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TRIBOLOGICAL CHARACTERISTICS OF ZDDP ADDITIVE ADDED EPOXIDIZED PONGAMIA BIOLUBRICANT

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Abstract: This study predicts the tribological characteristics of Zinc-Dialkyl-Dithio-Phosphate (ZDDP) additive added non-edible epoxidized pongamia biolubricant. The biolubricant samples are prepared by adding ZDDP additive into epoxidized pongamia oil at 1, 2 and 3 weight percentage (wt%) and their tribological characteristics such as kinematic viscosity, wear and friction are experimentally determined. Kinematic viscosities of biolubricant samples at different temperature ranging from 40 to 100 ^{o}C are determined using redwood viscometer and wear and friction characteristics of samples are determined using four-ball wear tester. The test results of ZDDP additive added epoxidized pongamia biolubricant samples are also compared with the test results of synthetic mineral oils SAE5W30 and SAE10W30. The epoxidized Pongamia biolubricant with 3 wt% of ZDDP additive is shown to provide a minimum wear scar diameter with less coefficient of friction as compared to synthetic mineral oil SAE5W30. Thus, the global demand for petroleum-based lubricants is found to be reduced by non-edible pongamia oil through proper chemical modification and addition of ZDDP additive in its proper wt%.

***Index Terms* – Pongamia biolubricant, epoxidation, ZDDP additive, tribological characteristics.**

1. INTRODUCTION

Increased consumption of petroleum products and their high depletion and environmental impact have strongly demand for synthesis of high biodegradable, low toxic and anticorrosive biolubricants from various edible and non-edible vegetable oils. Thus, many experimental works towards the synthesis of vegetable oil lubricants and improvement of their tribological properties through proper chemical modifications and addition of proper additives have been reported in the available literature. Generally, the unfavorable and unsaturated free fatty acid in the vegetable oil is removed using either epoxidation or double transesterification chemical modification process to improve its thermal and oxidative stability. Panchal et al. [1] presented a detailed review on development of bio-lubricants as well as their chemical modification processes. Fox and Stachowiak [2] reviewed the mechanism of auto-oxidation of vegetable oil and the methods used for improving their oxidation stability. Borugadda and Goud [3] converted the castor oil fatty acid methyl esters (COFAME) into epoxidized COFAME to use it as a lubricant base stock. Campanella et al. [4] used the epoxidation process for soybean, sunflower and high-oleic sunflower oils to obtain polyols with branched ether and ester compounds. Hashem et al. [5] converted the castor, linseed, sunflower and jatropha oils into polyoleate esters by simultaneous epoxidation and hydrolysis processes. These converted polyesters were shown to be promising candidates to use them as synthetic lubricants. Hashem et al. [6] and Heikal et al. [7] used double transesterification process to produce biolubricants from vegetable oils.

In addition to the various chemical modification processes, some additives are also added to the vegetable oils as anti-wear and anti-corrosive agents, viscosity modifiers, etc by many researchers. Talib and Rahim [8] added the hexagonal boron nitride (hBN) additive into Jatropa oil at different concentration ranging between 0.05 to 0.5 wt% and determined their tribological characteristics. Anand et al. [9] prepared the various vegetable oil blends by adding Benzoic acid into Pongamia oil in its different weight percentage and found the good antiwear and antifriction properties from these blends. Cheenkachorn [10] used a zinc-dialkyl-dithio-phosphate (ZDDP) as additive into different soybean oils including conventional soybean oil, epoxidized soybean oil and high-oleic soybean oil. The available literature reveals that the work on synthesis of bio-lubricant from pongamia non-edible vegetable oil is scant.

