Experimental Investigation of Coconut and Palm Oils as Lubricants in Four-Stroke Engine

Jagadeesh K. Mannekote and Satish V. Kailas*

Department of Mechanical Engineering, Indian Institute of Science
Bangalore -560012, INDIA

*Corresponding author: satvk@mecheng.iisc.ernet.in

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In the present work the evaluation of coconut and palm oil as lubricants in four-stroke engine was carried out and the performance was compared with commercially available engine oil. The tribological properties of oil samples collected from the engine at regular interval were evaluated by means of four ball tester. The emissions from engine were monitored by using exhaust gas analyzer. It was observed that antiwear properties of fresh vegetable base oils and engine oil were comparable at ambient conditions. The observed deviation with usage was linked to the oxidation and the absence of additives in vegetable oil. The increased wear with commercial engine oil was due to depletion of additives. Increased fuel efficiency and reduction in the concentration of oxides of carbon and nitrogen in the emission observed with vegetable oil based lubricant was linked to its high flash point.

Keywords: vegetable oils, four stroke engine, kinematic viscosity, four ball tester and ferrography

1. Introduction

Lubricants are in use ever since man had learnt to build equipments for various applications. Lubricants manufactured until the 19th century were completely based on vegetable and animal fats. Only after the discovery of the petroleum and establishment of the refineries resulting in producing of high quality base oils they gradually replaced these classical lubricants, due to the superior performance and stability of the mineral base oils at an affordable cost. Research investigations over the past six decades on mineral oil-based lubricants have improved the lubricating oil in terms of various properties like viscosity, dispersant, detergent qualities, to diversify their applications¹⁾. But it also increased the concerns related to the bioaccumulation, toxicity and disposal of mineral oil based lubricants. Therefore today the developing biodegradable functional lubricants has become top priority in lubricant industry, and the presence of long-chain fatty acids in vegetable oil, has increased the research interest in the use of vegetable oil as an alternative source to the mineral oil based commercial lubricants²⁻⁵⁾.

In general vegetable oils are very similar in structure; the similarity in structures makes them exist in only a

narrow range of viscosities limiting their applications to only few applications as lubricants. The fatty acids in vegetable oil triglycerides are all of similar chain lengths, between 10 and 22 carbons long. The fatty acids can either be saturated or unsaturated. Most of the vegetable oils have large percentage of unsaturated fatty acids. These unsaturated double bonds in the fatty acids are active sites for many reactions, including oxidation. A generalized structure of a vegetable oil is shown in Fig 1. In this figure three different acid moieties Lauric (C12:0), Myristic (C14:0) which are saturated fatty acids and Oleic (C18:1) an unsaturated fatty acids are attached to the glycerine molecule through the ester linkage. This triglyceride structure strongly interacts with metallic surfaces resulting in reduced friction and wear forming a high strength lubricant film. These strong intermolecular interactions are also resilient to changes in temperature resulting in high viscosity coefficient. On the other side most importantly, the same strong intermolecular interaction which is responsible for providing a durable lubricant film also results in poor low-temperature properties⁶⁾.

There are some interesting odd variants like castor and jojoba oils available in nature. Castor oil is a triglyceride, but the fatty acids is mostly Ricinoleic acid, monounsaturated hydroxyl fatty acid having 18-carbon

Fig. 1 Schematic representation of triglyceride structure

chain length, where as Jojoba oil is a vegetable wax, with both long chain monounsaturated alcohol and fatty acid, either 20 or 22 carbons. Because of their unique structural properties castor and jojoba oils display properties quite distinct to all other vegetable oils^{7,8}.

