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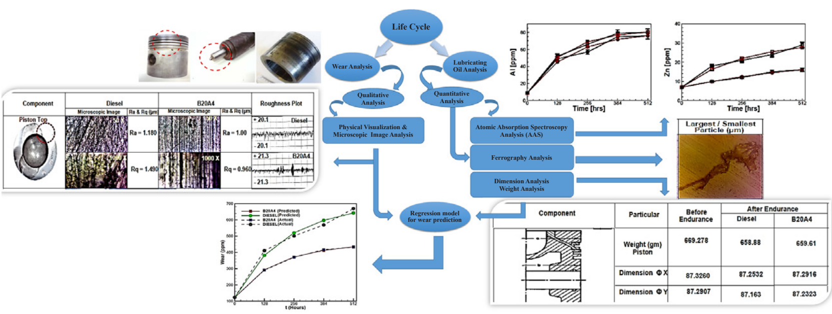
Study on tribological behavior of biodiesel – Diethyl ether (B20A4) blend for long run test on compression ignition engine

Sajan Chourasia, Paresh D. Patel, Absar Lakdawala*, Rajesh N. Patel

Nirma University Ahmedabad, 328481 Gujarat, India

GRAPHICAL ABSTRACT



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ABSTRACT

The gradual reduction of world petroleum reserves, growths in prices of petroleum-based fuels and environmental pollution has increased attention to the search for unconventional fuels such as biodiesel. It has remained the focus of extensive amount of research since it is renewable and reduces the emission of pollutants. Though, some of the significant issues like compatibility of biodiesel with the crankcase lube oil, thermal stability of lube oil with biodiesel, changes in physical and chemical properties of lubricating oil with biodiesel etc. have not been adequately inspected. These requirements are to be addressed in order to confirm the long-term suitability of biodiesel in a current family of diesel engines. In the present work, these problems are addressed. With an overall objective of life cycle analysis, a long run endurance test (512 h) is carried out on CI engines fuelled with diesel and the optimized blend of bio-diesel fuel (B20A4) respectively. The endurance tests are directed as per IS 10,000 for the examination of wear of engine components, lubricant's properties, suspended impurities, and wear metal debris. The wear of the various component of the engine is characterized by dimension and weight measurements. Lube oil analysis (Atomic Absorption Spectroscopy – AAS, Ferrography) were performed on oil samples, taken after every 128 h. The oil analysis suggested that the wear of B20A4 fuelled engine is substantially lower compared to the diesel. A regression model was also proposed to predict wear of the engine. The proposed regression model can be taken one step further to predict the overall wear of the engine. The total concentration of various metals debris collected in the lube oil sample (predicted using regression model) was found to be 640 mg/kg and 420 mg/kg for diesel and B20A4 respectively.

Abbreviations: AAS, atomic absorption spectroscopy; ASTM, American Society for Testing and Materials; B0, pure diesel; B10, 10% bio diesel + 90% diesel; B20A4, 20% bio diesel + 4% DEE + 76% diesel; CMM, coordinate measuring machine; DEE, di-ethyl ether; DLC, diamond like coating; FFA, free fatty acid; GRG, generalized reduced gradient algorithm; HCl, hydrochloric Acid; KOH, potassium hydroxide; LCA, life cycle analysis; PT, pressure transducer; TBN, total base number; VCR, variable compression ratio

* Corresponding author.
E-mail address: absar.lakdawala@nirmauni.ac.in (A. Lakdawala).

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Nomenclature

a_i & b_i	regression constant for various debris
Co_i	initial concentration of metal debris in the lubricating oil
C(t)	total concentration of metal debris collected in the lubricating oil
l	length of metal debris
n	number of observations
N	engine speed in RPM
S	standard deviation
T	temperature
t	random variable
X	weight of the component before endurance test
Y	weight of the component after endurance test - diesel
Z	weight of the component after endurance – B20A4
x_i.	initial value
x_m.	mean value
ω_A.	uncertainty in ampere
ω_E.	certainty in emission
ω_T.	uncertainty in temperature
ω_m.	uncertainty in measurement
ω_t.	uncertainty in time
ω_v.	uncertainty in voltage
Δ	confidence interval
$\|d_i\|$	deviation
Φ	diameter of the metal debris

1. Introduction

One of the biggest problems in current century is depletion of conventional fossil fuels and increasing air pollution. More than 10 million diesel engines are used in the country for transportation and farming activities [1,2]. With prevailing transportation situations in India, the use of alternative fuel in the unmodified diesel engine is recommended [3]. Moreover, stringent emission norms in CI engine increases emphasis on the use of biofuel and fossil fuel blends. Patel et al. [3] reported that the use of optimum blend B20A4 (20% Biodiesel + 4% DEE + 76% diesel) in unmodified diesel-engine meet stringent emission norms. This may permit the replacement of diesel with biofuel albeit, for a short run. However, it is suggested that while using different biofuels; it is very vital to strike the equilibrium among several conflicting constraints involving not only the performance and emission characteristics of the engine, but also the complete life of the engine [1].

