# Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 11 (10): 1797-1802, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.1797.1802

# Investigation of Worn Surface Characteristics of Steel Influenced by Jatropha Oil as Lubricant and Eco-friendly Lubricant Substituent

[1]A.M.H.S. Lubis, [2]M.B. Sudin and [3]B. Ariwahjoedi
[1,2] Department of Mechanical Engineering
[3]Department of Fundamental and Applied Sciences,
University Teknologi PETRONAS, Malaysia

**Abstract:** Jatropha oil has been known as alternative substitute for diesel fuel but its function as lubricant is not much known yet. In this work, wear preventive characteristic of jatropha oil has been investigated in order to find its potential as alternative lubricant base stock and lubricant substituent. Four ball wear test method was employed for this occasion. The results show that crude jatropha oil has comparable wear preventive capability to mineral oil. When treated as lubricant substituent, blending of 25% jatropha oil to mineral oil was able to reduce 33% wear of the mineral oil. However, wear was increased with 50 and 75% addition of jatropha oil. Wear coefficient was found in the range of $6.05\times10^{-11}$-$8.60\times10^{-10}$. Scanning electron microscopy analysis showed adhesive, abrasive and fatigue wear mechanisms were taken place during the sliding. EDX analysis shows steel ball lubricated with higher mineral oil content forms strong organo-iron compound layer and steel lubricated with higher jatropha oil content forms a typical metallic iron carbon layer. Based on these results we conclude that jatropha oil has great potential to be used as lubricant base stock or as lubricant substituent.

**Key words:** Friction, wear, lubricant, lubrication

## INTRODUCTION

Mechanical components friction and wear are still major concern in most industry. Improving friction and wear of mechanical components could lead to a longer life as well as better fuel economy and efficiency. Lowering friction and wear could save cost almost 15% GDP of several countries (Budinski and Budinski, 2002). Lubricant base stocks are mainly derived from mineral or petrochemical oils. Variety of lubricating fluids has developed to meet demands of new machines which having more tough requirements due to their operation under more severe condition or in challenging environments (Rudnick and Erhan, 2006). However, the reduction of petroleum reserves and environmental issues has encouraged efforts to find alternative source.

Biobased material, e.g. animal fats and vegetable oil, has already used as lubricant since long ago (Gawrilow, 2003). Global industrial communities have taken a keen interest in the use of bio-based fluids and have begun to explore potential areas to substitute mineral oil with these fluids. Recent study showed the benefit of using this oil due to its renewable source, biodegradability and environmentally safe compare to mineral oil (Adhvayu *et al*., 2004; Hwang *et al*., 2003; Erhan *et al*., 2006; Sharma *et al*., 2006; Weller, 2000; Lea, 2002; Stefanescu *et al*., 2002).

The main content of vegetable oils is triglycerides. Triglycerides are glycerol molecules with three long chain fatty acids attached at the hydroxy groups via ester linkages. The long fatty acid chain and presence of polar groups in vegetable oil structure makes it possible to be used as both boundary and hydrodynamic lubricants (Lea, 2002; Stefanescu *et al*., 2002; Biresaw *et al*., 2002). These oils also found capable to be used as lubricant additive. A study by Masjuki and Maleque (1997) has found that 5% addition of Palm Oil Methyl Ester (POME) to engine oil has significant effect to wear reduction (Masjuki and Maleque, 1997). On other study, they found micro cracking, pitting, and polishing wear mechanisms taken place under 5% addition of POME to mineral oil (Maleque and Masjuki, 2002).

