate.

Dhar and Agarwal [11] investigated diesel engine wear using Karanja biodiesel. They conducted a 250 h endurance test in a direct injection compression ignition (DICI) engine. In this study, weight loss and carbon deposits investigations were conducted on various

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engine and FIE components. They reported that weight of carbon deposits on the piston top of the engine using biodiesel was higher in comparison to the one using mineral diesel. Another endurance test was conducted by Liaquat et al. [12] for 250 h using two test fuels; diesel as baseline and palm biodiesel, in a single cylinder CI engine. Deposit formation on the fuel injector of biodiesel engine was found to be higher than that of mineral diesel. SEM images of the injector were taken after 250 h and these images confirmed that the deposits on biodiesel injector were indeed higher than mineral diesel. Birgel et al. [13] also reported similar results. Fuel properties play a very significant role in wear and weight loss of engine components. Variations in density and cloud point of SVO blends was shown by Abolle et al. [14]. Experiments on a four-ball wear tester were performed by Fazalet et al. [15] in order to investigate friction and wear characteristics of palm biodiesel. It emerged that both friction and wear slightly decreased with use of biodiesel. Moreover, with increase in rotating speed, the lubricity reduced. Chemical composition and physical properties of the fuel greatly affected injector wear, injector chocking and its life. This was also experimentally demonstrated by Galle et al. [16], while investigating the failure of injectors in a diesel engine operated on biofuels. This investigation revealed that there may be many possible reasons for injector failure such as plastic deformation of injector, clogging of injector passage, emergence of micro-cracks and erosion, and physical damage due to cavitation.

Tribological interactions play a significant role in wear and weight loss of FIE components. Test conditions also have a powerful impact on the tribological studies. Xu et al. [17] carried out a comparative study to determine the influence of test conditions (oscillation frequency and load) on the tribological properties of emulsified bio-oil, bio-oil and baseline diesel and the tribological mechanisms involved were analyzed. Apart from weight loss and dimensional loss, corrosion also plays a vital role in FIE wear. Karamangil and Taflan [18] performed experimental investigations to determine the effect of corrosion in a CRDI injector nozzle. Its effect on spray and injected fuel quantity was also investigated. They reported that engine emissions, performance and wear were effected by corrosion and they noticed that spray deviated from its original behavior due to deposits accumulated inside the nozzle holes due to wear/ corrosion. They observed narrow, thin and deep pits, which affected the spray shape. Fazal et al. [19] reviewed the literature for biodiesel's compatibility with engine components. They categorized engine parts into (i) static parts such as fuel tank, filter, fuel line etc. and (ii) dynamic parts such as connecting rod, inlet and exhaust valve, and piston. They concluded that in case of biodiesel, fuel temperature, metal exposure, moisture absorbed, and temperature of FIE influenced the degradation of metallic components. Corrosion of FIE was also highlighted. They indicated that short-term studies of biodiesel were performed by several researchers however long-term studies of biodiesel are very few in open literature and further detailed investigations need to be carried out in this domain. Hu and Du [20] reported that methyl esters and monoglycerides were the two most significant factors responsible for lubricity of biodiesel. It has been reported in the literature that higher is the biodiesel viscosity, higher will be its lubricity. However, higher viscosity also causes poor fuel atomization which in-turn affects the FIE adversely [21]. Vegetable oils and animal fats are mainly triglycerides, which are primarily responsible for lower friction and wear. When three OH groups on the glycerol molecules are esterified with the same fatty acid, it is called simple triglyceride Fig. 1 shows a simple triglyceride molecule structure and Fig. 2 shows the mechanism of thermal deposition of triglycerides, which helps in reducing friction and wear of the FIE.

Biodiesel produced from transesterification reaction is a mono-alkyl oxygenated fuel, which contains ~11% oxygen (w/w).

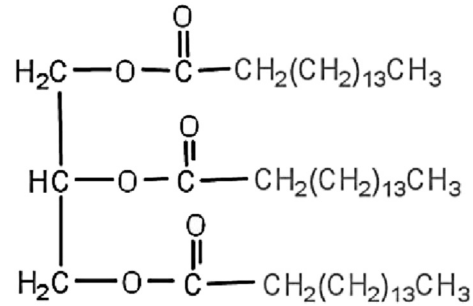


Fig. 1. Simple triglyceride molecule.

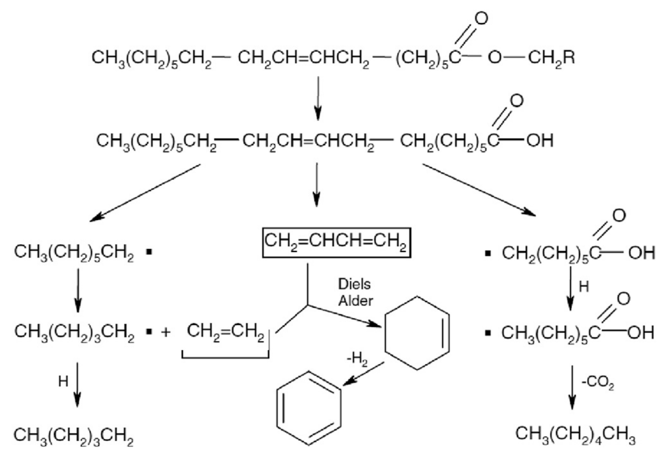
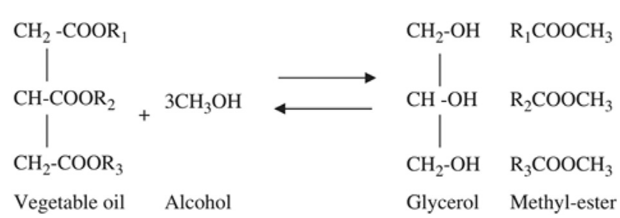


Fig. 2. Thermal decomposition mechanism of triglycerides (Schwab et al., 1988) [24].

Transesterification is a chemical process of converting large branched triglyceride molecules of bio-oils and fats into smaller straight chain ester molecules. Vegetable oils on the other hand are a mixture of triglycerides with varying alkyl chain lengths and varying degree of unsaturation. When SVO undergoes transesterification, then diesel like molecular range esters (from C_{10} to C_{20}) are produced. A typical transesterification reaction is shown below with fatty acids methyl esters (FAME) as product.



Biodiesel possesses mostly polar molecules, which are attracted to metal by electrostatic adsorption forces. As far as tribological aspects of wear and corrosion are concerned, there is a very small difference between corrosion and wear. Both corrosion and wear go hand in hand and are in broader category of tribo-corrosion. If corrosion occurs in a FIE, then it may increase the wear rate and vice-versa. Wear always occurs on the sliding surface of the FIE but corrosion occurs when metals in the FIE undergo electrochemical or chemical reactions. Whenever there is a contact between FIE components and biodiesel, metal removal may happen by any one or combination of processes such as corrosion, scuffing, abrasion, adhesion and additive depletion. This metal removal is reflected in the dimensional loss of FIE components. Ferrous and non-ferrous metallic parts, both undergo corrosion. The severity of corrosion