

Experimental Investigations of the Tribological Properties of Lubricating Oil from Biodiesel Fuelled Medium Duty Transportation CIDI Engine

Shailendra Sinha and Avinash Kumar Agarwal*
Indian Institute of Technology Kanpur, India

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ABSTRACT

Biodiesel is mono alkyl ester derived from vegetable oils through transesterification reaction and can be used as an alternative to mineral diesel. In the present research, methyl ester of rice-bran oil (ROME) is produced through transesterification of rice-bran oil using methanol in presence of sodium hydroxide (NaOH) catalyst. Various properties like viscosity, density, flash point, calorific value of the biodiesel thus prepared are characterized and found comparable to diesel. On the basis of previous research for performance, emission and combustion characteristics, a 20% blend of ROME (B20) was selected as optimum biodiesel blend for endurance test. Endurance test of 100 hours was conducted on a medium duty direct injection transportation diesel engine. Tests were conducted under predetermined loading cycles in two phases: engine operating on mineral diesel and engine fuelled with 20% biodiesel blend. Various tribological studies on lubricating oil samples drawn from both phases after regular intervals were conducted in order to assess the wear of the engine components and to correlate the comparative performance of the two fuels. A number of tests like density measurement, viscosity, flash point, moisture content, pentane and benzene insoluble, TBN (total base number) analysis, atomic absorption spectroscopy and ferrography have been carried out to compare the effect of fuel on the lubricating oil. Experimental results exhibited superior performance of biodiesel blends and less deterioration of lubricating oil with usage. This paper discusses the effect of biodiesel on lubricating oil vis-à-vis mineral diesel.

INTRODUCTION

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. The indiscriminate extraction and consumption of fossil fuels have led to reduction in underground based petroleum reserves. Petroleum resources of most of the non-OPEC countries have already peaked or are going to peak in near future [1]. At the same time, emissions of pollutants generated by

combustion of fossil fuels lead to environmental degradation. Transportation plays a key role in increasing emissions from fossil fuels. The Kyoto Protocol stressed upon the importance of cleaner environment and sustainable development i.e. development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Over the past few decades, diesel engine technology has significantly improved and these engines are gaining popularity in the passenger car segment also. Compared to the rest of the world, India's demand for diesel fuels is roughly five times that of gasoline (39% of the total petroleum products) [2,3]. It is in this context that the attention is now focused not only to conserve the conventional energy sources, but also to explore new energy sources, which are renewable in nature and can be developed indigenously for energy security of the country.

Many countries in the world have a general interest in vegetable oil as an alternative fuel to petroleum diesel. In fact, the use of vegetable oils in diesel engines is nearly as old as the diesel engine itself. However, it is only in recent years, systematic efforts have been made to utilize vegetable oil as fuels in the engines. Vegetable oils have approximately 90 percent heat content of petroleum diesel and their combustion related properties are somewhat similar to petroleum diesel [4-8]. However, several properties of oils, such as high viscosity, high molecular weight, and low volatility etc. cause poor fuel atomization leading to incomplete combustion resulting in problems like severe engine deposits, injector coking, piston ring sticking and lubricating oil degradation etc. [8-16]. Most of these problems are a consequence of high viscosity, low volatility and polyunsaturated character of vegetable oils. Thus, it has to be converted to more engine-friendly fuel called biodiesel (vegetable oil esters). Among the various fuel modification techniques available like pyrolysis, blending, micro-emulsion and transesterification, transesterification is the most effective and widely used technique for formulating

Corresponding Author's Email*: akag@iitk.ac.in

properties of vegetable oils close to petroleum diesel [8,9,17-23].

Transesterification is a well established chemical reaction in which alcohol reacts with triglycerides of fatty acids in presence of a catalyst. It is a reversible reaction of fat or oil with a primary alcohol, in which alcohol combines with the triglycerides to form one mole of glycerol & three moles of mono alkyl esters (biodiesel), molar mass of which is approximately one third of triglycerides [8,9,18-20,23-25]. Biodiesel is biodegradable, non-toxic, essentially sulphur free, renewable and can be produced from agriculture and plant resources available locally. Biodiesel degrades four times faster than petroleum diesel and carbon cycle time for fixation of CO₂ from biodiesel is quite small compared to petroleum diesel [26,27].

