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Epoxidized Pongamia Biolubricant with ZDDP Additive for Journal Bearing Lubrication

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***Abstract*—This work experimentally predicts the performance of Zinc-Dialkyl-Dithio-Phosphate (ZDDP) additive added non-edible epoxidized pongamia biolubricant for journal bearing lubrication. Crude pongamia oil is chemically modified using epoxidation and oxirane ring opening process to remove its free fatty acid and ZDDP additive is added to this epoxidized pongamia biolubricant at 1, 2 and 3 weight percentages. The circumferential pressure distributions of journal bearing under the lubrication of these biolubricant samples are determined using journal bearing test rig. The test results of biolubricant samples are also compared with the test results of synthetic mineral oil samples SAE5W30 and SAE10W30. For low-speed application of journal bearing, the circumferential fluid-film pressure distributions for 1 wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants were found to be almost same as those of synthetic oils SAE5W30 and SAE10W30.**

Keywords— Pongamia biolubricant, epoxidation, ZDDP additive, Journal Bearing.

I. INTRODUCTION

Petroleum based mineral oil lubricants are most commonly used for the bearing lubrication in industries and automobiles. These non-renewable lubricants are low degradable and release toxic materials into the environment and causes its pollution. This necessitates the synthesis of high biodegradable, low toxic and anticorrosive biolubricants from various edible and non-edible vegetable seeds. Hence, many works towards the synthesis and analysis of environmentally friendly vegetable oil biolubricants have been carried out and reported in the literature.

Vegetable oils are having triglyceride structural molecules with long fatty acid chains. These unsaturated fatty acid chains are susceptible to the oxidation and it needs to be removed through proper chemical modifications. Generally, the unfavorable fatty acid chains of vegetable oils have been removed using either epoxidation or double transesterification chemical processes. Panchal, Patel, Chauhan, Thomas, and Patel [1] presented a detailed review on development of bio-lubricants as well as their chemical modification processes. Goud, Pradhan and Patwardhan [2] used the epoxidation process to modify the pongamia oil and studied the effects of temperature, hydrogen peroxide to ethylenic unsaturation ratio, acetic acid to ethylenic unsaturation ratio and stirring speed on epoxidation rate and oxirane ring 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, Rustoy, Baldessari and Baltanas [4] used the epoxidation process for soybean, sunflower and high-oleic sunflower oils to obtain polyols with branched ether and ester compounds. Gorla, Kour, Padmaja, Karuna and Prasad [5] prepared the epoxidized oil and its alkyl esters from nonedible pongamia oil. Hwang and Erhan [6] used the epoxidation and oxirane ring opening reaction to produce soybean oil lubricant and investigated the effects of alkyl group on low-temperature properties of biolubricant. Abdullah and Salimon [7] studied the efficiency of epoxidation under various catalysts. The catalyst sulfuric acid was found to be more effective for the conversion to oxirane. Hashem, Abou Elmagd, Salem, El-Kasby, and El- Nahas [8] 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, Abou Elmagd, Salem, El-Kasaby and El-Nahas [9] and Heikal, Elmelawy, Khalil, Elbasuny [10] 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 [11] add 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, Peethambaran and Mahipal [12] prepared the various vegetable oil blends by adding Benzoic acid into Pongamia oil in its different weight percentage and found good antiwear and antifriction properties from these blends. Cheenkachorn [13] 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 wear scar diameters of conventional soybean, epoxidized soybean oil and high-oleic soybean oil were found to affected by ZDDP additive. Jayadas, Nair and Ajithkumar [14] used ZDDP additive into coconut oil to improve its tribological

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properties and they determined the optimum additive concentration using four-ball wear tester. Addition of 2 wt% of ZDDP additive into coconut oil was found to significantly improve the anti-wear and extreme pressure properties of coconut oil. Mahipal, Krishnanunni, Mohammed Rafeekh, and Jayadas [15] added ZDDP additive to pongamia oil and conducted wear test on four-ball wear tester. The 2 wt% ZDDP additive added pongamia oil was shown to have lower values of wear scar diameter and coefficient of friction as compared to mineral oil SAE20W30.

