

Tribological investigation of a compressor liner-ring material under various bio-based lubricants using HFRR tribometer

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Abstract. The main aim of this paper is to investigate the tribological performance of vegetable – based bio-lubricant as reciprocating air compressor oil. The tribological test at different operating conditions like frequency, stroke, load, temperature, speed and operating time was performed by the help of HFRR (High Frequency Reciprocating Rig) tribometer. The cylinder liner and piston ring material of reciprocating air compressor was taken for this tribological test under five different lubricants namely SAE30, PE, PE25, PE50 and PE75. The tribological results were shown that the experimental COF and Wear depth was reduced with PE 50 and PE75 as compared to other lubricants i.e., PE, PE25 and SAE 30. Also PE75 bio-lubricant was shown that the smoother worn surfaces of the tested specimen, which was confirmed by SEM and EDAX analysis.

1. Introduction

In all types of applications, namely industrial, automotive and other applications are fully depended on petroleum based fuels and lubricants because of its excellence in performance. But, on the other side, there is a severe problem with these fuels and oils in terms of pollution and degradation. Also, there is a depletion problem with crude oil, which relates to hiking in price. Therefore, it is necessary to produce an environmentally friendly oil and fuels from vegetable oils. All the vegetable oils have excellent lubricity and biodegradability, non-toxic and safety. But they have insufficient oxidation and thermal stability [1]. To overcome these drawbacks from raw vegetable oils, many researchers have done many works like transesterification, epoxydation etc. [2-3]. All process (transesterification, epoxydation etc.) was carried out using conventional method (Mechanical stirring), which consumes more reaction time and also obtained low yield percentage. Therefore, researchers are chosen ultrasonication technic to carry over the transesterification process for the production of biodiesel, which reduces the reaction time and obtained high yield [4-5] of the product by considering various parameters like frequency, temperature, alcohol ratio and catalyst concentration [6-7]. Chenga Reddy et al [8] was produced bio-lubricant from raw rapeseed oil using ultrasonication followed by transesterification process. Reported that the ultrasonication technic is an efficient one to produce bio-lubricant and also thermo-oxidative stability was improved by transesterification process, which were confirmed by TGA and DSC analysis. Investigated the physical and chemical properties of the modified vegetable based bio-lubricant, which impacts the vegetable oil applications in lubrication [9].

Bio-lubricants are not enough to prove their physico-chemical properties and thermo-oxidative stability of lubricity applications, also it have been proven their tribological behaviour in terms of wear and friction coefficient under lubrication regimes. With this connection Arumugam et al [10-12] was



completed the experimental work to find the tribological behaviour of the liner-ring material under various lubricants using a pin-on-disk, four ball and high frequency reciprocating rig tribometers. Experimental results of the chemically modified bio-lubricant shows better performance of wear and friction co-efficient than that of mineral based lubricants. Tiong chiong ing [13] proved that the palm oil based lubricant had performed better in wear and friction reduction when compared with the paraffinic mineral oil using four ball tribometer under the conditions of speed, load, varying temperatures and at 1 hr running time. Sevim z. Erhan [14] claimed that the chemically modified vegetable oil improves thermo-oxidative stability and reduces the friction and wear using four ball and ball-on-disk tribometer. Siniawski et al [15] studied friction and wear characteristics of the sunflower and soyabean oils as alternative to petroleum based lubricants using ball-on-disc tribometer. Reported that the friction and abrasion rate were lower than that of mineral oil.

From the literature study, many researchers are studying about bio based lubricants and its tribological behaviour using a pin-on-disk, four ball, ball-on-disk, HFRR tribometer etc. with this connection, main aim of this investigation is to synthesis of pentaerythryl ester (PE) from raw rapeseed oil as reciprocating air compressor oil and study its tribological behavior in terms of wear depth and friction co-efficient using high frequency reciprocating rig tribometer. The surface of the tested specimens was also discussed by scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy (EDAX).