In the previous study [28,29] with rice-bran oil biodiesel, it was found that hydrocarbon and carbon monoxide emissions reduce drastically with a small increase in the NO_x emissions as compared to petroleum diesel. Marginally higher NO_x emissions are due to the early start of combustion due to higher cetane number of biodiesel. It can be reduced by retarding the injection timing. Biodiesel provides significant fuel lubricity properties. Limited lubricity of sulfur-free petroleum diesel can accelerate engine deterioration and hence biodiesel may be added to petroleum diesel in order to compensate for loss of lubricity due to removal of sulfur compounds [30-36]. A minor inconvenience of marginally higher NO_x should not detract from the numerous advantages that biodiesel offers.

The effects of fuel on lubricating oil degradation is very important as it affects the fuel economy, emissions as well as engine durability. In an engine, the cost of the lubricating oil alone is approximately 6-7% of overall operating costs. Over the years, engine designers striving for greater efficiency, have increased the stresses on engine components. Additive packages in lubricants have also become more complex to cope with other engine problems (rust, detergency, sludge dispersancy, etc.) [37]. The commercially available lubricant oils are a combination of base oil and several additives, which are added to perform specific functions. Biodiesel provides significant fuel lubricity properties, which help in reducing wear of vital engine components. The lubricity of a fuel ultimately impacts engine wear. In addition, metals, such as Fe, Al, Ni, Cr, Cu and Pb are also present in used lubricants due to wear of the lubricated parts. Therefore, determination of the metal content in used lubricants is important to identify and repair any possibly defective functioning area/part of the lubricated equipment and to plan maintenance [38]. Modern instrumental techniques such as inductively coupled plasma - optical emission spectroscopy (ICP-OES), atomic absorption spectrometry (AAS), X-ray fluorescence spectroscopy (XRF) have been widely used for this analysis [39-41]. *Palus* [42] examined the used motor oil (LOTOS, 15W40) by flame AAS and found that the concentration of Zn, Ca and Ba decreased initially for few kilometers of the engine run but after that, the concentration of these metals started increasing. *Clark et al.* [12] found normal wear metal levels in

lubricating oil for soybean biodiesel fuelled engine throughout 200 hour test. Slightly higher levels of aluminum and lead were observed.

Kalam and Masjuki reported increased concentration of metals (Fe, Cu, Al and Pb) but decreased Zn and Ca with engine operation while performing 100 hour test with half throttle setting at constant speed of 2000 rpm for different blends of palm oil methyl ester. Comparatively lower reduction in viscosity and TBN was found with blends of palm oil methyl ester [43]. *Masjuki et al.* [44] reported that viscosity index (VI) of vegetable oil based lubricant was higher than that of mineral based lubricant. Accumulation of insoluble deposits on the engine parts cause poor lubrication and increased engine wear. When diesel engines are operated at high temperature, the viscosity of the engine oil can increase due to oil oxidation and nitration, evaporation of the lighter fractions of the base-stock, and accumulation of soot in the lubricating oil [45]. Detergent additives provide an alkalinity reserve to neutralize acidic by-products of combustion. They react with oxidation enhancing products to reduce the formation of insoluble and provide some measure of corrosion protection. Total Base Number (TBN) provides a measure of the remaining alkalinity of protective elements i.e. additives specially for neutralizing acid. Higher the base number, greater is the neutralizing capacity of the additive [46].

Ferrography is another useful technique to monitor the wear debris in the oil. Several researchers found that this technique can be well utilized for diesel engine condition monitoring and wear measurements of engine parts [47-49].