Hence, the present work is aimed to synthesize biolubricant from non-edible pongamia oil using epoxidation and oxirane ring opening processes and addition of ZDDP additives at its 1, 2 and 3 weight percentage. The tribological characteristics such as kinematic viscosity, wear and friction of these ZDDP additive added epoxidized pongamia oil biolubricant samples are experimentally studied and compared with synthetic mineral oils SAE5W30 and SAE10W30.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1. Epoxidation and Oxirane Ring Opening Processes

In the present work, the Pongamia oil is selected as base oil as it has good oily content, does not compete with food and it can grow in marginal land. Purified pongamia raw oil is purchased from Mandya district bio-fuel research, information and demonstration center, P E S College of Engineering, Mandya, Karnataka, India. The ZDDP additive and chemicals are procured locally.

The unsaturated fatty acid in the pure pongamia oil is removed through chemical modification processes via epoxidation and oxirane ring chain opening processes. Figure 1 shows the apparatus used for the epoxidation and oxirane ring opening chemical processes. During epoxidation process, a 750 ml of pure pongamia oil is poured into a three-neck round flask placed on a hot plate magnetic stirrer. Then, 66 ml of formic acid and 9 ml of sulfuric acid are added into the flask containing pongamia oil. Hydrogen peroxide of 150 ml is then added drop by drop using burette up to one hour at room temperature through first neck. The reaction is continued at 60^{o} C under vigorous stirring for 5 hours. Once the chemical reaction is completed, the resulting epoxidized pongamia oil is separated using separating funnel, cooled to room temperature, and washed with warm water until all the catalyst and reactants are removed.

Oxirane ring opening of above epoxidized oil is performed by heating 700 ml of epoxidized oil to 80^{o} C using magnetic stirrer and 400 ml of acetic acid which is preheated to same temperature is added to the three-neck flask. The rigorous stirring at 1000 rpm, during the rection, is continued for 6 hours. Ring opened pongamia oil is separated and washed with warm water.

Fig. 1: Apparatus for epoxidation and oxirane ring opening processes.

2.2 Viscosity Test

Kinematic viscosities of biolubricant samples as well as synthetic mineral oil samples at different temperature ranging from 40^{o}C to 100^{o}C are determined using Redwood viscometer. The cylinder of Redwood viscometer is 47.625 mm in diameter and 88.90 mm in deep and the orifice is 1.70 mm in diameter and 12 mm in length. Time taken to fill 50 ml of Kohlrausch's flask is noted down using stopwatch. Then the kinematic viscosity of the samples is determined using the following expressions,

$$\upsilon = 0.264t - \frac{190}{t} \text{ cSt} \quad \text{for } 40 < t < 85 \text{ sec}$$

$$\upsilon = 0.247t - \frac{65}{t} \text{ cSt} \quad \text{for } 85 < t < 2000 \text{ sec}$$

where, ν is the kinematic viscosity in centistokes (cSt) and t is the time of 50 ml of oil flow through orifice in seconds.

2.3 Four-ball wear test

The wear and coefficient of friction properties of biolubricant samples and synthetic mineral oil samples are determined using four-ball wear tester shown in Fig. 2. Wear property is determined in terms of wear scar diameter of stationary balls. The test is carried out according to ASTM D4172 standards shown in Table 1. Balls are made by AISI-E52100 chrome alloy steel with a diameter of 12.7 mm, hardness 64-66 HRC and extra polishing of 25 EP.

Table 1- Test conditions of ASTM D4172 standards

Parameters	Test conditions
Temperature	75 ±2^{0} C
Speed	1200 ±60 rpm
Duration	60 ±1 min
Load	392N

Fig. 2: Four-ball wear tester

3. RESULTS AND DISCUSSION

3.1 Kinematic Viscosity

Figure 3 shows the variation of kinematic viscosity of ZDDP additive added epoxidized pongamia biolubricant samples at different temperatures. The kinematic viscosities of all lubricant samples reduce as their temperature increases. For the entire range of temperature, the epoxidized pongamia biolubricant without additive (0 wt%) and with 3 wt% ZDDP additive shows higher kinematic viscosity than those of synthetic mineral oils SAE5W30 and SAE10W30. Epoxidized pongamia biolubricant with 1 wt% and 2 wt% of ZDDP additive shows almost same kinematic viscosity as those of synthetic oils SAE5W30 and SAE10W30 at higher temperature i.e.at temperature above 60^o C. Thus, the synthetic mineral oils, especially SAE10W30 oil, can be replaced by these 1wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants. Further, addition of ZDDP additive reduces the viscosity of epoxidized pongamia biolubricant.

