Polyester Based Lubricant from Waste Feedstock for Sustainable Environment: A Tribological Investigation

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Abstract: This study reported the tribological evaluation of polyester based lubricant synthesised from waste feedstock. The transesterification process was adopted for the formulation of lubricant from waste mango seed kernel oil. The polyols used in this formulation are neopentyl glycol, trimethylolpropane and pentaerythritol. The tribological investigation was conducted using four ball tribometer as per ASTM D4172. The frictional and wear behavior of vegetable oil-based polyester was analysed in addition to the wear morphology of investigated balls. The results indicated that the average frictional torque and mean wear diameter of pentaerythritol ester of waste mango seed oil was 0.12 Nm and 0.403 mm respectively and also found that the pentaerythritol ester showed improved tribological results as compared with other polyesters say neopentyl glycol ester and trimethylolpropane ester of waste mango seed oil. The waste mango seed oil is found suitable candidate for the formulation of polyester based sustainable lubricant.

1. Introduction

In general, many investigations were focused to find the alternate for petroleum-based products in the recent years [1-2]. In this connection, first and second-generation vegetable oil is found suitable for lubricant applications and it is used for many years ago specifically for lubrication purpose [3-5]. However, the formulation of lubricant from first- and second-generation vegetable oil is not cost-effective as its base stock cost is expensive than mineral oil [6]. To overcome this, base stock from waste feedstock is one such standby candidate [7]. Pierson et al experimented the use of waste mango seed oil as engine fuel [8]. The chemical modification was used to convert vegetable oils into lubricant formulations [9-10]. Here, the study reported the conversion of waste mango seed oil into polyester based sustainable lubricant through chemical modification process. The properties and tribological behaviour of the esters formulated were assessed to find their appropriateness as lubricant candidate.

2. Experimental work

2.1 Formulation of waste mango seed oil-based polyesters

The waste mango seed oil was used as a base candidate and polyols used in this study were pentaerythritol, trimethylolpropane and neopentyl glycol. The base oil is extracted from the kernel of waste mango seed by the
procedure adopted by Dutra et al [9]. The procedure adopted for the formulation of polyolester based lubricants is as follows:

Step 1: Hundred gram of waste mango seed oil was mixed with 20 ml of methyl alcohol and 1g NaOH, a catalyst in a glass beaker and the mixture was heated to 55˚C, under mechanical stirring for one hour. The resultant methyl ester of mango seed oil was separated from by product using a separating funnel. Now the methyl ester was reacted with pentaerythritol in the presence of a catalyst p-toluenesulphonic acid, and solvent xylene. The process was carried out at 150-160˚C under nitrogen environment for the period of 6 h. The resultant pentaerythritol ester was methodologically purified for further investigation.

Step 2: 200 g of waste mango seed oil methyl ester was mixed with desired amount of trimethylolpropane (TMP) and it is heated to over 130˚C under vacuum pressure of 0.1 mbar for 2h till the entire TMP gets melted. Then 0.9 % w/w of alkaline catalyst (sodium methoxide) was added slowly so as to avoid the spillage. The samples were drawn from the beaker at regular intervals for the completion of reaction. Then the resultant product ie., TMP ester of waste mango seed oil was cooled, vacuum filtered and distilled [13].

Step 3: Waste mango seed oil neopentyl glycol (NPG) ester were synthesized by the transesterification of 50g of mango seed oil methyl ester with 8g of NPG. The blended mixture was transferred to a flask and then, 0.3 g of calcium methoxide, a catalyst and 50 ml of isoctane were added to it. The flask mouth was attached with a stark cap so as to perform the azeotropic distillation of methanol–isoctane. The mixture temperature was maintained at 180˚C at ambient pressure condition. Then the pressure was reduced slowly to 0.5 mbar by using vacuum controller. Finally, the end product of NPG ester was rotary evaporated in order to remove isoctane from the final product.

2.2 Tribological investigation using four ball tribometer

A four ball tribometer, TR-30L-IAS, supplied by Ducom Instruments, Bengaluru was used to conduct the tribological experiment. The test lubricant is charged to the ball pot where three balls of AISI E-52100 chrome alloy steel with a diameter of 12.7 mm, extra polished to grade 25 and hardness of 65 HRC are loaded. The other ball was fixed on a collet and press against the bottom balls by the supply of standard load. The experiment was carried out at lubricant chamber temperature of 75˚C as per ASTM D4172. The frictional torque exerted on the three balls was measured. An optical microscope facilitated with image capturing software was used for measuring the wear scar diameter and wear scar image on the three ball surfaces and reported.