Various efforts are being made to overcome the shortcomings of vegetables oils, For example chemical modifications like interesterification, transesterification, hydrogenation and epoxidation⁹ can be used to improve their thermal and oxidative stability. The chemically modified vegetable oils have shown promising performance in terms of various parameters¹⁰⁻¹². It is also possible to do this by selective breeding and genetic modification¹³ of oilseed to Tailor the desired composition to suit the specific application. Since most of the research work has happened in either USA or Europe, resulting in the commercially available environmentally friendly lubricants based on soy bean and rape seed oils^{14,15}. Today these products are well accepted as they are readily biodegradable, cheaper than high quality synthetic base stocks and even show acceptable performance in many applications. Coconut and palm oils, which are basically triglycerides of saturated fatty acids, available in plenty in countries like India, Malaysia, Indonesia and Philippines. The overall production of palm and coconut oil stood at 38.3 and 3.098 million tonnes in 2007¹⁶. There is a tremendous interest in these oils over the last few years to use them as base oils for biodegradable lubricants in host of applications. Performance analysis of Palm oil in terms of wear, friction, viscosity, lubricant degradation and exhaust emissions was carried out and compared with a mineral oil-based commercial lubricating oil in a two-stroke gasoline portable generator set, followed by wear test on a four ball wear tester. Experimental results demonstrated that the palm oil based lubricating oil exhibited better performance in terms of wear, where as the mineral oil based lubricating oil exhibited better performance in terms of friction. In a few previous studies, it was found that the palm oil based lubricant was more effective in reducing the emission levels of CO and hydrocarbon¹⁷. It was also observed that the performance of the engines and exhaust emissions having the lubricating oils blended with Palm Oil Methyl

Table 1 Composition of coconut and palm oil in terms of constituent fatty acid

Constituent Fatty acids	Composition (in %)	
	Coconut oil	Palm oil
Caproic acid * (C6:0)	0.5	--
Caprylic acid (C 8:0)	7.8	--
Capric acid (C 10:0)	6.7	--
Lauric acid (C 12:0)	47.5	0.2
Myristic acid (C 14:0)	18.1	1.1
Palmitic acid (C 16:0)	8.8	44.0
Palmitolic acid (C 16:1)	--	0.2
Stearic acid (C 18:0)	2.6	4.5
Oleic acid (C 18:1)	6.2	39.2
Linoleic acid (C 18:2)	1.6	10.0
Linolenic acid (C 18:3)	--	0.4
Arachidic acid (C 20:0)	0.1	0.4

* (C X:Y) is a notation where X indicates Number of carbon atoms Y indicates Number of double bonds for a given fatty acid chain.

Ester (POME) were comparable with standard oil and reduction in friction ring wear was observed in presence of POME¹⁸. Coconut oil, which is abundantly available in the southern states of India, has a more than 90% of saturated fatty acid is reportedly being used as lubricant in two-stroke engines¹⁹. A systematic study showed that absence of additives caused an increase in wear when coconut oil alone was used as lubricant; subsequent addition of antiwear agent reduced the wear substantially²⁰. In the present work neat refined commercially available coconut and palm oil were used without further purification in four stroke engine as lubricants. The composition of coconut and palm in terms of constituent fatty acid²¹ is given in the Table 1.

Various parameters like engine performance, emission of exhaust gases, fuel efficiency and tribological characterization of used oil were evaluated and the overall performance was compared with standard engine oil.

Table 2 Specifications of four stroke engine used in the test rig

Type : 4 stroke air cooled engine
Cubic capacity : 109.3 cc
Ignition system : Digital Ignition
Maximum power: 8.1 bhp at 7250 rpm
Maximum Torque : 8.1 Nm at 5550 rpm

2. Experimental details

2.1. Internal Combustion (IC) engine test

In order to evaluate the performance of the vegetable oils a testing unit was built. This unit basically comprises three sub-systems: IC engine, alternator and loading unit. The technical specification of the engine is given in the Table 2.

In the present investigation, the engine crank case was loaded with A four stroke air cooled engine of 109.3 cc cubic capacity with digital ignition, was mounted on a test bed and coupled with an alternator, which in turn connected to a loading unit, consisting of incandescent bulbs in range of 100 W to 1000 W such that any load from 100 to 3000 W in Steps of 100 W can be applied. The arrangement of IC engine and alternator on the test bed is shown in Fig 2.

In the present investigation, the engine crank case was loaded with coconut oil and was initially tested under the running in condition for 100 hours. Fresh coconut oil sample was then loaded and tested under a load of 1200 W for the duration of 100 hours. The coconut oil samples from crankcase of the four stroke

Fig. 2 Arrangement of four stroke engine and alternator for evaluation of lubricants

Fig. 3 Flash point of test oils as determined by cleave land open cup tester

Engine oils collected at regular intervals of 20 hours were further analysed in terms of viscosity and wear properties. A ferrographic analysis of these test samples was also carried out. The same procedure was followed with palm oil and engine oil samples. A new engine was used for different oil samples.

