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Tribological characteristics of Pongamia oil methyl ester

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KEYWORD

Pongamia methyl ester
Four ball tribotester
Reciprocating wear testing

ABSTRACT

The tribological characteristics of biodiesel PME (Pongamia oil methyl ester) is analysed in this work. Three blends B20, B50 and B80 of pongamia methyl ester with diesel were prepared. Tribological studies were performed with these blends using fourball tribotester and reciprocating wear tester to analyse the friction and wear behavior at various operating parameters. It was observed that wear and frictional torque reduced with increase in biodiesel content. The frictional torque was found to decrease with time. Thus, higher blends have a lower coefficient of friction than lower blends. Wear in the steel ball for the B50 blend is 25% less than that for the B20 blend and the wear appears to stabilize for concentrations greater than B50. Reciprocating wear test on cylinder liner-piston ring suggested that PME could offer better lubricity between the sliding surfaces than that of pure diesel. SEM anlaysis of the worn surfaces suggested that the surface lubricated with PME blends were less affected during the wear process when compared to those with pure diesel.

1.0 INTRODUCTION

The consumption of automotive fuels and lubricants is on the rise, with the rapid growth in the number of automobiles world over. The requirement of an automotive fuel is not only to provide energy to drive the vehicle but also to emit less polluting gases and provide lubricity. The fuel also should be less corrosive and chemically stable. Automotive lubricants have the major function of reducing the friction and wear of engine and other components. In addition a lubricant

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also lessen the temperature rise of surfaces and transport worn particles. Both fuel and lubricant should be environment friendly. In the last few decades researchers have been investigating for finding substitutes for fossil fuels and lubricants.

Biodiesel is being considered as a technically feasible fuel due to its availability and renewable in nature (Kumar and Chauhan, 2013). In the current energy scenario, biodiesel is deeming to be economically competitive and environmentally acceptable fuel compared to other alternative fuels in the world. Nowadays, biodiesel has been recognized as an unlimited source of energy with high energy content comparable to diesel. Biodiesel also possesses excellent inherent lubricity and emits less pollutants. The major drawbacks include oxidative instability, increased NOx emission, high viscosity and density, unsaturation, lower volatility, water absorption, etc. Regardless of the associated problems, biodiesel provides a number of significant technical advantages compared to diesel such as biodegradability, renewability, reduced tail pipe emission and toxicity, etc (Kalam and Masjuki, 2002). Extensive research work has been carried out in the recent past related to engine performance and tribological studies based on biofuels.

Agarwal et al. (2003) analysed the engine performance of linseed oil methyl ester and its blends with diesel. The tribological effects on engine oils were also reported. Wear of various engine components were studied and reported that the lubricity effect of the biodiesel was better. Endurance tests with periodic examination of the oil proved the reduction in the soot, wear debris and other particulate matter in the engine oil. Low wear debris concentration were observed in ferrography test in lubricating oil samples drawn from biodiesel engine. Atomic absorption spectroscopy results showed that wear elements of Al, Fe, Ca, Mg, Mn, Cu, Zn, Cr and Ni were found to 30% lower in biodiesel operated engine. Agarwal et al. (2003) compared the physical wear of various engine parts in linseed oil methyl ester with diesel in conventional diesel engine. Endurance tests were performed on a diesel engine. Surface analysis results of engine components before and after the endurance tests in diesel and biodiesel engines were compared. It was found that carbon deposits on piston, injector coking were low in case of biodiesel engine than that of diesel engine. The lubricity of the biodiesel is enhanced by the presence of free fatty acids in them (Knothe et al., 2005). Low wear rates with 20% blend of rice bran oil methyl ester were reported by Sinha and Agarwal (2007). Analysis of the lubricating oil indicated lower amounts of worn metallic particles except lead and aluminum when tested with B20 blend. Lubricant tests for determination of viscosity, flash point, moisture content, total base number, pentane and benzene insolubles suggested that the condition of lubricating oil from biodiesel engine was superior (Sinha and Agarwal, 2008).