Agarwal et al. [50,51] performed 512 hour endurance test on two single cylinder constant speed diesel engines for 20% linseed oil biodiesel blend and diesel respectively as fuel and conducted various tribological studies on the lubricating oil samples drawn at regular intervals from both the engines. Lower wear in case of biodiesel fuel and better condition of lubricating oil hence longer life of lubricating oil for biodiesel operated engine was reported [51].

A lot of literature is available on the performance and emission characteristics of biodiesel fuelled engines but only a few studies regarding lubricating oil tribology were found in the literature. The behavior of biodiesel on wear of engine components and lubricating oil contamination is also to be analyzed critically before adopting it as fuel for diesel engines on a large scale. In present study, various tribological tests including AAS and ferrography are conducted on lubricating oil samples in order to correlate the comparative performance of the two fuels.

FUEL PREPARATION & EXPERIMENTAL DETAILS

Rice bran oil was transesterified, using methanol in presence of NaOH catalyst. Process parameters like temperature, catalyst amount, molar ratio of alcohol to oil, and reaction temperature were optimized and these were 9:1 molar ratio of alcohol to oil, 55°C temperature, 0.75 % (w/w) catalyst and one hour reaction time for transesterification of rice bran oil. This biodiesel is then blended in required quantities to form appropriate

blends. The blends were referred as Bxx where xx refers the percentage of ester in that blend. Characterization of rice bran oil, rice bran oil methyl ester (ROME) and petroleum diesel were done in laboratory as per ASTM standards. Some fuel properties evaluated are shown in the Table 1.

Table 1: Properties of fuels

Property	ASTM Method	ROME	Petroleum Diesel
Specific gravity @ 30 °C		0.877	0.839
Viscosity (cSt) @ 40°C	D445	5.29	3.18
Cetane No.	D613	63.8	51
Cloud/Pour Point (°C)	D2500	9/ -2	6/ -7
Flash/ Fire Point (°C)	D93	183/196	68/103
Calorific Value (MJ/kg)	D 240	42.2	44.8
Elemental Analysis (% w/w)	C	72.96	82.12
	H	12.73	14.72
	N	0.94	--
	S	ND	0.25

Keeping in view to utilize biodiesel in transportation sector specially cars and medium duty vehicles, a typical medium duty transportation direct injection compression ignition (CID) engine (Make: Mahindra & Mahindra; Model: MDI-3000) was used for this study. The specifications of the engine are given in Table 2.

Table 2: Specification of the engine

Manufacturer	Mahindra & Mahindra Ltd, India
Model	MDI 3000
Type of Engine	Four stroke, Naturally Aspirated, Water Cooled diesel engine
Number of Cylinders	Four
Combustion System	Direct injection, Re-entrant bowl
Bore/stroke	88.9/101.6 (mm)
Displacement Volume	2520 cc
Direction of Rotation	Anti-clockwise (flywheel side)
Compression Ratio	18 :1
Cylinder Liners	Cast Iron Replaceable Wet liner
Fuel Injection Start Timing	15±1° BTDC
Rated Power	55 HP at 3000 rpm
Max. Torque	152 Nm at 1800 rpm

The inlet valve opens 5° BTDC and closes 35° ABDC. The exhaust valve opens 42° BBDC and closes 10° ATDC. Tappet clearance recommended by manufacturer at cold condition for inlet valves are 0.016/0.014 inch and for exhaust valves are 0.020/0.018. The engine was coupled with an eddy current dynamometer and controller (Make: Schenck Avery, India; Model: ASE 70). Suitable instrumentation was done for conducting the experiment. Schematic diagram of experimental setup is shown in Fig 1.

The proportion of biodiesel in the fuel blend was optimized using performance, emission, and combustion characteristics investigations on several blends and 20%

blend of rice-bran biodiesel (B20) was found to be optimum [28].

