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Synthesis and tribological investigation of compressor's liner-tribo pair material under the influence of biodegradable compressor oil

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Abstract. The present investigation is intended to synthesis biodegradable compressor oil for reciprocating air compressors and analyses the tribological behavior of liner-ring tribo pair material under the influence of new formulations. A pin-on-disc tribometer was used to perform the tribological investigations. EN 31 steel and EN-JL 1020 was selected as disc and pin material, respectively. An ultrasonication based transesterification process was used to formulate a biodegradable compressor oil. TGA and DSC analysis was performed to examine the thermos-oxidative stability of compressor oil. The newly formulated bio compressor oil showed better tribological parameters in terms of coefficient of friction, wear and specific wear rate as compared with SAE 30 grade compressor oil. SEM and EDAX analysis of testing pin surfaces proved that the worn surfaces were smooth with bio compressor oil.

1 Introduction

At present, demand for crude oil and petroleum products are projected to continue climbing, further increasing the price of products and also rapid depletion of crude oil reserves in the world due to their usages in many applications like transport (63.7%), industrial (8.5%) and non-energy use and others (27.8%). On the other side, environmental issues with the mineral oils due to its non-degradability, air pollution and toxic problems [1]. This situation creates greater opportunity to produce environmentally friendly lubricating oil from vegetable oil for air compressors, because of its biodegradability, high viscosity index, good anti wear characteristics, low toxicity and high flash point in nature [2]. However, the main problem with the vegetable oil is relatively poor oxidation stability. To overcome this drawback, vegetable oil was formulated by chemically modified via epoxidation, hydroxylation followed by esterification process, which improves the oxidation stability and cold flow properties of the oil [3]. Waste cooking oil methyl ester (WCOME) was prepared using *In-situ* epoxidation process for industrial applications, for this reaction acidic ion-exchange resin was used as a heterogeneous catalyst. The modified WCOME had improved thermo-oxidative stability and also viscosity, which was confirmed by NMR, oxirane analysis by HBr titration method and FTIR reports [4]. Investigations were also made to improve the oxidative stability of vegetable oil by transesterification process. Hashem et al [5] was converted some vegetable oils into bio lubricants via two successive transesterification process using conventional method and the converted oils were shown good thermal and oxidation stability.

By conventional method, the synthesis of vegetable oil is consuming more reaction time with a low yield percentage of oil which leads to high processing cost. In this connection, researchers are making the attempts to reduce the production cost and faster reaction time by the use of ultrasound

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energy. Ponappa et al [6] was employed to optimize the process parameters for transesterification of kapok seed oil to produce biodiesel using ultrasonic energy. From the results found that the highest biodiesel yield was obtained by some of the important parameters like methanol/oil molar ratio, catalyst concentration, reaction time, ultrasonic frequency and temperature [7-9].

Many researchers have reported that the liner-ring Tribo pair is the important tribological component in reciprocating internal combustion engine, same as in reciprocating air compressors. Arumugam et al [10] was conducted several tests on cylinder liner and piston ring combination using a pin-on-disc tribometer under different lubricants. From the experimental results found that the newly formulated bio-lubricant and biodiesel were shown better performance in terms of friction, frictional force and wear, also its impact was shown positively on engine component life. Yashvir Singh et al [11-12] was developed bio based blended lubricants in the ratio of 15, 30, and 50% by volume with pongamia pinnata and jatropha oils for tribological investigations. It was found that the addition of pongamia and jatropha oil to the base lubricants (SAE 40 and SAE 20W40) resulted better reduction in terms of friction and wear. Trivedi et al [13] was investigated and compared the tribological behavior of the realistic engine oils (SAE 10W30, SAE 20W40 and SAE 20W50) with constant load and incremental load of 20 N to 140 N for 105 min run using a pin-on-disc Tribo tester and observed that the effect of viscosity of oil and variation of load plays an important role in wear and friction characteristics. Nuraliza et al [14] have studied the effect of vegetable oil as bio-lubricant on the friction and wear of piston ring and cylinder liner materials using a pin-on-disk tribometer under variable loads (50N and 100N) and varying sliding speeds (1, 2, 3, 4, 5 m/s), base oil as hydraulic and engine oil used for the comparison purpose. It is observed that the new alternative lubricant has shown good results in terms of wear, coefficient of friction and also shows the smother worn surface of the specimen, confirmed by SEM analysis.