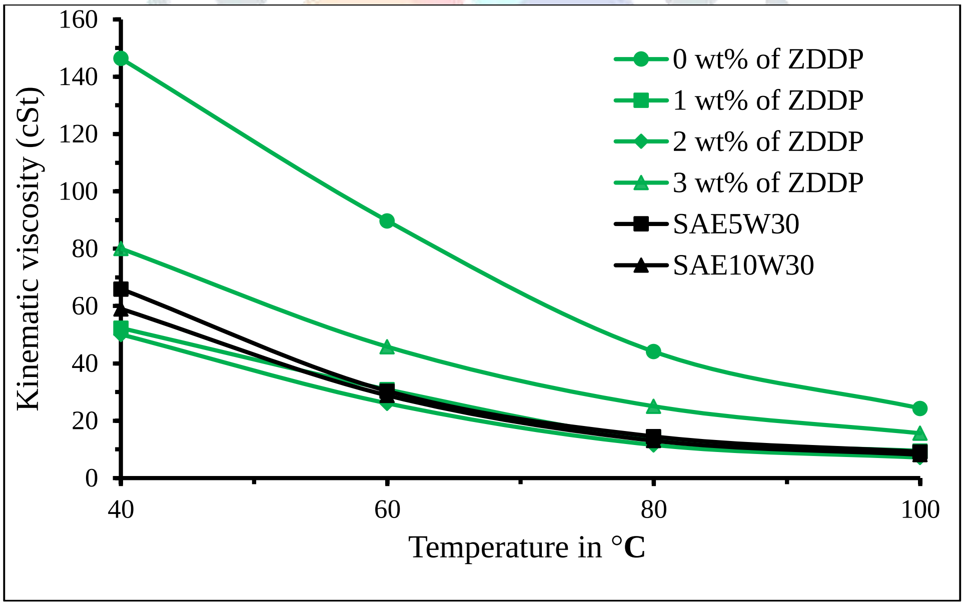

Fig. 3- *Kinematic viscosity versus rise in temperature.*

Figure 4 shows the percentage reduction in kinematic viscosities of lubricant samples at temperatures 60^o C, 80^o C and 100 ^{o}C with respect to that at 40^o C. All biolubricant samples show lesser reduction of viscosities as compared to synthetic mineral oils SAE5W30 and SAE10W30. For the lubricant temperature of 100 ^{o}C, the reduction of 86.14% in the viscosities of synthetic oils SAE5W30 and SAE10W30 is observed while the reduction of 81.93% and 80.47% is observed for epoxidized pongamia oil with 1 wt% and 3 wt% ZDDP additive, respectively. Thus, the variation of kinematic viscosity at higher temperature is comparatively less in biolubricants as compared to synthetic oils considered.

