Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 12 (24): 2503-2510, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.2503.2510

Four-Ball Study of Tricresyl Phosphate Effect to Jatropha Oil for Transmission Oil Application

[1]Abdul Munir Hidayat Syah Lubis, [3]Mustafar Sudin and [2]Bambang Ariwahjoedi
[1]Department of Mechanical Engineering,
[2]Department of Fundamental and Applied Science,
University Teknologi PETRONAS, Bandar Seri Iskandar,
31750 Tronoh, Perak, Malaysia
[3]Department of Engineering, Nilai University College No. 1, Persiaran Universiti,
Putra Nilai, 71800, Nilai, Negeri Sembilan, Malaysia

Abstract: Jatropha oil has been known as alternative substitute for diesel fuel but its potential use as lubricant is not much known yet. This work is meant to investigate the effect of Tricresyl Phosphate (TCP) to jatropha oil which subjected to be used for transmission oil. Crude jatropha oil was used as base oil and 0.5-5% v/v. of TCP were added to crude jatropha oil. Commercial SAE 80W/90 grade transmission oil was used as comparison. Ostwald-Fenske capillary viscometer was used to characterize viscosity of jatropha oil and TCP mixture. Four-ball method was used to characterize friction and wear of the oil samples. No significant changes were found on viscosity by addition of TCP. Anti wear characteristics of crude jatropha was greatly improved by addition of TCP. No significant effect to friction coefficient also found at 40 kgf load, but addition of sufficient amount of TCP was able to reduce friction at 80 kgf load.

Key words: Jatropha, four-ball, friction, wear, tricresyl phosphate

INTRODUCTION

Gear system is most recognized transmission system used in a mechanical system. It transfers power from one shaft to another while maintaining an exact ratio between the velocities of the shaft rotation.

Plant oils and animal fats already used as lubricant since a long time ago. During the industrial revolution many more demands were placed on gearing to transmit power reliability and to provide longer service life (Lauer, 2006). Along with current environmental awareness, a growing interest in development of biodegradable and non-toxic lubricants has been grown. However, lubricant performance, such as friction, wear, lifetime, load bearing, efficiency, etc. has a major impact on its overall environmental compatibility (Martins *et al*., 2006). Basic functions of gear lubricant are to reduce friction between gear teeth under contact, which reduces tooth wear and prolong life. Another critical function is to dissipate heat generated in contact zone, prevent corrosion, and reduce noise and vibration (Bala, 2003). Several studies of plant oils usage as lubricant showed benefit due to its renewable source, biodegradability and environmental safety compared to mineral oil. But due to its poor oxidative stability, low temperature behavior and other tribochemical degrading process makes their applications are limited (Gawrilow, 2003; Rudnick and Erhan, 2006). However, these weaknesses are be able to handled by using additives (Stunkel and Aguilar, 2008) or modifying the fatty acid chemical structure of the oil (Erhan *et al*., 2006; Gawrilow, 2003; Sharma *et al*., 2006).

Jatropha C. is a typical tropical and subtropical plant, which grown as non-cultivated and non-edible wild species. Jatropha oil (JO) has been known as alternative resource for biodiesel fuel. However, its function as lubricant oil is not much known yet. concluded that crude jatropha oil has comparable anti wear performance compared to mineral based engine oil and addition of small amount of this oil to mineral based engine oil also improve anti wear property (Lubis *et al*., 2011a). Other study by concluded that esterified jatropha oil ester showing good load carrying capacity when used as additive (Lubis *et al*., 2011b, c).

Commercially available gear lubricant usually contained of many different components, each of which having its own requirements for lubrication. Besides fulfilling basic lubricant requirement like viscosity grade, the lubricant must also capable to withstand extreme

Corresponding Author: Abdul Munir Hidayat Syah Lubis, Department of Mechanical Engineering, University Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

pressure since the gear teeth operate under extreme pressures. Generally, a gear oil consist 50-95% base oil, 0-35% viscosity index improvers, 0-2% pour point improvers, and 5-12% performance additive, e.g., anti wear, anti scoring and extreme pressure additives (Bartz, 1993). In order to reduce wear, anti wear additives usually included in the lubricants formulation. One such common anti wear additive is Tricresyl Phosphate (TCP). This study is meant to investigate effect of Tricresyl Phosphate (TCP) addition to viscosity, friction and anti wear property of jatropha oil for transmission oil application.