In the present investigation ultrasonication energy is used to develop bio-lubricant from rapeseed oil by the transesterification process for the application of reciprocating air compressors and its tribological tests were conducted on liner-ring tribo pair material using a pin-on-disc tribometer. The worn surfaces of the tested liner-ring tribo pair was examined by using scanning electron microscopy (SEM) and EDAX analysis.

2 Experimental Work

2.1 Synthesis of bio-lubricant

Raw rapeseed oil was synthesized following the two-step reaction. First the rapeseed oil was converted into methyl ester. In this process, the products of raw rapeseed oil (1000 ml), methanol (178.4ml) as alcohol, and sodium hydroxide (8.92 grams) as catalyst were taken in a 2000 ml capacity of three-necked round bottomed flask. The products were stirred at 200 rpm with 55^0C for the time of 3 hr. After the reaction, the contents were well washed with warm water for the purpose of removing the dissolved excess alcohol. The final content was formed as the mixture of methyl ester and glycerol as by product. Then the methyl ester was separated from glycerol by using a separate funnel without any disturbance and heated up the reactants at 55^0C to evaporate the water residue.

In the second step, methyl ester was converted into pentaerythritol ester (bio-lubricant) with the influence of low frequency ultrasound energy (20kHz). For this reaction, the obtained Methyl ester (640ml), pentaerythritol (149.366 grams), p-TSA (1 gram) as a catalyst and xylene (20 ml) as solvent were taken in a three-necked round bottomed flask and this was introduced into the ultrasound chamber in the transesterification process. Then the reactants were heated up on a heating mantle under a nitrogen atmosphere at 150^0C for 3hr reaction time. After the completion of the reaction, the pentaerythritol ester was well washed with warm water to remove the excess alcohol and heated up the reactants at 70^0C to evaporate the water residue.

2.2 Lubrication properties test

The physico-chemical properties of biodegradable compressor oil were measured in Ita labs, Chennai, Tamil Nadu, India, according to the ASTM (American Society for Testing and Materials) standards. The obtained results were shown in table 1.

Table 1. Properties of Biodegradable compressor oil

Parameters	Testing Standards	SAE 30	Biodegradable compressor oil
Kinematic Viscosity at 100^{0}C	ASTM D7279	10.5	9.02
Flash Point (^{0}C)	ASTM D93	250	206
Pour Point (^{0}C)	ASTM D97	-40	<-10
Viscosity Index	ASTM D7279	145	124

2.3 Wear and friction Test method

The Pin-on-disc tribometer is used to investigate the effect of PE on wear and friction properties of the liner-ring tribo pair. ASTM G99 standard test method was used to evaluate the wear preventive characteristics of lubricant. The test conditions are 50 N load, 50 mm track diameter, 1800 m of sliding distance, 5 m/s of sliding velocity, operational speed of 1061 rpm and 60 min of operational time.

2.4 Preparation of specimen

The specimens were prepared from EN 31 steel and grey cast iron EN JL 1020 material. EN 31 steel was used as disc specimen and EN JL 1020 material is used for the pin specimen. Before to conduct the tests, it was mandatory to clean the specimens properly to free from the foreign particles and debris with alcohol.

3 Results and Discussion

3.1 TGA (Thermogravimetric Analysis)

Thermal stability is one of the most important property of the lubricant and it is essential to determine for the oil and this analysis was carried out using TGA machine. The approximately sample weight was taken as 14.061 mg for the analysis. It can be seen that the biodegradable oil was stable up to 230^{0}C (onset temperature). From the TGA curve (Fig. 1), the weight loss occurred between 230^{0}C to 455^{0}C due to the combustion of organic matter present in the biodegradable oil. The maximum weight loss occurred at the decomposition temperature of 365^{0}C and 455^{0}C.