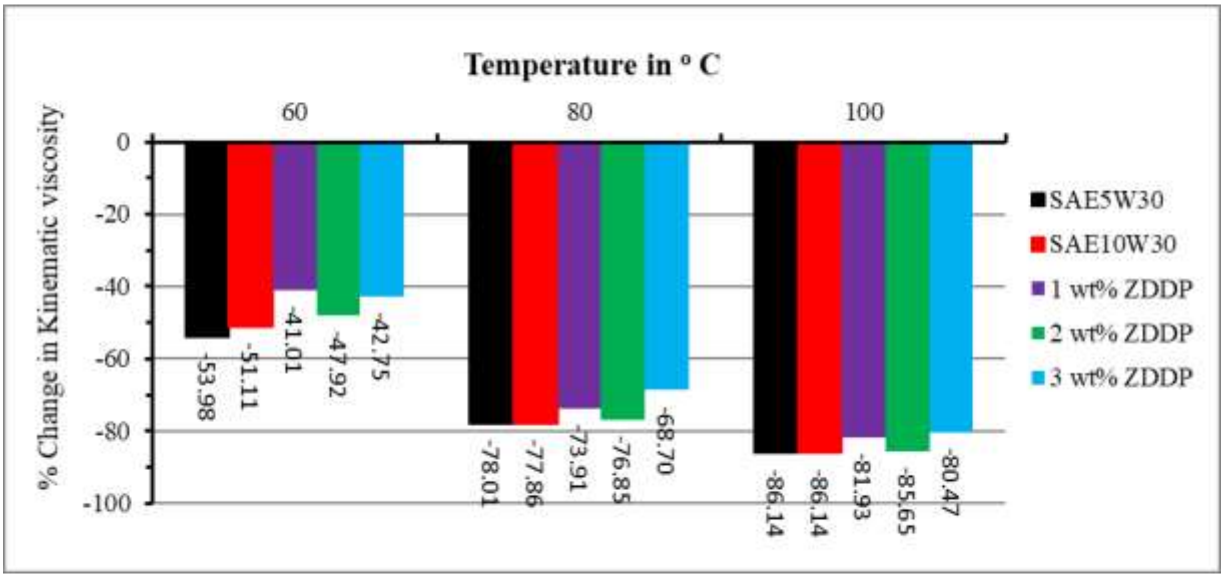

Fig. 4- *Percentage reduction in kinematic viscosity due to rise in temperature.*

3.2 Wear and Coefficient of Friction

The test results of mean wear scar diameter (MWSD) and mean coefficient of friction (MCoF) for ZDDP additive added epoxidized pongamia biolubricant samples and mineral oils SAE5W30 and SAE10W30 samples are tabulated in Table 2. The mean wear scar diameters of 1 wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants are higher than the synthetic mineral oils considered. However, the mean coefficient of frictions (MCoF) of these biolubricants are lesser than the synthetic mineral oils. Epoxidized pongamia oil with 3 wt% of ZDDP additive which shows higher kinematic viscosity (Fig. 3) provides lesser mean WSD and CoF than that of synthetic oil SAE5W30. It shows slightly higher mean WSD with lesser mean CoF than that of SAE10W30. From the point of view of minimum wear and CoF, the 3 wt% ZDDP additive added epoxidized pongamia biolubricant can be used as an alternative to the synthetic mineral oils SAE5W30 and SAE10W30.

Table 2- *MWSD and MCoF of different lubricant samples.*

Lubricant samples	MWSD (mm)	MCoF
SAE5W30	0.876	0.120
SAE10W30	0.646	0.142
Epoxidized pongamia + 1 wt% ZDDP	1.215	0.067
Epoxidized pongamia + 2 wt% ZDDP	1.139	0.086
Epoxidized pongamia + 3 wt% ZDDP	0.737	0.069

4. CONCLUSIONS

- Epoxidized pongamia biolubricant with 1 wt% and 2 wt% shows almost same kinematic viscosities as those of synthetic oils SAE5W30 and SAE10W30 at higher temperatures above 60 ° C. Thus, the synthetic mineral oils, especially SAE10W30 oil, can be replaced by 1wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants.
- Epoxidized pongamia biolubricant with 3 wt% of ZDDP additive provides lesser mean WSD and CoF than that of synthetic oil SAE5W30 and shows slightly higher mean WSD with lesser mean CoF than that of SAE10W30.
- From the point of view of minimum wear and CoF, the 3 wt% ZDDP additive added epoxidized pongamia biolubricant can be used as an alternative to the synthetic mineral oils SAE5W30 and SAE10W30.

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