MATERIALS AND METHODS

Oil sample: Fatty acids contained in natural plants oil are known to have good lubricity properties. It is assumed that by addition of anti wear additive to the oil could increase its load carrying capacity. Crude Jatropha Oil (CJO) was obtained from Bionas Sdn. Bhd., Malaysia and used as base oil. Tricresyl Phosphate (TCP), mixture of isomers, 90%, purchased from Aldrich Chemicals, Malaysia and used as anti wear additive to increase load carrying capacity of the oil. Schematic structure of the TCP is shown in Fig. 1.

Oil samples formulated in this work were prepared from mixtures of CJO and TCP with the ratio of 0.5, 1, 2 and 5% v/v. The oil samples were prepared by mixing the crude jatropha oil with TCP at 40°C for 1 h. Commercial SAE 80W/90 (COM) grade transmission oil was used as comparison for this study.

Viscosity: Viscosity of oil samples were determined using Ostwald-Fenske capillary viscometer according to ASTM D445 method at 40 and 100°C, respectively.

Friction and wear characterization: Four-ball method has widely used to characterize friction and wear preventive characteristic of transmission oil. DUCOM Multi-specimen Tester TR-701 with four ball test configuration was used to characterize the formulated oil sample. The equipment is equipped with load cell to measure torque produced during the testing and thus used to determine the friction coefficient. Schematic illustration of the test configuration is shown in Fig. 2. Four AISI E-52100 steel balls (1/2 inch dia., 62 HRC) were used as solid sample. All ball samples were clean up sonically with n-heptane and sprayed with acetone before and after the testing.

Three stationary steel balls were clamped together and immersed with the lubricant sample. At the top of these clamped balls, the fourth ball is pressed with 40 kgf and 80 kgf of load. The temperature of the test lubricant was regulated at 75±3°C. The top ball was then rotated at 1200 rpm for 60 min. Wear preventive characteristic of oil sample was determined from average wear scar diameter of the stationary ball.

Surface characterization: Characterization and chemical state determination of the observed surface were carried out on Zeiss Supra 55-VP Field Emission Scanning Electron Microscope (FESEM) equipped with energy dispersive X-ray (EDX) analyzer.

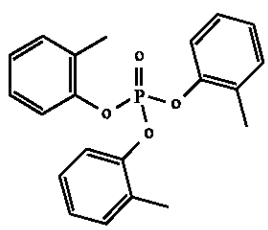

Fig. 1: Chemical structure of tricresyl phosphate

RESULTS

Viscosity: Effect of TCP to viscosity of the jatropha oil is shown in Table 1. The addition of TCP only has small effect to the viscosity and oil samples can be classified into SAE 80 class based on SAE J306 classification.

Table 1: Effect of TCP to viscosity of Jatropha oil

	Viscosity (cSt)	
Oil sample	40°C	100°C
COM	147.12	17.3
CJO	32.87	8.21
0.5% TCP-CJO	32.90	8.21
1% TCP-CJO	33.67	8.23
2% TCP-CJO	34.20	8.25
5% TCP-CJO	35.23	8.31