In order to quantify fuel efficiency petrol filled in the tank was passed through the graduated pipettes. The time taken for the known quantity of fuel was noted down. The process was repeated five times during the test for accurate values. The fuel efficiency of the engine was evaluated with different lubricants.

2.2. Viscosity and flash point of test oils

Viscosity, an important physical property of lubricating oil, is a measure of oil's flow characteristics. Though the significance of viscosity test results has been considered from the standpoint of new oils, these tests also have a significant place in the evaluation of base oils, as well as used formulated oils. In the present work, kinematic viscosity of fresh and oil samples collected from the engine at regular intervals of 20 hours were determined according to the ASTM Standard D445-04 and ASTM standard D446-04 using U-tube viscometers in a constant temperature bath capable of maintaining the temperature with an accuracy of $1 \pm K$ ^{22,23}. Flash point of the fresh oil samples was determined according to the ASTM Standard D92-05a using cleaveland open cup tester²⁴.

2.3. Evaluation of tribological properties of fresh and used lubricant oils

In the present work tribological performance of used oil collected from the crank case of the four stroke engine at regular intervals of 20 hours was carried out using a four-ball tester according to ASTM standard D4172-04, at 1200 rpm, 400 N, 348 K, and 60 min. Chrome alloy steel balls, conforming to AISI standard steel no. E-52100, with a diameter of 12.7 mm, Grade 25 EP (extra polish), having Rockwell C hardness of 62 were used for this purpose²⁵. The test balls were

Fig. 4 Schematic representation of ball pot with chuck

thoroughly cleaned, along with ball pot and ball holder (top) by first soaking in hexane for one minute and then with sonic agitation for 60 seconds and again rinsed with fresh hexane. Then they were wiped with fresh tissue paper and dried with a hot air blower. The ball pot with cleaned balls and test sample was assembled in the testing machine and the test was run at specified conditions mentioned earlier. Schematic representation of ball pot with chuck is shown in Fig. 4. Once the experiment was over, the test balls were cleaned properly and the wear scar images were captured with digital camera. The diameter was measured later using the software with an accuracy of $\pm 2 \mu\text{m}$.

2.4. Ferrography tests

Ferrography is a microscopic examination technique used for analyzing the ferrous and nonferrous particles present in fluids that indicate mechanical wear extensively used for predictive maintenance. It provides a non-invasive look at historic and current conditions of a machine's lubricated components. In this method combination of sample preparation and a magnetic field ensure all particles present in the lubricant sample are deposited on the substrate for examination. Ferrous wear particles are deposited in strings between the poles of the magnetic assembly positioned below the substrate, perpendicular to the flow of the sample. They are released in a general order of size, with the largest ferrous particles being collected at the entry end of the substrate. Non-ferrous wear particles are released in a random manner throughout the length of the substrate, often appearing between the strings of ferrous particles. Contaminants, such as sand, dirt, fibers and friction polymers also are distributed in an irregular fashion throughout the length of the substrate. But one problem with Ferrography is that it relies on a person, not a machine, to examine wear particles and interpret the results^{26,27}.

In the present investigation of oil samples collected at different intervals were subjected to ferrography analysis. The tests were carried out at Pridet India Technologies Ltd. Hyderabad; according to the standard procedure given in the previous section. Typical wear particles obtained from the experiments were shown in Fig. 5.

Fig. 5 Morphology of the wear particles as observed in the microscope with Ferrographic technique

3. Results and discussions

Performance of the four stroke engine was evaluated using different oils as lubricants under standard testing conditions as explained in the previous section. The fuel efficiency under given testing conditions is shown in Figure 6.

Fig. 6 Fuel efficiency of the four stroke engine lubricated with different oil samples

It is clear that the fuel efficiency of four stroke engine in presence of the neat vegetable oil without additives was better in comparison to the fully formulated standard mineral oil based lubricant. This is possibly due to the superior boundary lubrication properties of vegetable oils in comparison to the engine oil despite the other disadvantages like their inferior thermal and oxidative stabilities associated with them²⁸. The exhaust gas emissions from the engine were monitored continuously and are given in the Table 3.

It can be seen that a reduction in the level of hydrocarbon oxides of the carbon emissions were observed with coconut and palm oil when compared to the engine oil. Similar observation was made by others in the past²⁹. This might be due to the high flash point associated with the vegetable oils in comparison to the engine oil sample (ref. Fig 3).