Agarwal and Dhar (2010) reported that when tested with karanja oil as a fuel, the contamination of the oil was much higher due to oxidation. Effectiveness of the oil can be increased by addition of suitable antioxidants. Haseeb et al. (2010) performed wear tests using four ball wear testing machines to analyze the effect of temperature on the tribological behavior of palm oil methyl ester–diesel blends like B10, B20 and B50. Tests were performed at various temperatures of 30°C, 40°C, 60°C and 75°C with 40 kg loading condition for 1 hr duration at 1200 rpm. Wear of surfaces was found to be decreasing with increase in biodiesel concentration.

Agarwal and Dhar (2012) performed wear and durability of 10% straight vegetable oil (SVO)-diesel blend in direct injection diesel engine. Endurance tests conducted showed wear of the engine components were higher when tested with SVO 10% blends. Santa et al. (2011) in their work with pin-on-disk tests reported the reduction in friction and the specific wear rate in the case of lubricating oil mixture with animal fat feed stock. Xu et al. (2013) explored the emulsified biodiesel effect on friction and wear characteristics of a liner-ring combination using tribometer.

The tribological studies revealed that the cylinder liner-piston ring lubricated with bio-oil provided low friction coefficient than lubricated with diesel oil and emulsified bio-oil. The adsorption of polar groups of carboxylic acids and alcohols deteriorated the protection film between friction pairs. It was noticed that biodiesel produced corrosive wear whereas diesel oil and emulsified biodiesel produced abrasive wear between cylinder liner-piston ring interfaces.

Habibullah et al. (2015) analyzed the tribological behaviour of Calophyllum inophyllum biodiesel on a four-ball testing machine under various loads and temperatures. Oil analysis conducted showed that oxidation of the biodiesel produced corrosive products that increased wear. At higher temperatures it was found that Calophyllum inophyllum biodiesel has poor lubricity. Recently, friction and wear behaviour off palm and Calophyllum inophyllum biodiesels (10%, 20% and 30%) were evaluated by Mosarof et al. (2016a) Four ball tribotests indicated that 20% of palm biodiesel had good lubricity showed by the friction and wear scar analysis. Fazal et al. (2014) analysed the material compatibility of biodiesel. The observation was that lubricity property of biodiesel decreased by moisture absorption, auto-oxidation, corrosiveness and reduced viscosity.

Further, studies by Mosarof et al. (2016b), reported that the average coefficient of friction increased for pure diesel by about 28.8% and 23.4% than that of Calophyllum inophyllum and palm biodiesels respectively. But a 100% biodiesel showed lower friction coefficient when compared to diesel and other blends. Xu et al. (2014) investigated the friction and wear characteristics of methylesterified bio oils. The tested results suggested that coefficient of friction and wear loss of friction pairs were higher for lubrication with esterified biodiesel than the crude bio-oil. Farhanah and Syahrullail, 2016 analysed the lubrication performance of refined, bleached and deodorized (RBD) palm stearin oil under different loading conditions. Zinc dialky dithiophospshate was blended with the oil in different proportions. It was obeserved that when RBD was used as such, the tribological properties were poorer than that of SAE 40 oil but when ZDDP blending was done, the properties improved considerably.

Available literature shows that a study related to lubrication properties pongamia methyl ester biodiesel is limited. The lubricity and tribological properties of pongamia methyl ester is related to its ability to withstand higher temperatures. At higher temperatures, the viscosity of the oil reduces hence reducing the ability to form an active fluid film between the surfaces. But this effect when blended with pure diesel at different proportions need to be investigated. In the present work, the friction and wear behavior of various blends of pongamia biodiesel with diesel fuel has been investigated. The lubricity of the blends were examined by testing the blends in a four ball tester. The friction and wear behaviour of the blends using specimens of engine liner-ring pair was tested in a reciprocating wear tester. After the tests the specimens were characterised by scanning electron microscopy.