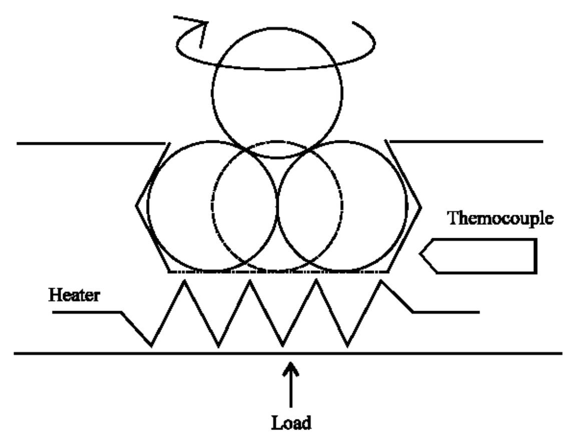

Fig. 2: Four-ball testing configuration

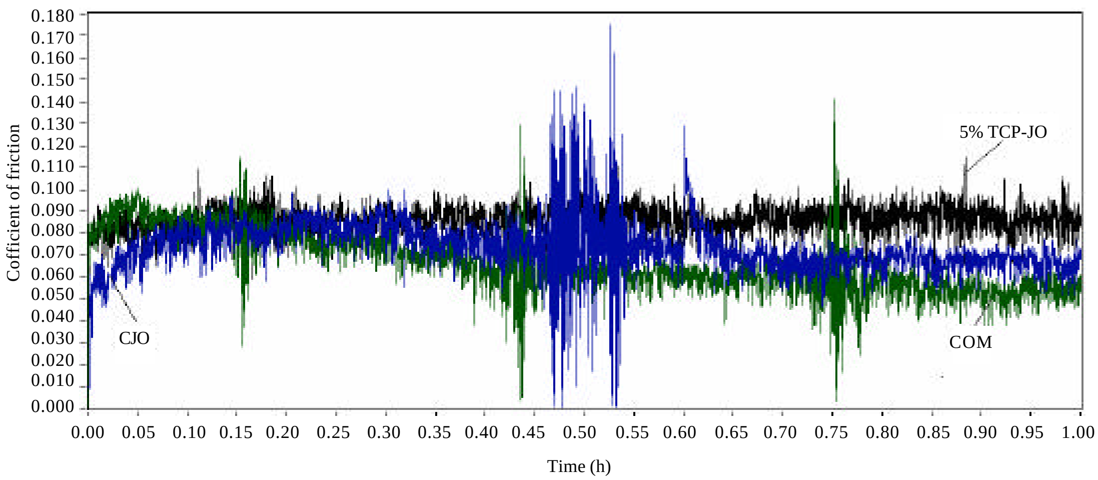

Fig. 3: Typical frictional characteristics of oil samples at 40 kgf of load

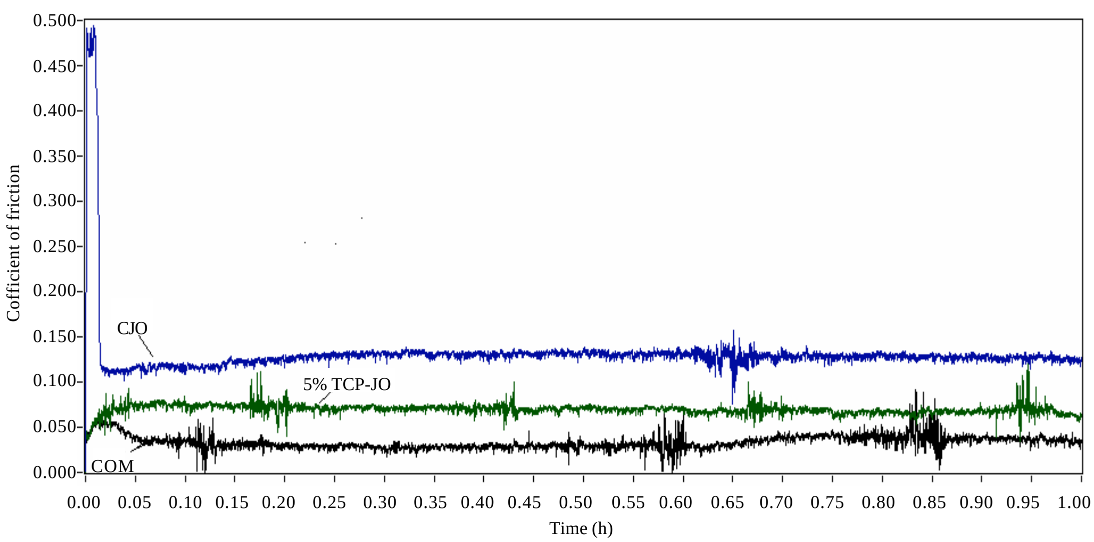

Fig. 4: Typical frictional characteristics of oil samples at 80 kgf of load

Friction and wear characteristics: Effect of TCP addition to friction coefficient is shown in Fig. 3 and 4. The COM sample was showing the lowest dynamic friction coefficient compared to CJO sample. There was no significant effect of TCP addition to friction coefficient of the CJO at 40 kgf of load. But at 80 kgf of load, the additive significantly reduces static friction at the beginning of the friction as well as maintains steady the dynamic friction coefficient. Increasing the load also significantly increases the friction coefficient.