Table 3 Exhaust gas emission profile of the four stroke engine lubricated with different oil samples

Sample	HC (ppm)	CO (%)	CO ₂ (%)	O ₂ (%)	NO (ppm)
Engine oil	104	0.92	4.5	14.02	12
Coconut oil	99	0.67	2.9	15.82	11
Palm oil	102	0.73	3.4	15.66	14

Fig. 7 Variation of kinematic viscosity of lubricant oil samples collected from the four stroke engine

Viscosity measurements were carried out at 313 K according to the standard procedure given in the previous section for the fresh and the samples collected at the regular intervals of 20 hours and is shown in Fig. 7. It can be seen that an increase in kinematic viscosity was observed with usage of the oil in the engine. This is basically because of the oxidation of the oil samples³⁰. It was also noticed that the lubricant was contaminated with fuel during use. Sludge formation was also noticed during the experiments.

The variation of wear scar diameter with load for coconut, palm and engine oil is shown in Fig. 8. The results show that antiwear properties of fresh vegetable base oil and to engine oil were comparable. But with usage of oil in the engine increase in wear scar diameter was observed and was much higher in case of vegetable oils when compared to a fully formulated commercial engine oil sample. This found to be related to the extent of oil oxidation^{31,32}. Variation of coefficient of friction with time for coconut, palm and engine oil is shown in Fig. 9. It is observed from the four ball test results that the coefficient of friction increased with usage in the engine. This was linked to the formation of polymeric compound as secondary products through active carbonyl compounds³³. It is interesting to note that the increase in coefficient of friction with time is highest for the unformulated vegetable oils whereas it does not increase much for commercial oil.

Fig. 8 Variation of wear scar diameter of lubricant oil samples evaluated by using four ball tester

Fig. 9 Variation of coefficient of friction with time of lubricant oil samples evaluated by using four ball testers

Though curiously one must note that coefficient of friction is highest for the commercial engine oil. When lubricants are formulated one of the requirements is that the properties of the oil do not change with time of usage.

The Ferrographic results have showed that the deterioration of the oil has increased with time. It can be noted that under running in conditions the overall condition of the sample were comparable even after 100 hours, as conditions are not severe. But under loading conditions vegetable oils have deteriorated after 50 hours whereas mineral oils condition was deteriorated after 100 hours of usage. The improved performance of mineral oil based lubricant is basically related to its constituents. It is made from highly refined petroleum base having good thermal and oxidative stability with variety of performance enhancing additives; whereas the vegetable oils have been used without any performance enhancing additives.

Interestingly on qualitative terms, it was observed that the engine lubricated with coconut oil resulted in less eye irritation and suffocation to the engine operator when compared to the palm and commercial engine oil.

4. Conclusions

Performance of the four stroke engine using coconut and palm oil as a lubricant was evaluated and compared with mineral oil based engine oil. The following conclusions can be made with the present work.

1) Increase in viscosity was observed for all the samples and was due to the oxidation of oil in the crankcase. The change in viscosity of coconut and palm oil was more when compared to the 4 stroke engine oil.

2) It was observed that fuel efficiency of coconut and palm oils was comparable to that of fully formulated engine oil under given testing conditions. The improved performance of vegetable oils was possibly due to the superior lubricating properties of Triglycerides.

3) In the present study the difference in the exhaust emissions from the engine lubricated with coconut and palm oil when compared to 4 stroke engine oil might be

due to their high flash point, from practical point of view it was also observed that the exhaust emissions from engine lubricated with coconut oil were not suffocating when compared to palm and 4 stroke engine oil samples.

4) Four ball tests have shown the increased wear with coconut and palm oil samples collected from engine with use and this is due to the oxidation of the oil evident by increase in viscosity and also the absence of performance enhancing additives in the coconut and palm oil. It was found that coconut and palm oil have better antifriction properties compared to the engine oil. The observed increase in coefficient of friction with use was more with respect to vegetable oils compared to engine oil. This was due to their tendency to undergo rapid oxidation forming possibly polymer kind of material.

5) Ferrographic results have showed that the overall performance of these oils were comparable when tested under running in condition. When load is applied the overall performance of engine oil was better when compared to coconut and palm oil.

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