2.0 MATERIALS AND METHODS

Pongamia oil is extracted from the seeds of the Millettia pinnata tree. Each tree yields about 10-50 kilograms of seeds. Oil is extracted from the seeds by various methods including expeller pressing, cold pressing, or solvent extraction. The oil is yellowish-orange to brown colored. The pongamia methyl ether is prepared from the pongamia oil by transesterification with methanol and using NaOH as catalyst. The major thermophysical properties of Pongamia methyl ester biodiesel are mentioned in the Table 1. Biodiesel is blended with diesel oil at different proportions like 20%, 50%, and 80% by volume and were used as lubricating oils.

Table 1: Properties of Pongamia Oil.

Property	Value
Boiling point	316°C
Density	0.924 gm/cm^3
Viscosity	40.2 mm^2/s
Cetane number	42
Pour point	-3°C

2.1 Lubricity test

Bench tests are conducted prior to adopting any fuel or lubricant for equipment or vehicle use in order to avoid high cost and time associated with research and development as well as field testing. The lubricity of the oil was tested using a four ball tester. A four ball test is generally conducted to assess the antiwear and extreme pressure behavior of an oil additive by analysing the frictional torque obtained from the test. Lower the frictional torque, better will be the extreme pressure performance.

A schematic sketch of the four ball tester is presented in Figure 1. In this tester, three 12 mm diameter steel balls are held in contact and covered with the lubricant to be analysed. The fourth ball of same diameter, referred to as top ball is held in a special collet inside spindle, rotated by ac motor. Inside the ball pot, the balls are held in position against each other by clamping ring and force applied by tightening lock nut. Additional provision to heat and control the temperature of oil sample is also provided at bottom of ball pot. Normal load is applied on the balls by loading lever and dead weights placed on loading pan. The ball pot is supported above the loading lever on a thrust and plunger and beneath plunger a load cell is fixed to loading lever to measure normal load. The frictional torque is thus exerted on the three balls and is measured by frictional force load cell.

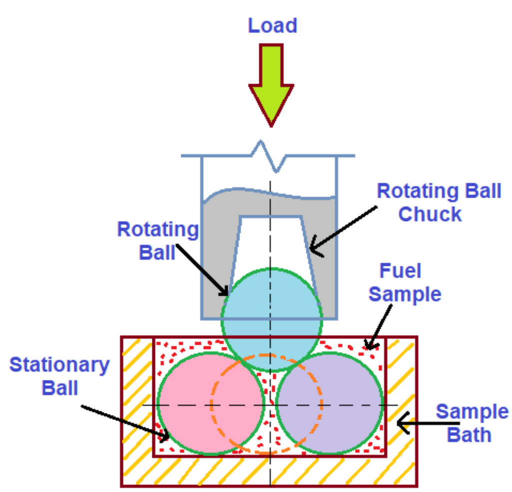

Figure 1: Four ball tester.

Four ball tests were carried out with the lubricant blends prepared. The balls used were standard bearing balls made of AISI 52100 steel with a diameter of 12.7 mm. The required quantity of the lubricant blend was maintained at the contact zone. A load of 400 N was applied on the rotating upper ball. The applied load value was selected based on the calculation that the contact zone is subjected to a nominal Hertzian pressure of 8 GPa under 400 N normal load when a ball-on-flat geometry is considered. This simulates an extreme pressure condition. The test was performed for a duration of 1 hr. After completion of the test, the balls were taken out of the holders, cleaned and preserved for further surface analysis.

2.2 Reciprocating wear test

The friction and wear characteristics of blended fuels were investigated by a reciprocating friction and wear testing machine (Ducom, Bangalore). A schematic sketch of the test setup is given in Figure 2.