Thin protective layer formed during sliding of material in dry or lubricated sliding system is often mentioned in literatures as a typical substrate that provides wear prevention of material. In steel lubricated sliding system, this film is dependent on lubricant chemistry, material composition, original surface roughness and load/speed sequence (Cavdar and Ludema, 1991). Cavdar and ludema identified the constituent of this layer as: (i) iron carbon and iron metallic iron mixture, (ii) a weak organo-iron compound and (iii) a strong organoiron compound (Cavdar and Ludema, 1991). However, Stachowiak and Bachelor (2001)

---

**Corresponding Author:** A.M.H. Lubis, Department of Mechanical Engineering, University Teknologi PETRONAS, Malaysia

Table 1: Fatty acid contents of jatropha oil (Akbar *et al.*, 2008)

| Fatty acid | Composition (%) |
|---|---|
| Oleic acid | 44.7 |
| Linolienic acid | 32.8 |
| Palmitic acid | 14.2 |
| Syearic acid | 7.0 |
| Palmitoleic | 0.7 |
| Other acids | 0.6 |

implied this layer as soap layer, product of metal hydroxide with fatty acid reaction, and amorphous layer.

Jatropha oil has been known as alternative resource for bio-diesel fuel (Achten *et al.*, 2008; Henning, 2000). However, its function as lubricant oil is not much known yet. Akbar *et al.* (2008) stated that this oil has potential as non-edible vegetable oil feedstock due to its high oil content (61–64%). Content of fatty acid in jatropha seed is shown in Table 1. Gunam Resul *et al.* (2008) concluded that after transestrification of jatropha oil with Trimethylol Propane (TMP), the product behaves as an excellent lubricant. They found that viscosity index and thermal-oxidative stability improved by this method.

This work is intended to investigate wear preventive characteristics of jatropha oil as potential alternative lubricant base stock and lubricant substituent.

## MATERIALS AND METHODS

Ducom Multi Specimen wears tester TR701 was employed to investigate anti wear properties of the lube oils. Wear preventive characteristic test was conducted by four ball method according to ASTM D-4172. SAE 40 grade mineral based engine oil (MO) with viscosity index 96 and Jatropha Oil (JO) with viscosity index 109.2 were used as lubricant. The jatropha oil was obtained from Bionas Sdn. Bhd. Three different percentages of jatropha oil, 25, 50 and 75%, were blended with mineral oil to investigate effect of jatropha oil as lubricant substituent. Four AISI E-52100 steel balls (1/2 inch dia., 64 HRC) were used as solid sample. All ball samples were clean up using n-heptane and acetone before and after the tribological testing performed.

Three steel balls were clamped together and immerses with the lubricant sample. At the top of these clamped balls, the fourth ball is pressed with a 40 kg weight. The temperature of the test lubricant was set at 75°C. The top ball rotated at 1200 rpm for 60 min. The testing configuration is shown in Fig. 1.

Anti wear characteristic of the lubricants were obtained from (i) average Wear Scar Diameters (WSD) on the three lower clamped balls, (ii) wear coefficient and (iii) wear surfaces analysis. Wear scar diameter was measured by measuring optical microscope supplied with the equipment.

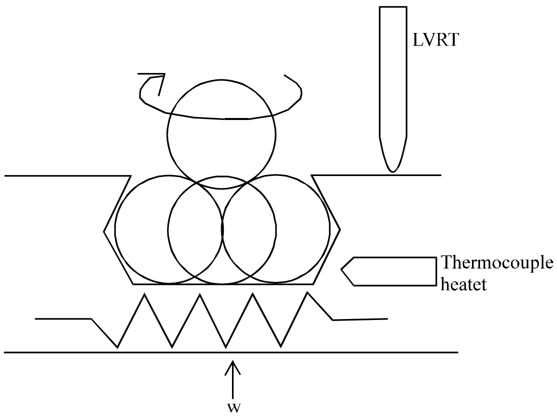

Fig. 1: Four ball testing configuration

Wear coefficient of the ball is calculated by an approach proposed by Rowe to calculate wear coefficient for four ball testing apparatus (Rowe, 1980):

$$K \frac{VH}{2.33(v)(t)(0.408W)} \quad (1)$$

$$V = (15.5\times10^{-6}D^3 - 1.03\times10^{-8}W)\,D \quad (2)$$

where, D wear scar diameter (mm); d, sliding distance (m); H, hardness of steel ball taken as 725 kg mm$^{-2}$; K is wear coefficient; testing time (min); V is wear volume (cm$^3$), v, rotational speed (rpm); and W is load (kg).