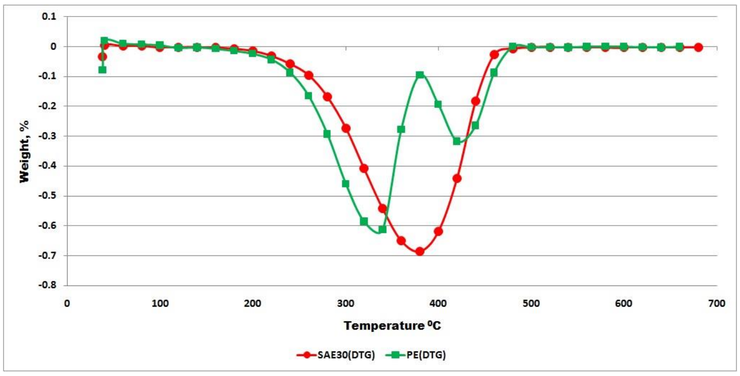

Fig 1. TGA Analysis

3.2 DSC (Differential Scanning Calorimetry)

It is a technique of thermoanalytical, which determines the temperature and heat flow difference between a sample and reference material. This technique is mainly used for the measurement of oxidative stability which is very important for the lubricating oil. The sample of oil was evaluated at a rated temperature of 10^{0}C/min with the sample weight of 14.723 mg under the air of 150 psi. From the DSC curve in Fig 2. The thermic peak represents the melting point between 230^{0}C and 263^{0}C.

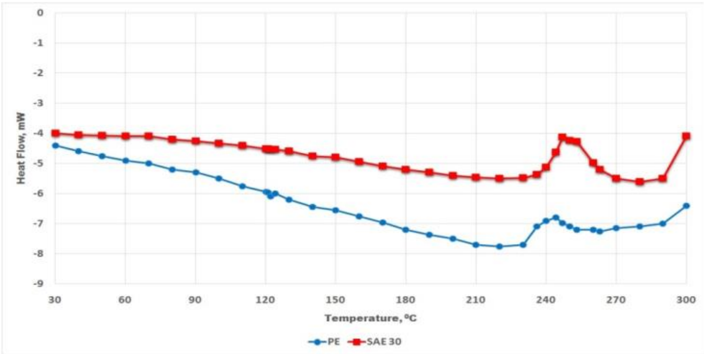

Fig 2. DSC Analysis

3.3 COF (Coefficient of friction)

Pin-on-disc tribometer was used to examine the wear and friction characteristics of the liner-ring material under biodegradable compressor oil and SAE 30 compressor oil. The testing oil was filled up in a tank and a pump, which is used to monitor the oil continuously between the contact area of rotating disc and a pin. The coefficient friction was measured for the constant load (50N) condition and working speed of 1061 rpm for the duration of 3600s under lubrication. From the Fig 3. observed that the coefficient of friction at starting of the test of biodegradable oil was lower than that of SAE 30 grade compressor oil. At one stage, the COF value of the lubricants were same. This is due to viscosity of the lubricants were closer each other, that forms the thinner film between the sliding surfaces in contact.

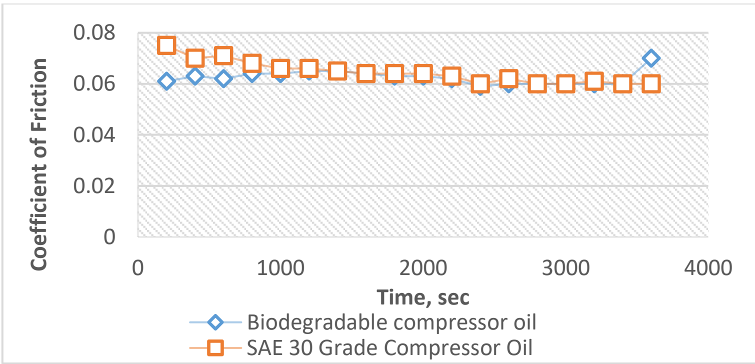

Fig 3. Coefficient of Friction

3.4 Wear characteristics

For the same load conditions, wear experiments were conducted with same lubricants. The variations in wear with the load for one-hour duration is shown in Fig 4. In general wear behavior increases with the increase of time and always sliding surface plays a vital role to increase the wear.Also, the irregularities of the surface increase the area of contact between the sliding surfaces, resulted maximum wear. In this study, Biodegradable oil showed minimum wear as compared to the synthetic air compressor oil due to maintain its film thickness between the contact areas. The wear characteristics of SAE 30 grade compressor oil was increased with the increase of running time.

The specific wear rate of biodegradable compressor oil and SAE 30 compressor oil were calculated by the equation given below. The values are 3.397E-06 mm^3/N-m for bio lubricant and 7.078E-06 mm^3/N-m for SAE grade compressor oil.The specific wear rate of biodegradable compressor oil was lower than the SAE 30 grade compressor oil. Where V is volume loss in cubic millimeter, F is applied load in Newton and D is Sliding distance in meter.