2. Experimental Work

2.1 Synthesis of transesterification process

A pentaerythryl ester was prepared by a two-step transesterification process. In the first step, synthesized the methyl ester of rapeseed oil via conventional methods under atmospheric pressure. Ultrasonication was used for the conversion of methyl ester to pentaerythryl ester under nitrogen atmospheric pressure, as a second step. The various materials were taken for the process and the procedure of synthesis of pentaerythryl ester was followed by Chengareddy and Arumugam [8].

The prepared pentaerythryl ester was blended with the synthetic compressor oil (SAE 30) on a percentage basis of 25%, 50% and 75% by volume. These blends were prepared using mechanical stirring process at 300 rpm by maintaining the temperature of 80°C for the purpose of homogeneous mixing.

2.2 Properties of Pentaerythryl Ester

Kinematic viscosity at 100°C and viscosity index measurements were found, according to ASTM D 445 and ASTM D 2270 for PE, PE25, PE50, PE 75 and SAE 30 taken as base oil for comparison. The comparative properties of oils were shown in Table 1.

Table 1. Properties of PE and its Blends

Properties		
Lubricants	Kinematic Viscosity, cSt @ 100°C (ASTM D 445)	Viscosity Index (ASTM 2270)
SAE 30	9.16	95
PE	9.02	124
PE 25	8.23	98
PE 50	8.42	100
PE 75	8.66	103

2.3 HFRR Tribometer

This method is developed to characterize the tribological performance of materials and lubricants by varying the operating conditions in a small volume of lubricant as shown in Fig. 1. For this purpose, a ring material was fixed in a steel plate with a fixed force and moved with a bracket back

and forth (reciprocating). The ring specimen slides in a liquid bath from the lubricating oil to be tested on the liner material back and forth. The specimens of liner-ring material before and after the tribological tests are shown in Fig. 2

By following the standard method ASTM D 6079, the lubricity performance was used HFRR with a 10 N load; 10 mm of sliding stroke; a frequency of 15 Hz; 50°C of lubricity temperature and operating time of 1 hr for each sample separately. The liner-ring (specimen) material of reciprocating air compressor was chosen for tribological tests. The specimens are shown in Fig. 2, which were cut by using wire cut EDM and the dimensions of the specimens were followed by Arumugam [12].

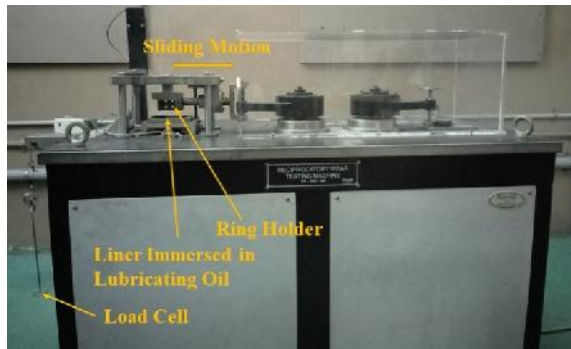


Fig. 1. HFRR Tribometer

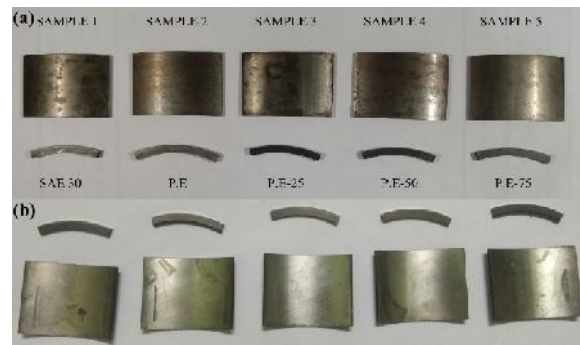


Fig.2. Liner-Ring Specimens (a) before and (b) after

3 Results and Discussions

3.1 Properties of Pentaerythryl Ester

All the four samples (i.e. PE, PE25, PE50 and PE 75) of kinematic viscosity range is 8-9 cSt, which were closer to the viscosity of SAE 30 synthetic grade compressor oil. From the Table 1. shows that the viscosity index of pentaerythryl ester had highest about 124, which indicates that have viscosity stability even at high temperatures.