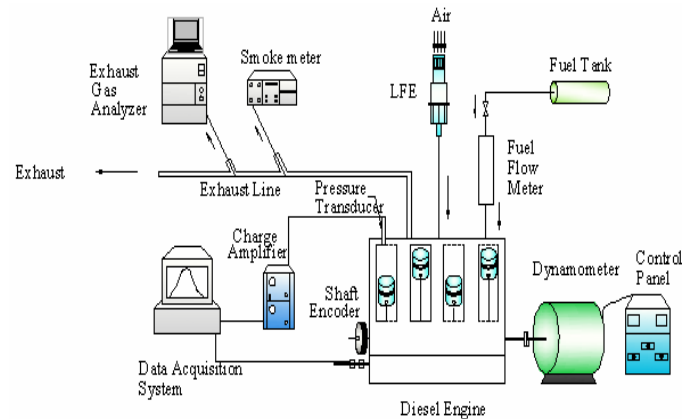


Figure 1: Schematic diagram of experimental setup

The long term endurance experiment was conducted in two phases. In the first phase, the engine was run with diesel (B00) and in the second phase, the engine was run with B20 blend. Engine was dismantled and new set of cylinder liners, pistons, piston rings, big end bearings were used for conducting experiments for each of the two phases. After preliminary run, lubricating oil from the sump was drained off and the engine was refilled with fresh lubricating oil (SAE 20W40) as specified by the manufacturer and the engine was then ready for long term endurance test. The endurance test was performed as per Indian standard Code (IS: 10000 Part IX, 1980) [52]. The test was conducted for a total of 100 hours, which consists of 10 non-stop running cycles of 10 hours duration, each. Each running cycle consists of five repetitive runs of two hour duration each (table 3).

Table 3: Engine loading cycle

Engine Speed (rpm)	Load (% of rated load)	Running time (minutes)
Maximum speed (3000)	75	50
Maximum torque speed (1800)	100	45
Idling (950)	No load	5
Maximum speed (3000)	100	20

The lubricating oil samples were collected from the engine after every 20 hours for various tribological studies. A number of factors affect lubricating oil performance: oil thickening/thinning, depletion of wear protection additives, and deposit control additives, sludge formation etc. [51]. The following tests were conducted on the lubricating oil samples to assess the comparative condition of engine oil drawn from petroleum diesel and biodiesel-fuelled engines: density, kinematic viscosity, ash content, moisture content, total base number (TBN), flash point, pentane and benzene insoluble. In addition, metals such as Fe, Al, Cu, Zn etc. get accumulated in oil in the form of wear debris. Therefore, determination of the metal content in used oil is important to identify possible defective functioning areas of the oil-lubricated equipment and to schedule maintenance accordingly. Weight measurements were

done with analytical balance (Make: Mettler; accuracy ± 0.1 mg). Density was measured by high precision digital density meter (Make: Kyoto Electronics, Japan; accuracy ± 0.0001 gm/cm³), flash point using Seta closed cup flash point tester (Make: Stanhope Seta; UK; accuracy $\pm 0.5^\circ\text{C}$) and kinematic viscosity was measured using Setavis Kinematic viscometer (Make: Stanhope-Seta, UK; accuracy of timer ± 0.01 s), Atomic absorption spectroscopy (AAS) and ferrography for wear debris analysis was also conducted on the lubricating oil samples collected at regular intervals from both the engines. These tests provide valuable information on the effect of biodiesel on lubricating oil compared to the effect of petroleum diesel.

RESULTS AND DISCUSSIONS

During endurance test on engine, durability problems such as fuel filter plugging, injector coking, carbon deposits in combustion chamber, ring sticking were found to be lower for the B20 fuelled engine. The fuel handling system was found to operate normally on both the fuel i.e. petroleum diesel and B20 blend. Experimental results of several tests conducted on lubricating oil samples are discussed below.

Density

The density of lubricating oil samples collected at regular intervals from both experiment was measured. Addition of wear debris, fuel dilution and moisture content variation affects the density of the lubricating oil. The density of lubricating oil samples from both the engines show an increasing trend with usage (figure 2). Faster density increase in the initial phase of engine operation may be due to higher wear of engine components initially.