Surface wear feature and composition of the bearing balls were observed by Carl-Zeiss SUPRA55VP Field Emission Scanning Electron Microscopy (FESEM) and Inca-Oxford Energy-dispersive X-ray (EDX).

## RESULTS

Wear scar diameter of the sample is shown in Fig. 2. Wear preventive property of 100% JO was found as good as 100% MO. Interesting result was found when jatropha oil was treated as lubricant substituent. Addition of 25% jatropha oil to mineral oil was able to reduce 33% wear of the mineral oil. However, when the percentage of jatropha oil increased to be 50 and 75%, the wear was increased 15.7 and 10.5% respectively. Wear coefficient of the tribo-system is shown in Fig. 3. Similar to its WSD, wear coefficient of 75%MO-25%JO oil blend has the lowest value and the highest was 50%MO-50% JO oil blend.

Wear micrographs are shown in Fig. 4 and 5. In Fig. 4, darker and rougher surface was observed when the bearing lubricated with bearing lubricated with MO and blend of 25%JO-75%MO. However, Smoother and shiny look surfaces were observed when JO used as lubricant as

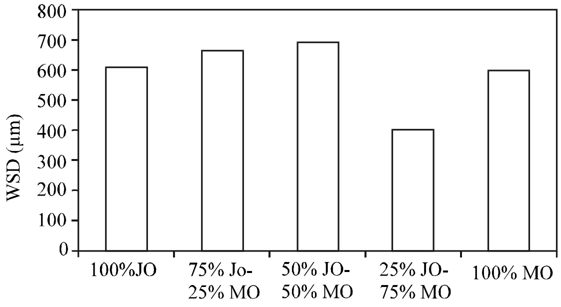

Fig. 2: Wear scare diameter of ball bearings

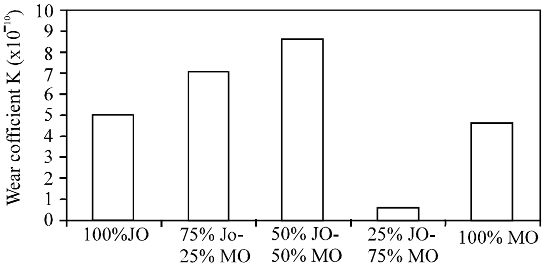

Fig. 3: Wear coefficient of the sample

well as when higher content of JO added to MO. In Fig. 5, general wear mechanism of the bearing samples were shown. Adhesive and abrasive wear mechanisms were found to be main wear mechanisms. Both of their symptoms were revealed on bearing worn surfaces lubricated with all lubricant samples. The occurrence of adhesive wear can be identified from typical smeared layer on the wear surfaces. Both of mild and severe wear symptoms were found (Fig. 5a and b). Appearance of abrasive wear can be identified from typical micro cutting trail on the surface (Fig. 5c). This mechanism typically caused by hard wear particles which abraded the surface during the tribotest (Fig. 5d). A typical fatigue wear symptom also found on the worn surface (Fig. 5e).

## DISCUSSION

Comparable wear property of 100% JO to 100% MO is possibly due to fatty acid composition in JO. JO is contained of high unsaturated hydrocarbon (oleic acid, C18:1) which polar head of the fatty acid is known to have a tendency to be attached to metal surface. Fatty acid polar head consisting in JO is believed react