3.2 HFRR Tribometer Testing Analysis

3.2.1 Co-efficient of Friction

The tribological properties of vegetable based PE as bio lubricant was investigated using HFRR tribometer under various test conditions. Fig 3. Shows the coefficient of friction of the liner material, lubricated with various blends of PE with SAE 30 and also with pure SAE 30 synthetic reciprocating air compressor oil as base oil for comparison purpose. During the starting of operation there is a rapid increase in coefficient of friction due to the sudden contact between the liner and ring specimens. However, within a few seconds the coefficient of friction was stabilized and there are some slight variations till the end of operations. Among all the five lubricants, PE 75 lubricant was shown the lowest coefficient of friction, which avoids the metal-to-metal contact because of the formation of an oil film between the specimens.

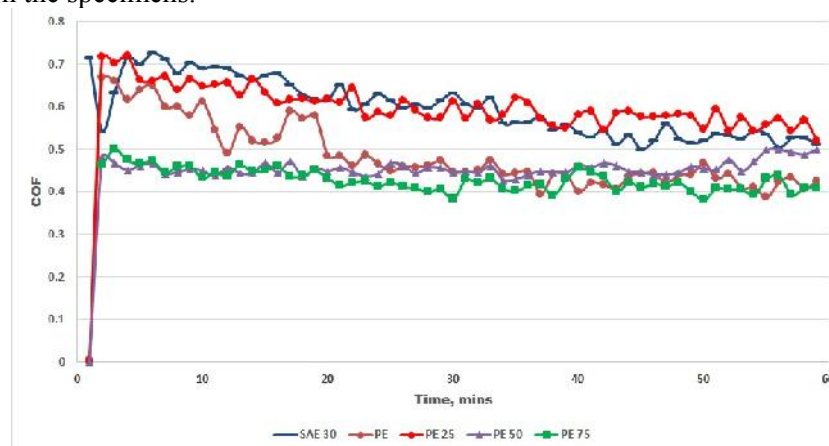


Fig. 3. Co-efficient of Friction

3.2.2 Wear Characterization

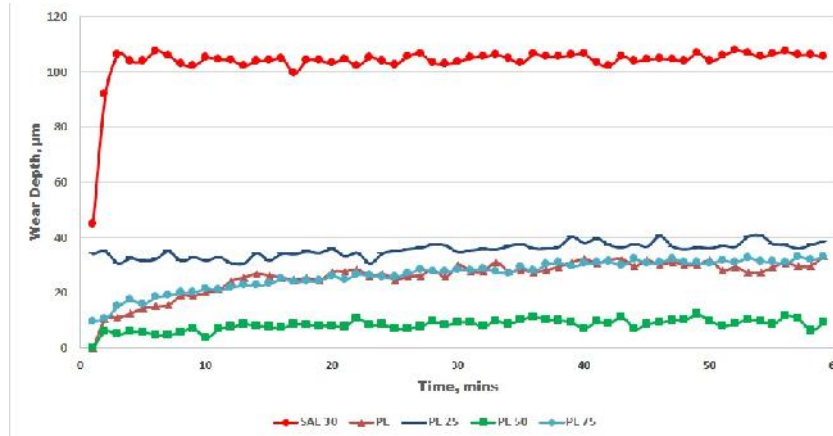


Fig. 4. Wear Depth

Fig 4. Shows the linear wear plotted against the sliding time for various vegetable based pentaerythryl ester under the load of 10 N and frequency of 50 Hz with a 1 hr operating time. It is observed that the highest wear depth was occurred on SAE 30 lubricated tested specimen. Whereas the lowest wear was observed from all the four blended lubricants (i.e. PE, PE25, PE50 and PE 75) than that of SAE 30. Out of which PE 50 shows the least wear, because of it may be the presence of oil film thickness on the liner material throughout the running time (about 1 hr) and it showed better lubricity in reducing the metal to metal contact.