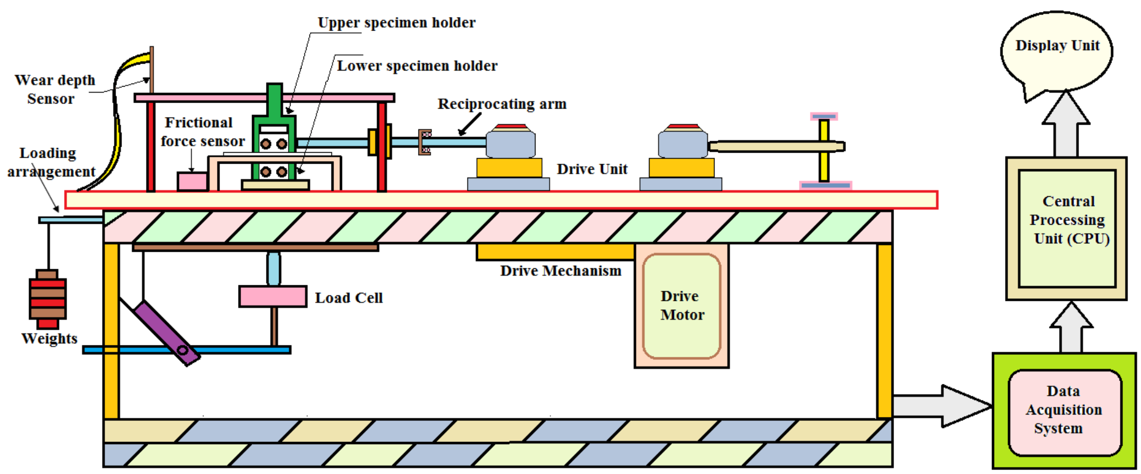

Figure 2: Schematic sketch of the reciprocating friction and wear testing machine.

The equipment is provided with sample holders to fix the upper sample – ring and the lower sample – liner. Sensors for acquiring the wear depth, load, temperature and frictional force are also provided. The normal force on the upper sample is applied by a dead weight loading arrangement. Contact temperature can be varied by a heating coil placed below the lower sample holder. The frictional force is measured by a pressure transducer. Cumulative wear depth of the lower and upper samples is measured by a linearly variable resistance transducer (LVRT). The acquired data is processed with a personal computer equipped with Winducom® software.

Reciprocating wear tests were performed with the prepared biodiesel blends. A new cylinder liner and ring was machined to the specified size in a wire electrical discharge machine (Wire EDM). Schematic sketches of the ring and liner specimens are presented in Figure 3 and Figure 4. The specimens were cleaned with acetone. The liner and ring specimens were fixed on the holders and the biodiesel blend was poured in the container holding the lower sample such that it was completely immersed. The applied load was decided based on an available literature to nearly simulate the nominal pressures acting on the cylinder walls of a heavy-duty diesel engine (Truhan et al., 2005). A stroke length of 15 mm was set such that boundary lubricated conditions prevail at the reversal positions of sliding. Friction test was commenced after setting the test parameters as mentioned in the Table 2. After completion of the test, the specimens were removed from the holders and they were cleaned. SEM analysis of the worn surface of the liner was performed.

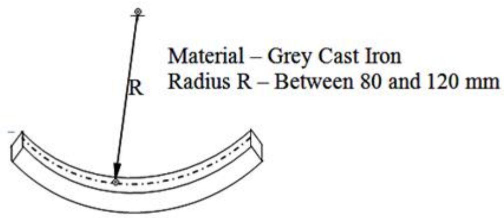

Figure 3: Ring specimen

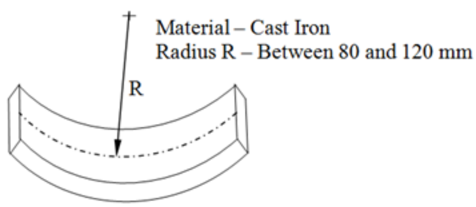

Figure 4: Liner specimen.

Table 2: Test parameters for reciprocating wear test.

Parameters	Value
Load	130 N
Temperature	100°C
Oscillation frequency	10 Hz
Duration	120 min
Stroke length	15 mm

2.3 Pin-on-disc friction and wear test

Pin-on-disc friction and wear tests were carried out to assess the effectiveness of lubrication under constant sliding speed conditions. The equipment used is a pin-on-disc machine (Ducom, Bangalore) as per ASTM G99. A 10 mm diameter pin was made to slide against a rotating disc subjected to load. The sliding velocity was kept constant. The test parameters were set as mentioned in Table 3. All the three blends and pure diesel were used as the lubricant at the contact zone.

Table 3**:** Test parameters for pin-on-disc test.