The combustion-associated properties of biofuels are slightly similar to mineral diesel oil. However, either biofuel or their mixtures with diesel pose many long-standing problems in CI engines, e.g., Poor atomization characteristics, ring-sticking, injector-choking, injector deposits, injector pump disappointment, and lubricating oil thinning by crankcase polymerization. Such difficulties do not arise with short-range engine operations [4]. Occasionally, the engine fails terribly while operated on biofuels for an extended period. To avoid such failures, it is always essential to established wear analysis of vital parts of CI engine such as cylinder liner, piston, pistons rings, crankshaft, crankshaft bearing and journals etc. for a long-run utilization of biofuel or diesel-biofuel blend. With this objective, a long run endurance test to establish wear properties of CI engine fuelled with the biofuel-diesel blend and its comparison with the diesel fuelled engine was carried out in this work.

Although the literature on life cycle analysis of CI engine is limited, few researchers have reported wear during long run endurance in terms of dimension and weight measurement, [1,4–7], microscopic and surface roughness analysis [4,9–14] and lubricating oil analysis using Atomic Absorption Spectroscopy (AAS) [8,15–24].

Agarwal et al. [1] examined the influence of B20 blend (20% Biodiesel and 80% Diesel) of the linseed oil methyl ester on the tribological characteristics of engine components when the engine runs for an extended period of time. They reported the wear in terms of dimensions of various components. It is found that the wear of nearly all components of the engine is substantially lower with B20 fuelled engine as compared to the neat diesel fuelled engine. Truhan et al. [7] summarized the wear in terms of weight measurement while using different lubricants in the engine.

Agrawal and Dhar [4] examined the surface roughness profile of the engine components at the different location when running for an extended period. They reported wear of cylinder liner in terms of roughness parameters. The overall wear for cylinder liner in B20 fuelled engine is lower as compared to diesel fuelled engine. Further, they observed that the wear of cylinder liner at top position is slightly higher as compared to the mid and tail position in both the engines. This may be due to the higher combustion temperature when the piston is at top dead center. Cesur et al. [11] and Fazal et al. [12] experimentally analyzed the amount of wear for piston ring and cylinder under varying engine speed and load conditions using scanning electron microscope. It is observed that wear is more in the diesel fuelled engine as compared to biodiesel.

Petroleum or bio originated fuel composition and structure plays a vital role in performance and life of engine lubricating oil [6,7]. Variances in physical and chemical properties of the biofuel and diesel are the source of dilution in engine lubricating oil. Moreover, properties of engine lubricating oil vary with its usage, due to fuel thinning and addition of impurities or contaminants through wear of various moving components of the engine. Therefore, the effects of usage of biodiesel on the engine lubricating oil degradation need to be assessed through long-term engine endurance test. Very limited studies are reported in the literature on lubricating oil degradation in the long run endurance test with biofuel. Karanja oil is considered as a significant feedstock with a perspective of making biodiesel on an enormous scale for the long run test, since it exists in excess amounts all over South Asian County [9,10]. Agarwal [6] examined the tribological characteristics of engine lubricating oil when the engine run with the linseed oil methyl ester. He reported that the dilution of lube oil is much lesser in B20 fuelled engine as compared to the diesel. In a similar study, Sinha and Agarwal [5] carried out ferrography analysis of the lubricating oil taken from engine sump at regular interval. They reported that the concentration of nearly all debris metals (Cu, Mg, Fe, Cr, Ni and Zn) is found lower in case of B20 as compared to diesel. It is also reported that the concentration of Al and Pb is found slightly higher with B20. This may be due to corrosive effect by biodiesel on the bearings and other components [8]. Several researchers have investigated the wear and frictional behavior of CI engine components with biofuels for various durability aspects [15–23]. Ashraful et al. [17] have studied the effect of tribological compatibility of lube oil in CI engine fuelled with palm biodiesel. Similarly, Basinger et al. [24] determined the oil change frequency in CI engine fuelled with straight plant oil when operated for several hundred hours. Forsberg et al. [25] have suggested the multilayer diamond-like coating (DLC) on CI engine to reduce the wear during the durability condition. Habibullah et al. [26] studied the tribological characteristics of calophyllum inophyllum biodiesel as lubricity enhancer by using four ball tribometer. The average results reveals from their studies that the diesel fuel shows 16% higher friction coefficient and 40% higher wear scar diameter than pure biodiesel. The tribological performance of biodiesel is crucial for its application in automobiles. Habeeb et al. [27] reported that lubricity of palm oil biodiesel in terms of friction and wear is decreased with increasing temperature. They have also investigated that deformation of the worn surface increases with increasing temperature and at the same time it