Effect of TCP addition to anti wear characteristics of the CJO is shown in Fig. 5. Higher amount of TCP addition gives significant effect to wear preventive characteristics of jatropha oil at load of 40 kgf. However, significant effect of TCP addition only found at 2-5% v/v addition at the higher load. The result also shows a comparable wear preventive property result to the COM sample at the higher loads.

Surface characteristics: Micrographs of the bearing samples lubricated with crude jatropha oil at 40 kgf and 80 kgf are shown in Fig. 6 and 7, respectively. Scratch marks were obviously found on both of the wear surfaces. It also can be seen adhesive wear mechanism symptom (scuffing) were increased on the bearing surface with the higher load (Fig. 7). Addition of TCP to CJO significantly reduces this scratch mark. The shape of wear scar also changes, from a circle to elliptical like feature (Fig. 8) and

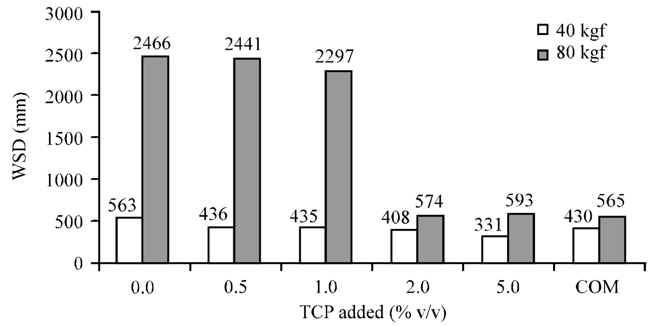

Fig. 5: Effect of TCP to wear preventive characteristics of jatropha oil compared to COM sample

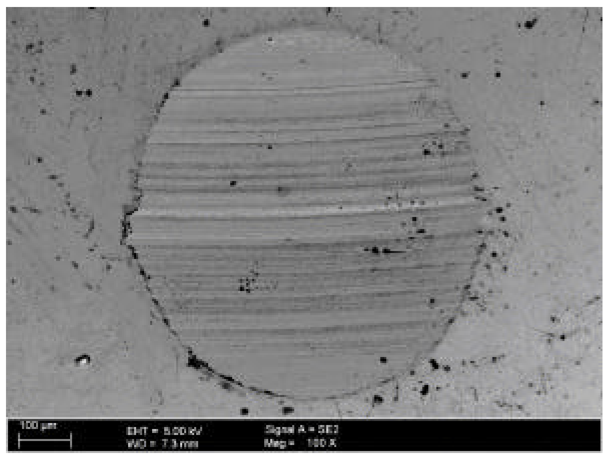

Fig. 6: Wear surface micrograph at the load of 40 kgf in the presence of CJO

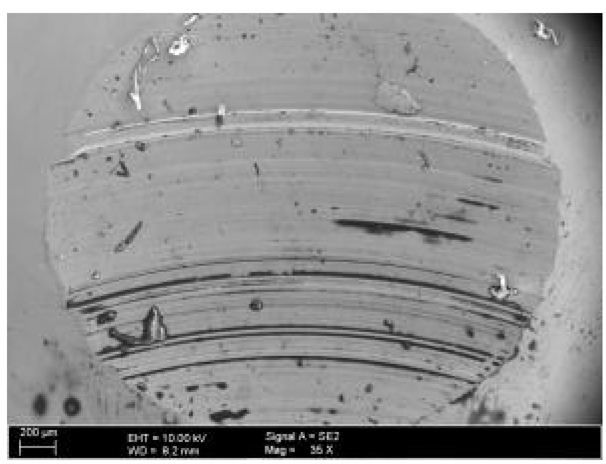

Fig. 7: Wear surface micrograph at the load of 80 kgf in the presence of CJO

at the higher load, scuffing effect is significantly reduced by addition of tricresyl phosphate (Fig. 9).

EDX analysis of the wear surface in the presence of CJO and 5%TCP at marked area are shown in Fig. 10-13. Elements of potassium and phosphorous were only found on the surface lubricated with 5%TCP-JO at high load. Although the layer not detected at wear surface of bearing loaded with 40 kgf of load, but the authors believe that similar layer also exist on the surface but too thin to be able to be detected by EDX method.