Generally, most of the experimental works published in the available literature on the analysis of synthesized vegetable oils biolubricants are limited to predicts their physical and tribological characteristic. However, few published works on application of biolubricants for the realistic bearing lubrication are also available in the available literature. Among these works, Durak and Karaosmanoglu [16] studied the effect of cottonseed oil as an additive in mineral oil SAE20W30 on coefficient of friction in a journal bearing test rig. Cottonseed additive was shown to minimize the coefficient of friction at low journal speed and small loads. Baskar and Sriram [17] compared the circumferential pressure profiles of journal bearing under rapeseed and soybean oils with that of SAE20W40 oil. Among these biolubricants, rapeseed oil was found to have comparable pressure profile with SAE20W30. Baskar, Sriram and Arumugam [18] further studied the usage of chemically modified rapeseed oil with CuO, WS_2 and TiO_2 nano additives in journal bearing. Variations in wear, coefficient of friction and oil-film thickness for different lubricant samples were determined using journal bearing test rig. Katpatal, Andhare, and Padole [19] studied the circumferential pressure distributions and frictional behavior in journal bearing for three blends of jatropha oil with ISOVG46 oil in different volume ratios and Del Din, and Kassfeldt [20] studied rapeseed oil-based semi synthetic oil in mixed lubrication regime on a full-scale journal bearing test rig. The semi synthetic oil was found to have lower wear rates and frictional torque than the mineral oil irrespective of the contamination conditions. McCarthy, Glavatskih, and Byheden [21] determined the temperature, power loss and minimum film thickness of journal bearing test rig lubricated with three environmentally accepted lubricants such as propylene glycol dioleate, VG32 saturated ester and rapeseed oil against ISOVG32, ISOVG46 and ISOVG68 mineral oil. Environmentally accepted lubricants were found to function satisfactorily as compared to mineral oils tested. Zulhanafi, Syahrullail, and Ahmad [22] studied the performance of palm mid olein bio-based lubricant in journal bearing application. Palm mid olein oil was found to provide higher maximum pressure and better thermal resistivity compared to SAE40 oil and it also found to provide lower coefficient of friction in all testing conditions. Dhanola, and Garg [23] considered the nanoparticles added canola oil and investigated the performance characteristics of journal bearing. Addition of nanoparticles to canola oil was found to be favorable. The available literature indicates that the experimental works on use of ZDDP additive added epoxidized pongamia biolubricant for the lubrication of journal bearing are not yet exists.

Therefore, the present work is planned to predict the circumferential pressure distribution of a journal bearing lubricated with ZDDP additive added and epoxidized pongamia oil biolubricant samples. The biolubricant samples are prepared by adding ZDDP additive in 1, 2 and 3 weight percentage (wt%) to epoxidized pongamia biolubricant. The variation of circumferential pressure under these lubricant samples are predicted using journal bearing test rig and the results are compared with the corresponding results of synthetic oil samples SAE5W30 and SAE10W30.

II. EXPERIMENTAL METHODS

A. Epoxidation and Oxirane Ring Opening Processes

First, epoxidized pongamia biolubricant is obtained by the epoxidation of crude pongamia oil. 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 60ºC 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 80º 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.

B. Sample Preparation

Biolubricant samples are prepared by blending ZDDP additive into epoxidized pongamia oil at 1 wt%, 2 wt% and 3 wt%. This blending is done using hotplate magnetic stirrer as shown in Fig. 2.

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C. Journal Bearing Test Rig

Photographic view of journal bearing test rig is shown in Fig. 3 and its schematic diagram is shown in Fig. 4. The shaft (journal) has a diameter of 15 mm and is made of EN8 steel. One end of shaft is supported by two ball bearings and the other end is mounted inside the bearing bush. The bearing bush is made of gunmetal and has a bore diameter of 16 mm. The bearing length is 90 mm and radial clearance is 0.5 mm. The bearing assembly is mounted inside an aluminium casing. The bearing assembly with aluminium casing weighs 1.5 kg and this weight is taken as steady load on bearing. Twelve pressure taps are drilled on bearing bush along the circumference at 30 deg. interval and at axial mid-plane of bearing bush as shown in Fig. 4. There are four more pressure taps along the axis of the bearing bush at an interval of 17 mm. Plastic hoses are connected to the pressure taps and are fixed on a vertical wooden support. An oil container with a capacity of 3L is mounted at approximately mid height of the pressure column and a hose is connected to the low-pressure region of the bearing to supply the lubricant into bearing clearance.

During the experiment, the rise in the lubricant level in monometers (i. e. plastic hoses) connected for circumferential pressure taps is measured by the scales provided near the plastic hoses. These readings provide the circumferential pressure distribution. The tests for all biolubricant and synthetic mineral oil samples are conducted at room temperature of 27^{o} C and a bearing load of 1.5 kg and three different speeds of 100, 125 and 150 rpm.

III. RESULTS AND DISCUSSION

The circumferential pressure distributions in terms of the height of lubricating oil are obtained under lubrication of journal bearing with different biolubricant and synthetic mineral oil samples. The results obtained for biolubricant samples are compared with the results obtained for synthetic oils SAE5W30 and SAE10W30.

Fig. 2- Magnetic stirrer for additive blending

Fig. 3- Journal bearing test rig

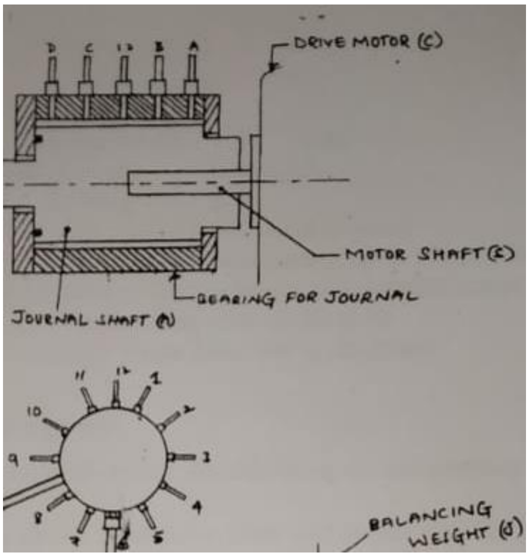
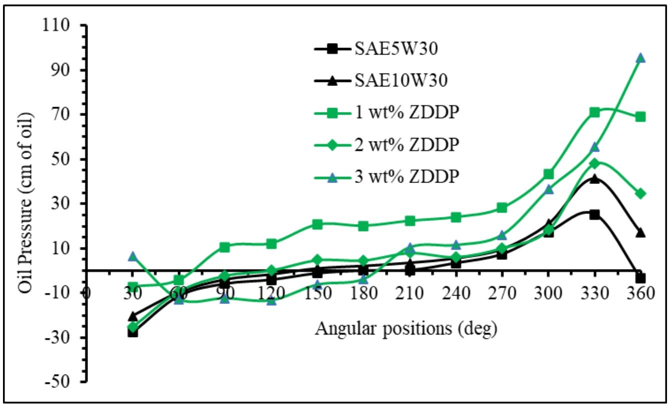
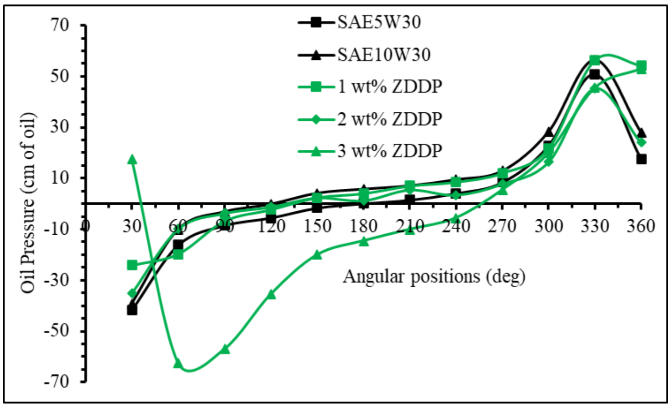


Fig. 4- Schematic diagram of journal bearing test rig.