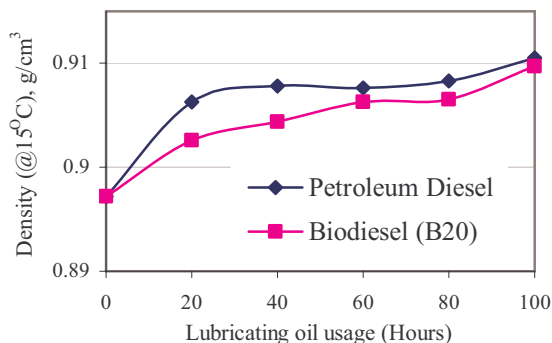


Figure 2: Variation in lubricating oil density with usage

It can be noticed that the density of lubricating oil from petroleum diesel fuelled engine increased at a faster rate compared to B20 fuelled engine, which may be due to:

- Lower wear debris generation in biodiesel fuelled engine.
- Lower fuel dilution in biodiesel fuelled engine as biodiesel may be helping reduce blow-by.
- Moisture addition in lubricating oil from blow-by gases may be lower for biodiesel fuelled engine.

These possible reasons indicate that blending of biodiesel in petroleum diesel improves the density change pattern in the lubricating oil thereby indicating

better performance in terms of engine wear, fuel dilution and moisture addition to the lubricating oil.

Ash Content

Ash content mainly indicates metallic wear debris in the lubricating oil samples since carbonaceous materials such as oil, soot, fuel and non metallic parts of organo-metallic additives are converted to CO₂ after thermal decomposition. Since both set of experiments were performed under identical conditions, the contribution of other factors like atmospheric dust particles etc. was assumed to be similar. Variation in % ash content in lubricating oils ($w_{\text{ash}}/w_{\text{lubricating oil}}$) with its usage is shown in figure 3.

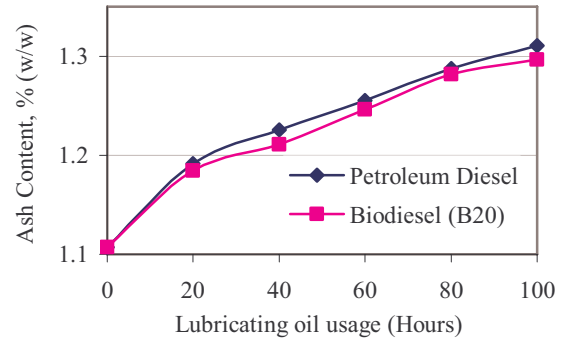


Figure 3: Lubricating oil ash content with usage

It can be observed from figure 3 that ash content in lubricating oil from biodiesel fuelled engine is slightly lower than that of petroleum diesel fuelled engine. It suggests that biodiesel fuelled engine produces lower wear debris indicating its superior engine performance.

Moisture Content

Water contamination of lubricating oil is undesirable since moisture promotes oxidation of the lubricating oil base stock and also causes with additive drop out from the lubricants. Moisture rusts and corrodes metallic surfaces, thus increases wear. The presence of water traces in lubricating oil indicates excessive fuel dilution, coolant leakage and short trip driving conditions. A Karl-Fischer titration unit (Make: Mettler, USA, Model: DL18) was used to determine the moisture content in the lubricating oil samples. The experimental results for moisture content in lubricating oil for biodiesel and petroleum diesel fuelled engine are shown in figure 4.

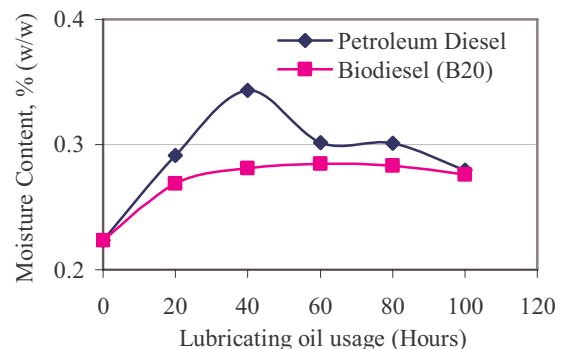


Figure 4: Lubricating oil moisture content with usage