Parameters	Value
Load	40 N, 70 N, 100 N
Operating temperature	35°C
Speed	100 rpm
Time duration	60 min

3.0 RESULTS AND DISCUSSION

The results of the various tests performed are presented as followed. The data obtained from the four ball tester was analysed and graphs were plotted. Table 4 presents the average wear scar diameter and average coefficient of friction.

Table 4: Results of the lubricity test with four ball test.

Biodiesel Sample (Blend with diesel)	**Load (N)**	**Number of tests**	**Average wear scar diameter (mm)**	**Average coefficient of friction**
B20		2	0.92	0.069035
B50	400	2	0.69	0.055820
B80		2	0.72	0.053625

The Figure 5 presents a comparison of the frictional torque with respect to time for the various biodiesel blends when tested in a four ball tester. From the graph it may be seen that the frictional torque falls in the range of 0.08-0.12 Nm for all the blends. The steady-state values are 0.09 Nm, 0.095 Nm and 0.11 Nm for the blends with 80 %, 50 % and 20 % PME respectively. The lower values of frictional torque for higher blends of biodiesel are attributed to the presence of higher content of unsaturated fatty acids. Table 5 presents the values of the coefficient of friction for blends 20%, 50%, 80% PME when tested on a pin-on disc machine at various loads. From the Table 5, it may be observed that for higher PME blend ie. B80, the coefficient of friction was found to be low at 40 N load. Lower.

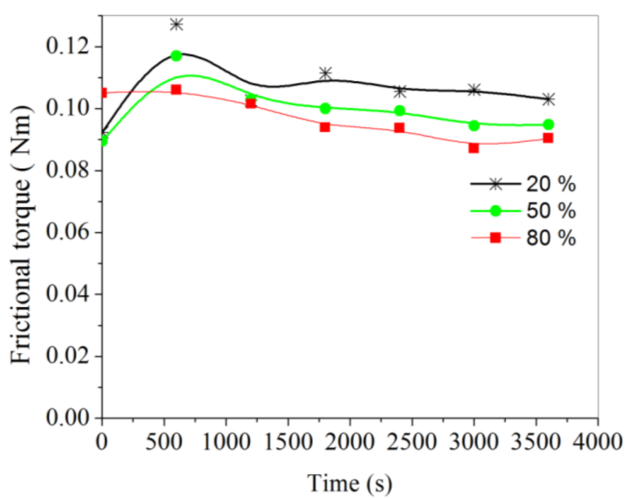

Figure 5: Comparison of frictional torques between samples tested with various blends in a four ball tester.

Table 5: Values of the coefficient of friction for blends 20%, 50%, 80% PME.

Sample	Load (N)	Coefficient of friction
B20	40	0.091
	70	0.095
	100	0.098
B50	40	0.105
	70	0.128
	100	0.083
B80	40	0.071
	70	0.114
	100	0.099

3.1 Analysis of friction and wear

Figures 6 and 7 present the results of the reciprocating wear test carried out with liner–ring samples when lubricated with various blends. Figure 6 presents the variation of coefficient of friction of different blends with respect to time. It is seen that friction coefficient is significantly higher for petroleum diesel than that of all PME blends. As observed from the figure, friction coefficient increased with increase in time duration for petroleum diesel whereas the friction coefficients seem to be nearly steady for all PME blends. It is also noted that higher reduction in friction coefficient with higher concentration of PME in the blend. This may be attributed to the availability of fatty acid in pongamia biodiesel providing better lubricity when compared to petroleum diesel between the contact surfaces. Apart from this, the presence of oxygen content in PME could reduce the friction between the cylinder liner and piston ring as indicated by Wain et al. (2005).