3.3 SEM and EDAX Analysis

Reduction of lubricant film thickness leads to the surfaces to come closer to each other and can higher wear. Fig. 5 shows the SEM and EDAX images of the wear scars on each liner specimen treated by lubricants under the test conditions. It was observed that the ploughings are there in all the wear scar images due to its sliding motion during the test of 1 hr. However, there is some other scars were also observed like deep grooves, cavities, pits, ruptures etc. from the micrographs of specimen. The deep grooves, cavities and pits were observed from SAE 30, PE and PE 25 lubricated specimens, which indicates that a chance of oil film breakdown between the specimens due to the long running time of operation. From the SEM images observed that the PE 50 and PE 75 shows the minimum wear scars than that of the SAE 30, PE and PE 25. Therefore, it concluded that the wear scar can be reduced by the increase of PE in volume basis with SAE 30.

From the EDAX (Fig. 5 right side) spectrum, indicating that the percentage of carbon present in the PE 50 and PE 75 is little higher than that of other lubricants. Therefore, an increase in hardness and tensile strength of material due to the presence of carbon, should be an increase of wear resistance. Various elements are appearing in the specimens from the analysis are carbon (C), Oxygen (O₂), Chromium (Cr), Aluminium (Al), Silicon (Si) and Chromium (in SAE 30 only), as shown in Table 2.

Table 2. Elemental Analysis of PE and its Blends

Lubricants					
Elements	SAE 30	PE	PE 25	PE 50	PE 75
C	9.41	9.68	9.32	11.03	12.06
O ₂	1.82	1.39	1.65	1.32	1.56
Al	0.23	0.45	0.22	0.16	0.17
Si	1.22	1.42	1.24	1.34	1.31
Fe	84.55	87.05	85.86	87.87	87.56
Cr	0.11	----	----	----	----