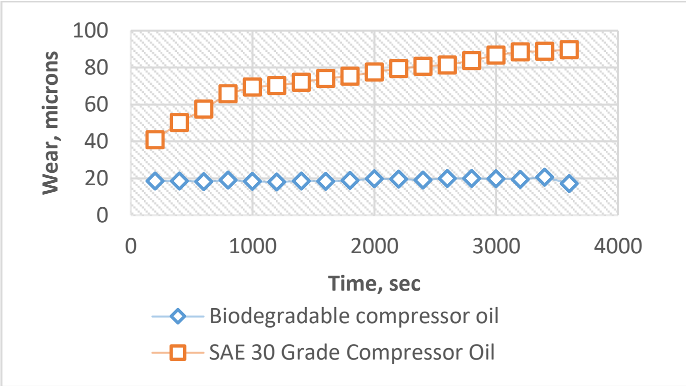

Fig 4. Wear Characteristics

Specific Wear Rate $SWR = \frac{V}{F \times D}$ mm^3/N-m

3.5 SEM Analysis

The rubbed surfaces of the pin were examined by the SEM (Scanning Electron Microscope) analysis. The obtained worn surfaces of the samples were shown in Fig 5 (a) and 5 (b) for the synthetic oil and biodegradable oil. It can be easily found that after running a 3600s of time, Fig 5 (a) represents the presence of cavities and pits under synthetic oil. From Fig 5 (b) observed that, with the biodegradable air compressor oil, appears cavities and grooves due to the metal-metal contact between liner-ring surfaces.

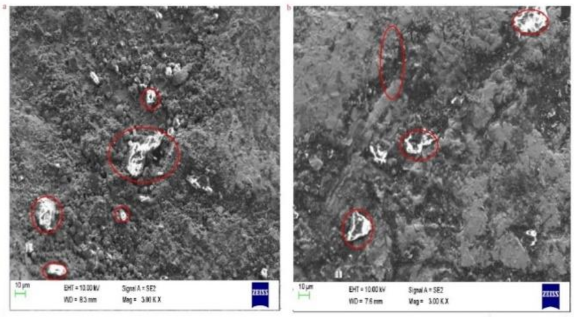

Fig 5. SEM image of the cylinder liner wear surface: a) Synthetic lubricant b) Bio-lubricant.

3.6 EDAX Analysis

Energy Dispersive Analysis of X-rays (EDAX) of the pin worn surface is shown in figure 6 (a) and 6 (b). From the figure 6 (a) it is clear that C, O, Fe and Si peaks are observed in the energy dispersive analysis X-ray lubricated by SAE 30 grade compressor oil. Figure 6 (b) shows worn surface under bio-lubricant, the elements like Al, Ca, C, Na, Fe, Mg and Si peaks were observed.

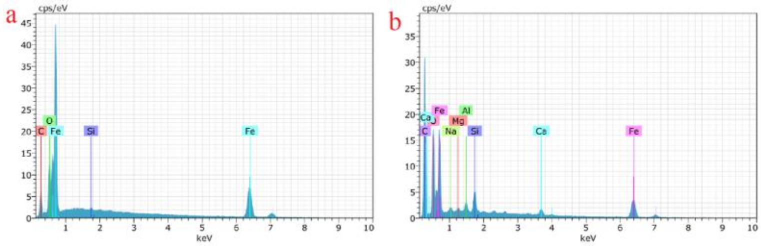

Fig 6. EDAX images of the cylinder liner wear surface: a) Synthetic lubricant b) Bio-lubricant.

4 Conclusions

In this study coefficient of friction, wear and specific wear rate of liner-ring material at constant load were carried out using a pin-on-disc tribometer under lubricants. The following conclusions were made from the obtained results:

- The ultrasonic energy is found to be suitable for transesterification process to produce biodegradable compressor oil by reducing the reaction time with high yields.
- Physico-chemical properties of the bio-lubricant meets the ASTM standards.
- Improved in thermo-oxidative stability and heat flow properties of the bio-lubricant by transesterification process, which was analyzed by TGA, DSC and DTA.
- The biodegradable oil reduced the coefficient of friction, wear and specific wear rate compared with SAE 30 grade compressor oil. With this proved that the bio-lubricant had excellent lubricity as compared to the synthetic lubricant.
- From the observation of the worn surfaces, biodegradable compressor oil showed smoother surface than the SAE 30 grade compressor oil.
- EDAX technique was used to show the chemical composition of the specimens, the various peaks of the elements were shown clearly in figure 6.

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