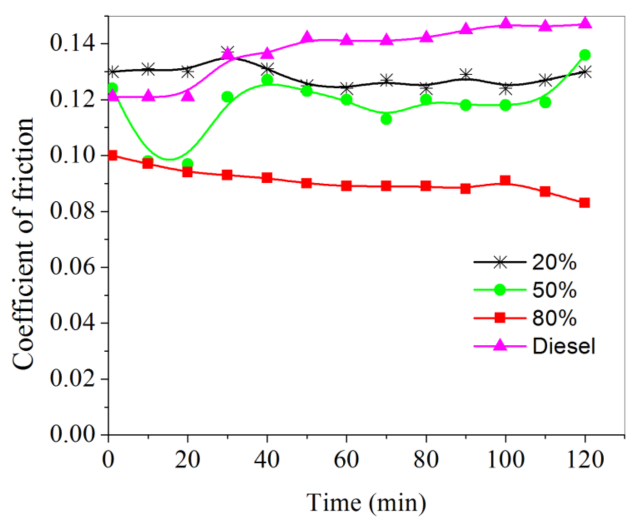

Figure 6: Comparison of coefficient of friction between various blends obtained from a reciprocating wear test.

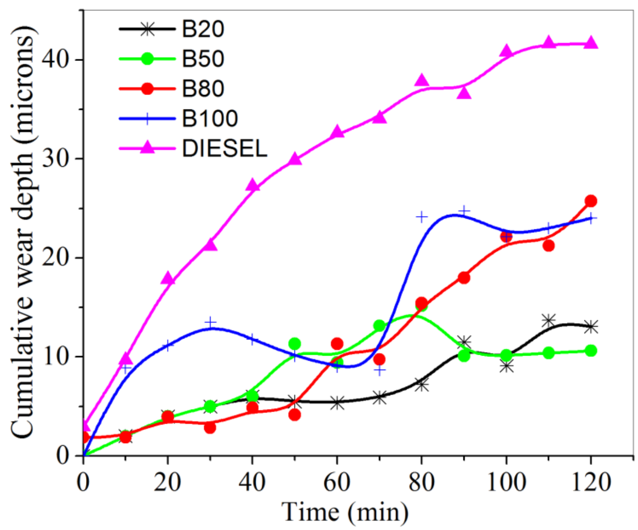

Figure 7: Comparison of wear depth between the various blends.

Figure 7 shows the comparison of cumulative wear of the liner and ring specimens. Wear depends on applied load, sliding velocity and temperature. Liner-ring samples lubricated with PME blends indicated low wear depth compared to samples lubricated with petroleum diesel. The lower wear in these cases is attributed to the lubricity of the oil. The presence of fatty acid compounds in the methyl ester aids in formation of a thicker film that reduces the wear rate by preventing a surface to surface contact (Syahrullail et al., 2013). Different blends of PME, up to about 50 minutes of the test, show similar kind of behaviour till the first 50 minutes of sliding. After 50 minutes the wear behaviour changes significantly. This behaviour is explained as follows. Surface of the liner has honing marks on them. The deep grooves generated during honing acts as lubricant retainers. During the sliding process, the lubricant is drawn to the plateau region by the effect of a traction force generating vacuum pressures at the interface. As the sliding time increases the deep grooves become shallow and the lubricant retain ability reduces. In the case of PME 80, it can be seen from the Figure 6 that the coefficient of friction reduces after 50 minutes. With continued sliding, the roughness of the surface reduces during this period. This can offer a less coefficient of friction as compared to the initial stage. Wear depth in the case of pure biodiesel B100 varies significantly as seen from Figure 7. The presence of higher amounts of unsaturated fatty acids contained in higher blends is prone to more oxidation during sliding. The corrosive nature of this will generate reactive products in the form of worn out particles. The variation in the cumulative wear depth is due to the trapping of these particles at the interface.

3.2 SEM analysis

SEM image of the liner at a less wear affected zone is presented in Figure 8. The honing marks are visible on the surface and are unaffected. SEM images of worn cylinder surfaces lubricated with petroleum diesel, PME20, PME50 and PME100 are presented in Figure 9. It is seen that cylinder surface lubricated with petroleum diesel showed bigger cavities than that of other surfaces like PME20, PME50 and PME100 and the severity of wear is low with PME blends. This may be attributed to the better lubricity of the PME blends.