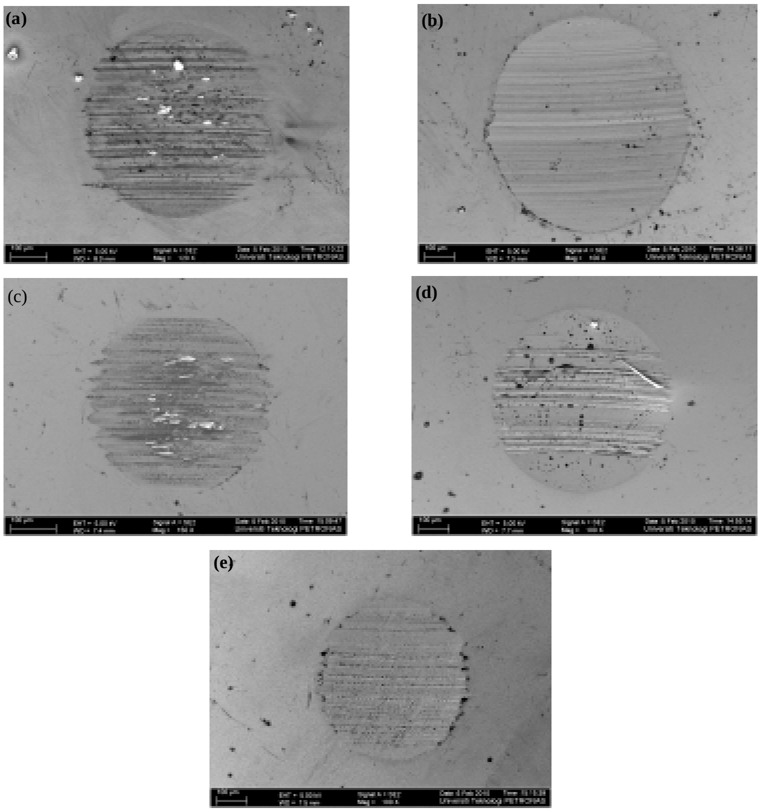

Fig. 4: SEM micrograph of bearing worn surface: (a) 100% MO, (b) 100% JO, (c) Blend of 25% JO-75% MO, (d) Blend of 50% JO-50% MO and (e) Blend of 75% Jo-25% MO

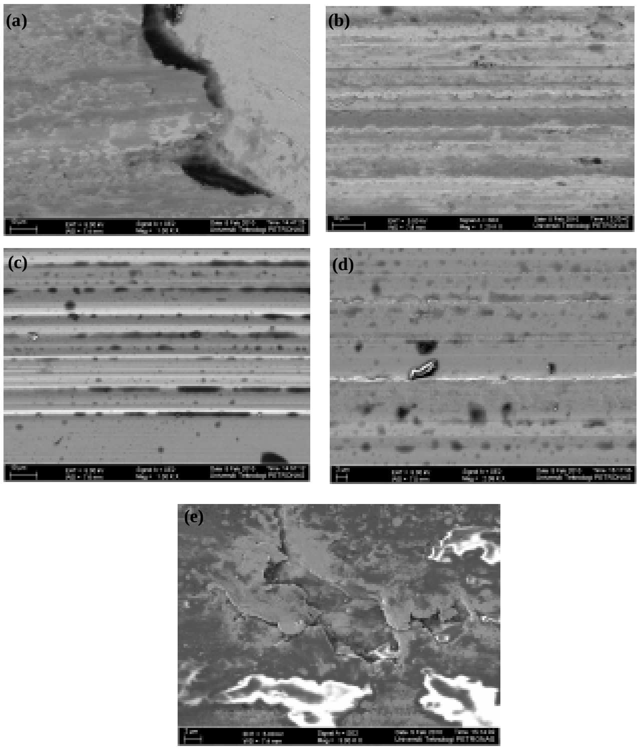

Fig. 5: Wear mechanism features of worn bearing steel sample

Table 2: EDX analysis of ball bearing surfaces

| Initial | | 100% MO | | 75% MO-25% JO | | 50% MO-50% JO | | 25% MO-75% JO | | 100% JO | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | %Wt. | Element | %Wt. | Element | %Wt. | Element | %Wt. | Element | %Wt. | Element | %Wt. |
| C K | 22.59 | C K | 7.88 | C K | 6.21 | C K | 12.41 | C K | 10.59 | C K | 7.81 |
| Cr K | 1.63 | Cr K | 1.29 | Cr K | 1.01 | Cr K | 1.32 | Cr K | 1.32 | Cr K | 2.06 |
| Fe K | 75.78 | Fe K | 78.53 | Fe K | 75.02 | Fe K | 86.27 | Fe K | 88.09 | Fe K | 89.66 |
| | | P K | 1.37 | P K | 1.59 | | | | | