Assessment on Tribological Characteristics of Waste Ayurvedic Oil Biodiesel Blends using High-Frequency Reciprocating Rig Tribometer

R. Balakumar [a,*], G. Sriram [b], S. Arumugam [c]
[a, b, c] Department of Mechanical Engineering,
Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya,
Kanchipuram-631561. Tamilnadu, India
Corresponding author : [a,] *balavhd@gmail.com, [b]drg.sriram@gmail.com, [c]aru_amace@yahoo.co.in

Abstract. In general the components of the engine create more wear and friction in metal to metal contact surface, when the engine runs with petroleum based fossil fuel. This may damage the mating parts especially cylinder liner and piston ring, this may lead engine life reduction, increase of service cost. The biodiesel will give good lubrication property than the petroleum based fossil fuels. Basically, the researchers are mainly focusing on waste management system and its processes in the way of reduction in the virgin feed stocks used as a alternate fuel. This study dealt to investigate the tribological property of Waste Ayurvedic Oil (WAO) biodiesel blends by comparing with diesel fuel to improve fuel lubricity by using High Frequency Reciprocating Test Rig. The experimental investigation was conducted with load: 10N, frequency: 50Hz, stroke length: 15mm, time: 75min, temperature: 60°C. From the test results it is concluded that the range of blending of biodiesel from 10%, 15% and 20% of WAO with diesel fuel will results remarkable amount of improvement in the lubricity. Coefficient of friction and wear has been decreased with the increases percentages of biodiesel in blends. The WAO20 gives better reduction values in terms of co-efficient of friction, wear depth and frictional force than other WAO blended fuel and diesel fuel. The tested surfaces of cylinder liner were investigated using Scanning Electron Microscope (SEM) and atomic force microscopic analysis (AFM). The image shows a better impact and less wear scars for the WAO blended fuels than diesel fuel.
Keywords: Waste Ayurvedic Oil Biodiesel, HFRR, wear, friction.

1. Introduction

The drastic falling down of petroleum based fossil fuel reservoirs and fastest increasing pollution is increasing every day. Many researchers are working to bring out the suitable alternative fuels as a substitute for petroleum based fossil fuels [1]. The biodiesels are mainly called as fatty acid methyl esters (FAME) which is of long-chain derived from many sources such as vegetable oils, animal fats and various waste oil sources. Basically the biodiesel will have better lubrication property which used as an additive which used in petroleum based fossil fuels [2, 3]. The most and critical component of internal combustion engine is cylinder liner and piston ring tribo pair. The clear study about the wear and friction of liner rig pair will reduce the wear and friction of engine simultaneously it will lead the increase of engine life [4, 5]. There are more number of researches were undertaken to investigate the feasible method of production, performance in the diesel engines and tribological studies of biodiesel from various waste oils and animal fats [6]. The reduction in frictional force, frictional coefficient and wear of biodiesel blends over diesel fuel indicates that the rapeseed oil biodiesel blended fuel will produce an excellent lubricity characteristic. From the physical observation on the wear surfaces of the tested specimens, the rapeseed oil biodiesel contaminated lubrication oil appears a smoother surface than diesel contaminated lubrication oil [7].

The fuel quality is makes a major difference in the lubricity level. The important parameter in the engine is wear and friction between cylinder liner and piston ring tribopair material. Many researchers have analysed the biodiesel in terms of tribology perspective from vegetable oils, waste frying oil, and various fats from animals [8-14]. Goodrum and geller [8] investigated the lubricity of castor and lesquerella oil esters over diesel fuel in HFRR test. The high concentrations of methyl esters will give better lubricity for the mating parts and which lead the reduction in wear. Bhatnagar [9] investigated the lubricity and wear scar diameter of different biodiesels from nonedible oils like Jatropha Pongamia glabra, curcas, Madhuca indica, and Salvadora oleoides using HFRR. From the analysis, the addition of biodiesels to diesel fuel improves the lubricity and reduced the wear scar diameter. From the test results the biodiesel blend range varies from 5% to 20%.

Taravus et al. [10] investigated the physical properties of sunflower oil and beef tallow methyl ester blends. Even though the beef tallow gives more viscosity and poor physical properties but, the main advantage is to reduce the raw source cost which consist of 70% of total cost of biodiesel. Fevzi Yasar [11] studied about the combination of canola oil and inedible animal tallow in the volume basis of 0% to 100% (25% interval). The HFRR results experiences that the kinematic viscosity increased for biodiesels especially because of animal tallow which gives better wear prevention. Sulek et al. [12] analysed about the rapeseed oil methyl ester along with diesel using HFRR (ball on flat) tribometer. The blended rapeseed oil biodiesel reduces 5% of frictional coefficient and 20% reduction in wear than that of diesel fuel. The stable file thickness leads the reduction in wear and friction.

Arumugam et al. [13] studied about environmentally lubricant i.e. rapeseed oil bio lubricant using HFRR by adding the copper oxide (CuO) nano particle with synthetic lubricant and bio lubricant. SEM and AFM results proved that the surface morphology of cylinder liner tested with CMRO addition with 0.5 wt% of CuO explicit less friction. Xianguo et al. [14] investigated the waste cooking oil ethyl ester (WCOEE) using four ball tribometer and compared with diesel fuel. The investigation reveals that the improvement in the wear resistance of WCOEE blend fuel resulted from free fatty acids in biodiesel. The scanning electron microscopy (SEM) and atomic force microscopic analysis (AFM) was used to investigate the image and texture of the tested surface.

From the above survey it is very clear that no one touched through in the area of waste ayurvedic oil (WAO).The main theme of this investigation is to analyze the effectiveness of waste ayurvedic oil methyl ester blends as a better lubricity enhancer for diesel fuel. The tribological study was conducted using high frequency reciprocating rig as per the ASTM standards. In this investigation the commercially available cylinder liner and piston ring was used as a test specimen. After the tribological study, the tested liner and ring was undergone image morphology and surface texture analysis.

2. **Materials and Experimental methods**

2.1. Synthesis of Waste Ayurvedic Oil Biodiesel

The waste ayurvedic oil (after treatment) was collected from Sri Jayendra Saraswathi Ayurveda College and Hospital, Chennai, India. The chemicals used for transesterification like sodium hydroxide, methanol, hydrochloric acid and anhydrous sodium sulphate was purchased from M/S Ganapathy trading company, Chennai. The collected WAO was filtered to remove the dust and unwanted particles present in it. Transesterification process was carried out to convert the waste ayurvedic oil into waste ayurvedic methyl ester (WAOME). Finally, the WAO biodiesel blends were prepared by mixing with diesel fuel via. 90% of diesel fuel with 10% WAOME referred as WAO10, 85% of diesel fuel with 15% WAOME referred as WAO15 and 80% of diesel fuel with 20% WAOME referred as WAO20. The properties of biodiesel and diesel were considered from balakumar et al. [17].

2.2. Preparation of cylinder liner and piston ring test samples

The lubricity and frictional coefficient of WAO biodiesel blends along with diesel fuel was analysed by using HFRR tribometer. The test samples was cut using wire cut EDM process from the real engine cylinder liner (AISI-316) and piston ring (AISI-304) segment as per the manufacturer at Sree Krishna Enterprises, Chennai. The figure 1 shows the photographic view of cylinder liner and piston ring segment. Separate cylinder liner and piston ring segment were used for all the tests.

Figure 1 Photographic view of cylinder liner and piston ring segment

2.3. High frequency tribometer setup

The tribological study of engine liner ring segment under various biodiesel blends were analysed using HFRR tribometer (Model – Ducom TR-282) as per standard ASTM G181. The HFRR machine setup is shown in figure 2. The cylinder liner is fixed on the bottom of the oil tray and which is filled with the test fuel samples and the piston ring was fixed in the fixture holder which reciprocates over the liner. The operating conditions of HFRR are listed in the table 1.

Figure 2 Photographic view of HFRR tribometer

Table 1 HFRR test conditions

Parameter	Value
Load	10N
Frequency	50Hz
Temperature	60°C
Time	75 min
Stroke length	15mm

3. Result and discussion

The HFRR testing results on the blends of WAO biodiesel blends and the diesel fuel via coefficient off friction, wear depth along with time are shown in figure 3 (a, b).

3.1. Coefficient of friction

In this present analysis the coefficient of friction for all WAO biodiesel blends were tested and compared with diesel fuel. The frictional value is high at the beginning of the test. After few minutes the values become stable fluctuations. Markable results were absorbed for all the WAO biodiesel blends in terms of friction, wear depth and frictional coefficient than the diesel fuel. The coefficient of friction (COF) for WAO biodiesel blend was considerably lesser than the diesel fuel. The average COF for WAO20 is 56.85% better than that of diesel fuel. Similarly, for WAO10 and WAO15 is 4.54% and 27.66% better than diesel fuel. From the COF value results, the viscosity values of all the biodiesel are gives better scuffing protection behavior which leads a reduction in frictional values for the applied test conditions. For all the WAO biodiesel blends it is analysed that the addition of fatty acid methyl esters gives beneficial result on the lubricity of diesel fuel. The experimental results were consistent with Zulkifli et al. [15].

3.2. Wear depth

The wear depth is depends on the fuels used. The wear depth was less for the increasing concentrations of WAO biodiesel than the diesel. At the initial testing the wear depth value is fluctuates very high for all the WAO biodiesel blends and diesel fuel after that there is a stable results were marked. The average wear depth for diesel is 65.67% more than WAO20. Similarly for the other biodiesel blends like WAO10 and WAO15 which is 22.41% and 53.47% better than the diesel fuel. The increase in WAO biodiesel concentration reduces the wear depth than the diesel because of better scuffing protection behavior of biodiesel properties and close binding of molecules.

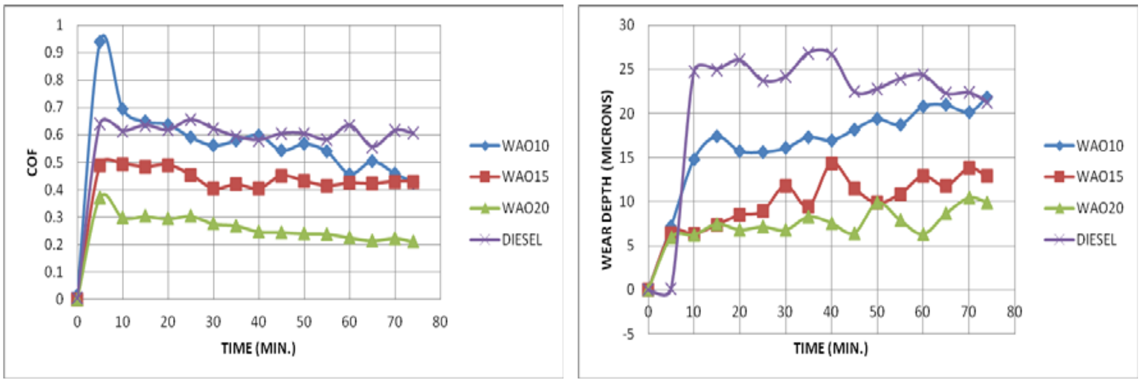


Figure 3 a) Time vs COF b) Time vs wear depth

3.3. Surface morphology analysis of tested cylinder liner surfaces using SEM

The tested surface was cleaned properly and the cylinder liner segment was investigated using scanning electron microscope (SEM) to find out the type of wear mechanism. The figure 4 (a-d) shows the SEM image of wear surfaces of liner with WAO biodiesel blends and diesel fuel. The cylinder liner surface deformation is quite more and severe for diesel fuel. The rubbed surface lubricated by the diesel fuel has more number of wide and deep furrows. Furthermore the severity of wear scar, cavities, deformation surface and grooves were decreased with increase of WAO biodiesel concentrations because of more free fatty acids present in the biodiesel. The closest analysis of tested surface of engine cylinder liner segment for diesel fuel shows that the depth longitudinal grooves and more pits which is the result of adhesive wear. But, abrasive wear were found with the WAO biodiesel blended fuels because of pull out materials form the cylinder liner and piston ring segment was less with biodiesel fuels. Especially, comparing with all the biodiesel blends WAO20 gives less wear depth, furrows and grooves than the other WAO blended fuels and diesel fuels. The test results consistent with the results from Fazal et al. [16].

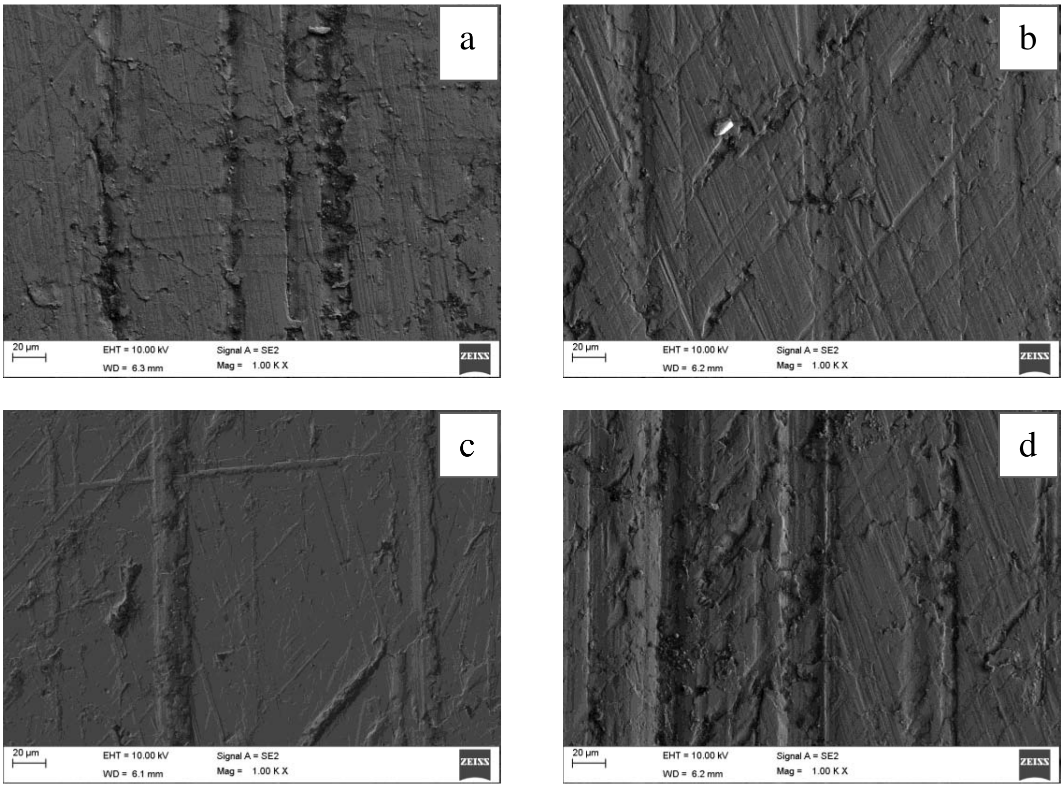
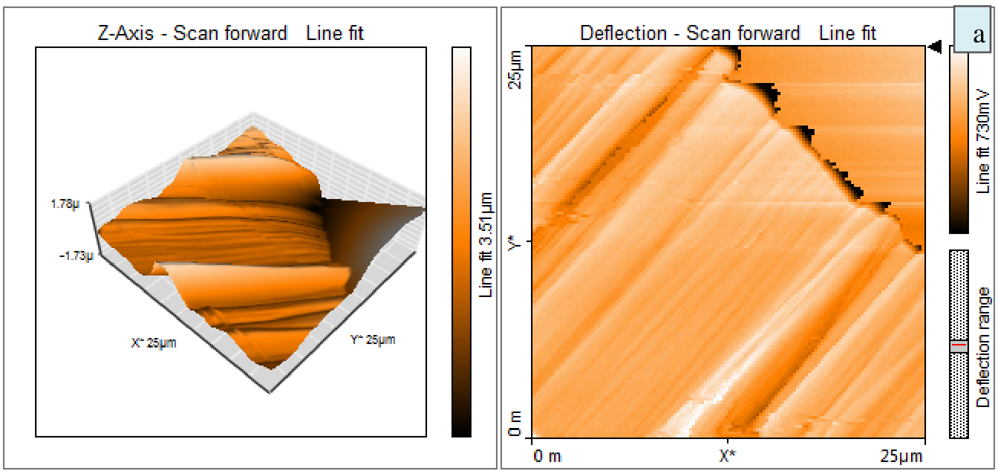


Figure 4 SEM images of tested liners for different fuels (a) WAO10 (b) WAO15 (c) WAO20 (d) diesel

3.4. Surface morphology analysis of tested cylinder liner surfaces using AFM (2D and 3D)

The three dimensional (3D) and two dimensional (2D) view of a tested cylinder liner surface by Atomic Force Microscopic (AFM) analysis were shown in figure 5 (a-d)



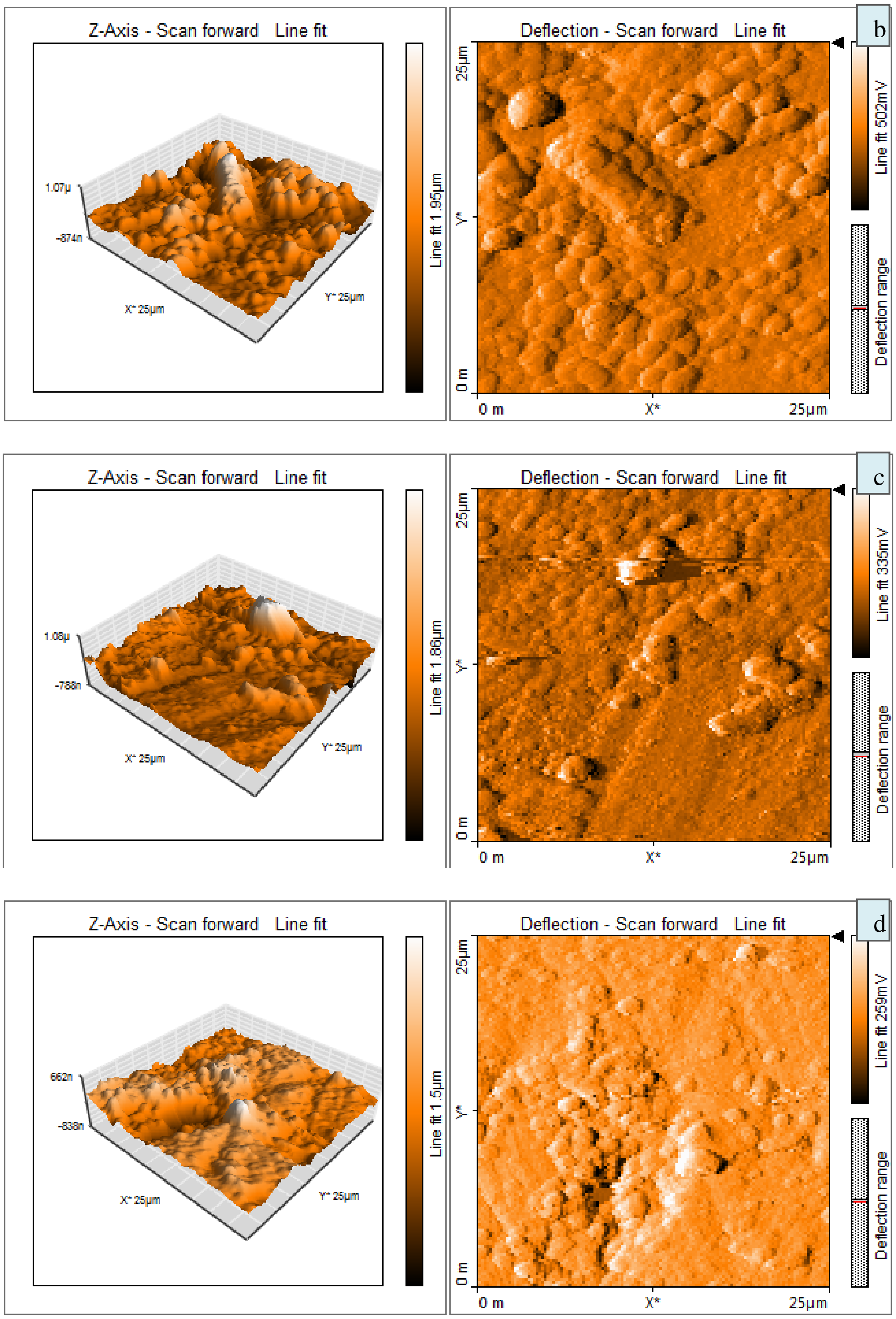


Figure 5 AFM images of tested liners for different fuels (a) WAO10 (b) WAO15 (c) WAO20 (d) diesel

The AFM surface profile investigation represents the roughness of the engine cylinder liner surface. The various roughness parameters of engine cylinder liner analysed by AFM were Sa (average roughness), Sq (root mean square value), Sy (peak-valley height), Sp (peak height), Sv (valley depth), Sm (mean value) listed in the table 2.

Table 2 Roughness parameters of tested engine cylinder liner for different fuels

Parameters	B10	B15	B20	Diesel
Sa (nm)	257.1	196.7	107.41	119.5
Sq (nm)	319.2	260.17	163.88	362.72
Sy (nm)	2508.7	2157.6	1955.3	2810.1
Sp (nm)	1479.2	1262.4	1081.7	1672.52
Sv (nm)	-1729.7	-873.6	-895.68	-837.62
Sm (pm)	-10.024	-10.024	-10.028	-10.025

From the above table and AFM images it is very clear that all the WAO biodiesel blends gives less roughness values than the diesel fuel. From both 2D and 3D images more number of red regions, valleys and peaks can be seen. The average roughness value (Sa) for WAO20 gives lower roughness value of 107.41nm which is very lesser than the diesel fuel. The other WAO blended fuels also gives lesser average roughness value than diesel fuel and quite higher than WAO20. The root mean square value (Sq) also gives less value i.e., 163.88 nm for WAO20 than other blended fuels and diesel fuels. The roughness values are less because of fatty acid contents present in the biodiesel. From all the above AFM images it is found that the WAO biodiesel blends represents less average surface roughness. Among all the biodiesel blends the WAO20 gives a better markable result than the diesel fuel.

Conclusions

The results obtained from the current investigation with HFRR tribometer, the following conclusions can be summarized.

- The frictional coefficient and wear depth were decreased with increase of WAO biodiesel concentrations due to the availability of ester content, unsaturated molecules etc.
- The COF values for WAO biodiesel fuels vary between 5% to 56% which is efficient than diesel fuel.
- The wear depth for WAO20 is 65% better than the diesel fuel. Similarly other biodiesel blends produces less wear depth than diesel but more the B20. This is because of
- From the SEM image it is concluded that less wear scar, cavities and grooves were observed in all the WAO biodiesel concentrations than the diesel fuel. Among all the SEM analysis images WAO20 gives a better result than other blended fuels and diesel fuel.
- The AFM results expose that the average roughness value, peaks and valleys were more for diesel fuel than WAO biodiesel blends. Comparatively with all the biodiesel concentrations WAOB20 gives marginal better result than the diesel fuel.

  From the above findings it is suggested that the WAO20 explores fabulous lubricating performance in the way of wear, friction and it can be used as a partial substitute for diesel engine.

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