3. Results and Discussion

3.1. Physio-Chemical Properties of Polyolesters

The properties of various esters were reported in the Table 1. Table 1 was depicted the properties of the pentaerythritol ester (PEE), neopentyl glycol ester (NPGE) and trimethylolpropane ester (TMPE). The viscosity at 40˚C of PEE, NPGE and TMPE were 69.1, 66.3 and 60.9 cSt respectively. The viscosity at 40˚C of PEE was 4.22% and 13.46% higher than NPGE and TMPE respectively. The viscosity at 100˚C of PEE, NPGE and TMPE were 12.9, 11.4 and 10.8 cSt respectively. The viscosity at 100˚C of PEE was 13.15% and 19.44% superior to NPGE and TMPE respectively. The cloud point for PEE, NPGE and TMPE were -9˚C, -5˚C and -8˚C. The pour points of PEE, NPGE and TMPE were -20˚C, -31˚C and -35˚C. The flash point of PEE, NPGE and TMPE were 311˚C, 262˚C and 249˚C. The properties of PEE showed better results as compared with NPGE and TMPE. The structure of PEE has better stable and superior when exposed at an elevated temperature, whereas NPGE and
3.2. Analysis of tribometer results

Figure 1 showed the average frictional torque of various polyol esters. From Figure 1, the average frictional torque of PEE, NPGE and TMPE were 0.12 Nm, 0.14 Nm and 0.18 Nm respectively. The lower value of frictional torque and its corresponding co-efficient friction was observed for PEE as compared with the NPGE and TMPE. The higher viscosity of PEE is responsible for lower COF value. This lesser frictional behavior of PEE showed its tribological effectiveness. Figure 2 showed the mean wear scar diameter (MWSD) of PEE, NPGE and TMPE were 0.4031 mm, 0.5762 mm and 0.6651 mm respectively. The minimum mean wear scar diameter was noticed for PEE as compared with NPGE and TMPE. The presence of four carboxylate ester group in PEE could be responsible for its improved anti-wear behavior. On the counter part, the NPGE has only two carboxylate ester group. The larger pentaerythritol ester group was stable enough to protect wear. This trend is in agreement with Aziz et al [16].

Table 1- Properties of polyolesters of mango seed oil.

| Properties                      | Standard | PEE   | NPGE  | TMPE  |
|---------------------------------|----------|-------|-------|-------|
| Kinematic Viscosity @ 40 °C (cSt) | ASTM D445 | 69.1  | 66.3  | 60.9  |
| Kinematic Viscosity @ 100 °C (cSt) | ASTM D445 | 12.9  | 11.4  | 10.8  |
| Cloud point (°C)                | ASTM D2500 | -9    | -5    | -8    |
| Pour point (°C)                 | ASTM D97  | <-20  | <-31  | <-35  |
| Flash point (°C)                | ASTM D93  | 311   | 262   | 249   |
3.3 Surface Morphology of Ball Surfaces

The worn balls were examined by scanning electron microscope. Figure 3 depicted the surface morphology of sample ball tested under PEE, NPGE and TMPE. Fig. 3 indicated that the ball lubricated with PEE showed the smooth wear surface. The balls lubricated with NPGE and TMPE showed crack and minor voids. The microbrusqueness bonding, surface plastic deformation and damaged surfaces are the consequence of friction and wear with the use of NPGE and TMPE.
4. Conclusions

The properties and tribological characteristics of various esters were evaluated and the findings were:

- The viscosity, cloud point, pour point and flash point of PEE was showed better values as compared with NPGE and TMPE.
- The average frictional torque of PEE was found to be 14.3% and 33.3% lower as compared to NPGE and TMPE.
- The MWSD of PEE was found to be 30.1% and 39.4% lower as compared to NPGE and TMPE.
- The worn ball surfaces lubricated with NPGE and TMPE showed the presence of crack and void. The smooth surface was observed on the worn ball surface lubricated with PEE.

5. References

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