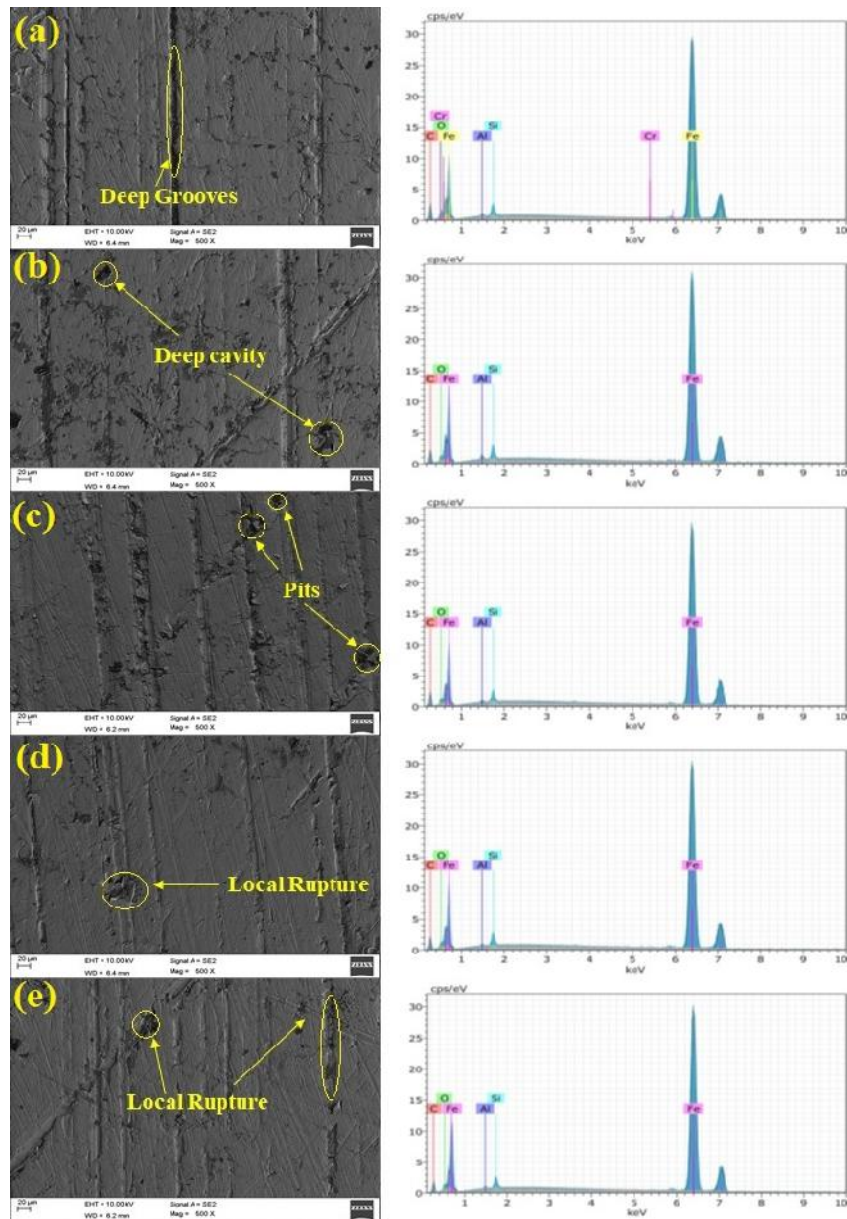


Fig. 5. SEM and EDAX Spectra of worn liner specimens lubricated by a) SAE 30 b) PE c) PE 25 d) PE 50 e) PE 75

Conclusions

The tribological behaviour of various PE based blended lubricants was evaluated using High Frequency Reciprocating Rig (HFRR) tribometer under various conditions and the results were compared with the SAE 30 grade compressor oil. The following conclusions were made from the experimental study:

- PE was produced successfully from raw rapeseed oil by the transesterification process using ultrasonication technic.
- The properties of the produced PE and its blends were closer its viscosity and viscosity index with the SAE 30 grade compressor oil.
- During the 1 hr running time, the COF (0.41) of PE 75 bio-based lubricant was shown better result than that of other four lubricants.
- Among all the five lubricants PE 50 shows the lower value of wear depth (10µm) compared to SAE 30, PE, PE 25 and PE 75.

- The addition of PE 75 and PE 50 with the synthetic lubricant SAE 30 grade compressor oil shows the smoother worn surfaces, which means an increase of PE percentage could be increase of lubricant performance.

References

- [1] N.J.FoxG. W.Stachowiak 2007, Tribol. Int. 40 pp 1035-1046.
- [2] Zoran S. Petrovic, Alisa Zlatanovic, Charlene, C. Lavaa, Snezana Sinadinovic-Fiser 2002. Eur. J Lipid. Sci. Tech. 104. pp 293–299.
- [3] Chandu S. Madankar, Subhalaxmi Pradhan, S.N. Naik 2013, Ind. Crops Prod. 43 pp 283– 290.
- [4] Dharmendra Kumar Gajendra Kumar Poonam C.P. Singh 2010. Ultrason. Sonochem. 17 pp 555-559.
- [5] K.G.Georgogianni M.G.Kontominas P.J.Pomonis D.Avlonitis V.Gergis 2008, Fuel Process Technol. 89 pp 503-509.
- [6] Veera Ganeswar Gude, Georgene Elizabeth Grant 2013, Appl. Energ. 109 pp 135-144.
- [7] Priyanka Chand, Venkat Reddy Chintareddy, John G. Verkade, and David Grewell 2010, Energy Fuels 24 pp 2010–2015.
- [8] P. Chenga Reddy, S. Arumugam, G. Sriram, and R. Parthasarathy 2018, Advanced Science Engineering and Medicine 10 pp 1-5, doi:10.1166/ase.2018.2171.
- [9] A.Adhvaryu Z.Liu S.Z.Erhan 2005, Ind. Crops Prod. 21 113-119.
- [10] S. Arumugam and G. Sriram 2012, Tribol. Trans. 55 pp 438-445.
- [11] S Arumugam and G Sriram 2012, J Engg. Tribol. 227 pp 3-15.
- [12] S. Baskar a, G. Sriram a, S. Arumugam 2015, Tribology in Industrial 37 pp 449-454.
- [13] Tiong Chiong Ing, A. K. Mohammed Rafiq, Y. Azli and S. Syahrullail 2012, Tribol. Trans. 55 pp 539-548.
- [14] Sevim Z. Erhan, Brajendra K. Sharma, Zengshe Liu, and Atanu Adhvaryu 2008, J. Agr. Food Chem. 56 pp 8919-8925.
- [15] Matthew T, Siniawski, nader Saniei, Bigyan Adhikari and Lambert A 2007. Journal of synthetic lubrication 24 pp 101-110.