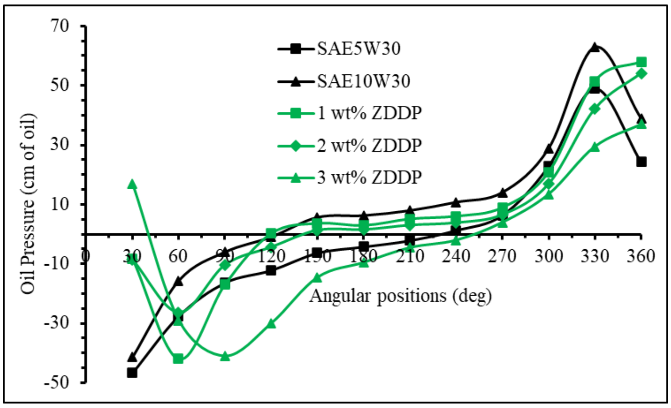
Figure 5 illustrates the circumferential pressure distributions of journal bearing at its axial mid-plane under its lubrication with different biolubricant and synthetic mineral oil samples at different operating speed of journal under constant load of 1.5 kg. At lower journal speed of 100 rpm, all ZDDP additive added epoxidized pongamia biolubricant samples provide enhanced positive fluid-film circumferential pressure distributions as well as maximum pressures than those of synthetic oils SAE5W30 and SAE10W30 as shown in Fig. 5(a). Extent of negative pressure zone is less than synthetic oils for 1 wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants. Though the 3 wt% ZDDP added biolubricant provides higher maximum fluid-film pressure than those of 1 wt% and 2 wt% additive added biolubricants and synthetic oils, the extent of negative pressure zone for this biolubricant is observed to be more. At journal speed of 125 rpm, the 1 wt% and 2 wt% additive added epoxidized pongamia biolubricants provides almost same circumferential profile as those of synthetic oils as shown in Fig. 5(b). However, the extent of negative pressure zone is observed to be more for 3 wt% additive added biolubricant.



(a) At 100 rpm



(b) At 125 rpm



(c) At 150 rpm

Fig. 5- circumferential pressure distributions of journal bearing under different lubricants.

At journal speed of 150 rpm (Fig. 5(c)), the circumferential fluid-film pressure distributions for 1 wt% and 2 wt% additive added epoxidized pongamia biolubricants are observed to be better than the synthetic oil SAE5W30 and are less than SAE10W30 oil. The maximum fluid-film pressures for these biolubricants are more than SAE5W30 and less than SAE10W30. For lower journal speeds 100 rpm and 125 rpm, the 1 wt% ZDDP additive added epoxidized pongamia lubricant provides better circumferential fluid-film pressure as compared to synthetic oils SAE5W30 and SAE10W30. As the speed of journal increases to 150 rpm, the same 1 wt% ZDDP additive added epoxidized pongamia lubricant provides better circumferential fluid-film pressure than SAE5W30. It fails to provide better circumferential fluid-film pressure than SAE10W30.

IV. CONCLUSION

For low-speed application of journal bearing, the circumferential fluid-film pressure distributions for 1 wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants are found to be almost same as those of synthetic oils SAE5W30 and SAE10W30. Thus, the application of synthetic oils SAE5W30 and SAE10W30 in journal bearing lubrication can be replaced by 1 wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants when the bearing operates at lower speeds. At higher speeds of journal bearing, the 1 wt% and 2 wt% ZDDP additive added epoxidized pongamia biolubricants can be used as alternative to only SAE5W30 oil.

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