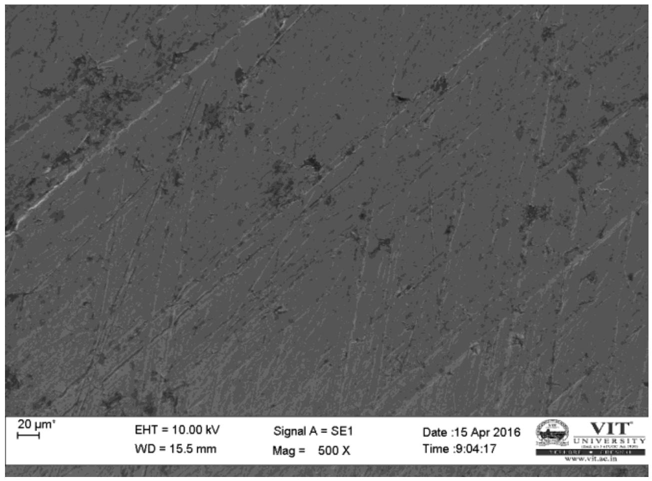

Figure 8: SEM image of the liner at a less wear affected zone.

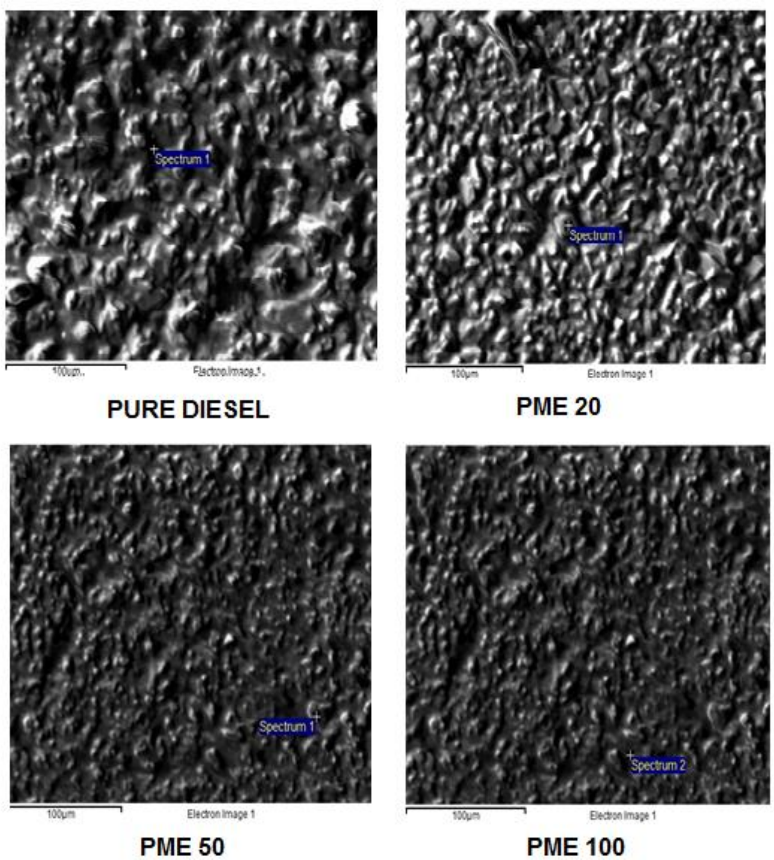

Figure 9: SEM images of worn cylinder surfaces for different lubricating oils.

CONCLUSIONS

The following conclusions were made from the analysis of four ball tribotester:

(a) The wear scar diameter decreases as the concentration of Biodiesel in the blend increases.
(b) The wear in the steal ball for the B 50 blend is 25% less than that for the B 20 blend and the wear appears to stabilise for concentrations greater than B 50. Thus, higher blends help decrease the wear.
(c) The frictional torque gradually decreases with time. Thus, higher blends have a lower coefficient of friction than lower blends.
(d) Since lubricity is inversely proportional to frictional torque and coefficient of friction, it can be safely concluded that lubricity of the selected Biodiesel increases with increase in the concentration of the blends.
(e) The reciprocating wear test on cylinder liner with compression ring suggested that PME could offer better lubricity between the sliding surfaces than that of petroleum diesel with low friction and wear depth.
(f) SEM analysis of the worn surfaces suggested that the surface lubricated with PME blends were less affected due to the interaction when compared to those with pure diesel.

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