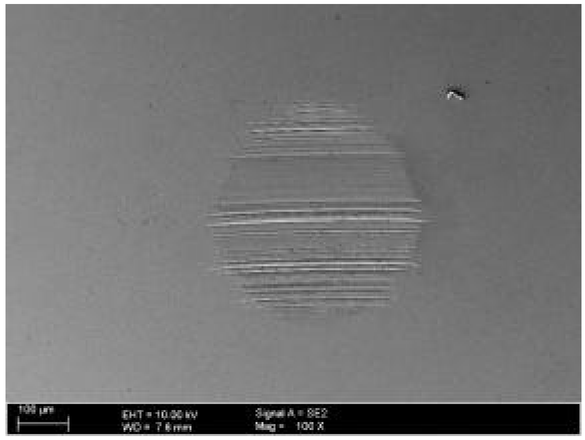

Fig. 8: Wear surface micrograph at the load of 40 kgf in the presence of 5% TCP-CJO

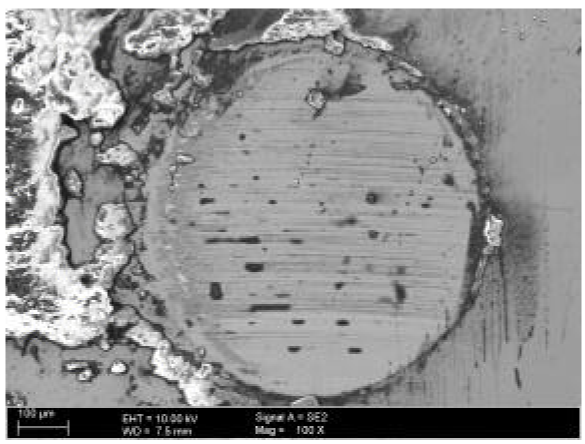

Fig. 9: Wear surface micrograph at the load of 80 kgf in the presence of 5% TCP-CJO

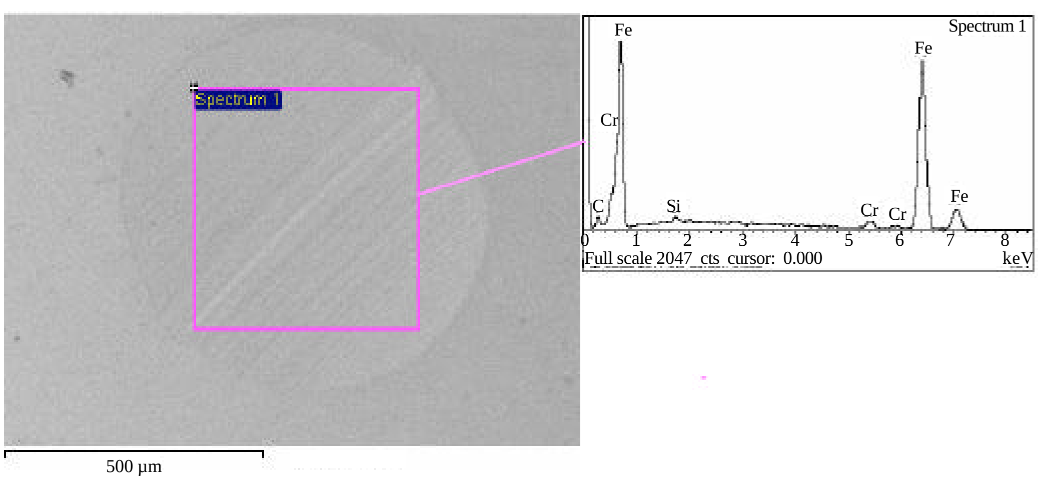

Fig. 10: Surface micrograph and associated EDX spectra at the load of 40 kgf in the presence of CJO only

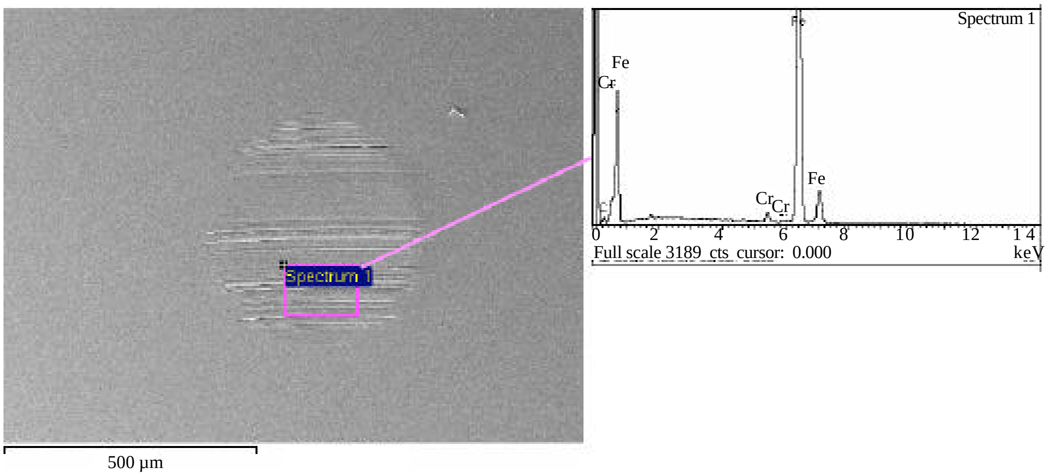

Fig. 11: Surface micrograph and associated EDX spectra at the load of 40 kgf in the presence of 5% TCP-JO

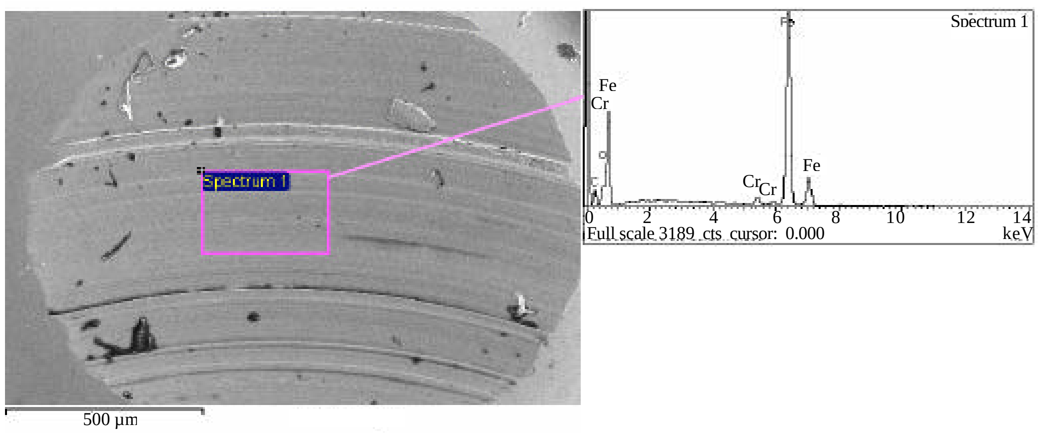

Fig. 12: EDX spectra of 5% TCP-JO loaded with 80 kgf load

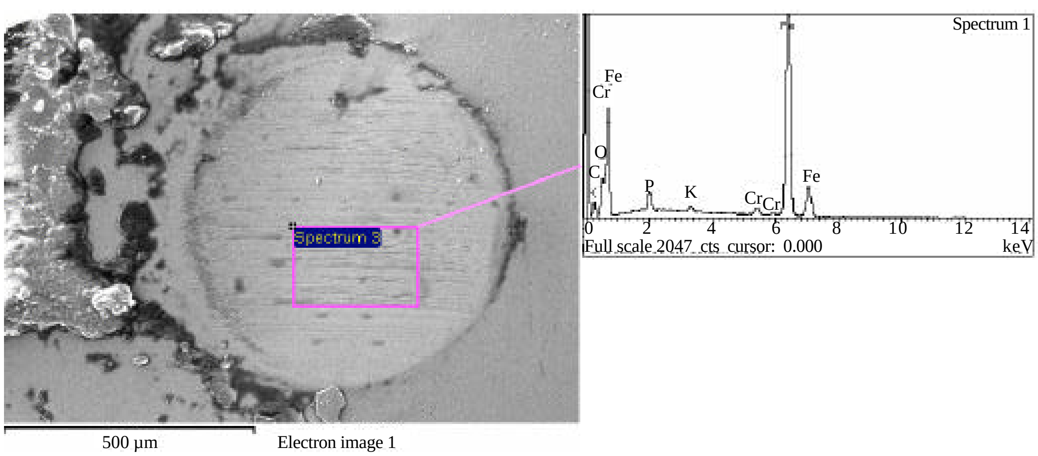

Fig. 13: Surface micrograph and associated EDX spectra at the load of 80 kgf in the presence of 5% TCP-JO elastohydrodynamic to boundary lubrication regime, anti wear additive like TCP will work effectively

DISCUSSION

TCP is non viscous ashless antiwear additives used in lubricant formulation. Therefore, it would not affect viscosity of the base oil. However, the viscosity of jatropha oil, as base oil, could be increased by addition of proper viscosity index improver. In lubrication theory, viscosity has significant effect if machine components operate in hydrodynamic lubrication regime. In this regime, the surfaces are fully separated by lubricant oil thus the surfaces are not in direct contact. But when the lubrication regime changes to elastohydrodynamic to boundary lubrication regime, anti wear additive like TCP will work effectively.

Highly loaded machine component such as gears mostly operates in elastohydrodynamic to boundary lubrication regimes. From friction characteristics graph of the oil samples, it can be concluded that the oil operates in elastohydrodynamic regime where the friction coefficients are still <0.1. When load increased to 80 kgf, high static friction coefficient of steel lubricated with crude jatropha might caused by oil film was insufficiently formed at beginning of sliding resulting in high plastic deformation of contact asperities. The dynamic friction also still high at the rest of sliding and the sliding was in boundary lubrication regime (>0.1). Although most seed oil has good boundary lubrication properties, addition of anti wear additives is surely able to enhance its lubrication properties. Addition of TCP significantly provided sufficient protection layer to separate the surfaces at beginning of sliding and also reduced friction to the rest of sliding.

In boundary lubrication tendency of wear to occur is high. Adhesive, abrasive, surface fatigue, and chemical wear are common wear mechanism occurred in lubricated gear surfaces (Bartz, 1993). SEM micrograph of steel lubricated with crude jatropha oil reveals that adhesion and abrasion significantly taken place during sliding although this oil has good boundary lubricant. The scuffing even dominantly occurred when the load was increased. When the anti wear additive was added to jatropha oil, effect of adhesion and abrasion significantly reduced. This indicates that addition of TCP increases the formation of protective layer on the wear surface. The EDX spectra result shows occurrence of a typical phosphorous oxide layer. This layer is typically an iron salt layer (Pawlak, 2003), which is believed due to phosphorous compound reaction with iron oxide during the sliding to form iron phosphate. Similar phosphorous layer also found by Ghose *et al.* (1987), which used auger emission spectroscopy (AES) for their study.

Friction and wear resistance mechanism of this additive might result from complex chemical transformation on the metal surface. According to antiwear additives function, it can form multilayer film which thick enough to supplement marginal hydrodynamic films and prevent asperity contact altogether (Randles, 2006). This can be seen from bearing lubricated with 5%TCP-JO sample friction characteristics. The anti wear additive also able to develop easily replenishable monolayer films that reduce the local shear stress between contacting asperities and are preferentially removed in place of surface material. Others bond chemically with the surface and slowly modify surface asperity geometry by controlled surface material removal until conditions conducive to hydrodynamic film generation reappear (Randles, 2006). This factor is possibly the main reason why the phosphor element was only detected on bearing lubricated with 5%TCP-JO sample loaded with 80 kgf wear surface.

CONCLUSION

Crude jatropha oil has the capability to be used as alternative base stock and TCP is compatible with it and can be used as anti wear additive to enhance tribological properties of the crude jatropha oil.

Addition of TCP has significantly improved wear preventive properties of crude jatropha oil. The improvement in the wear prevention is due to the formation of iron phosphate tribofilm on the steel surface. Additions of TCP also improve friction and lubrication properties of jatropha oil at higher load which also by typical phosphate tribofilm during sliding.

ACKNOWLEDGMENT

The authors would like to thank Universiti Teknologi PETRONAS for funding this research under grant URIF No. 23/2011.

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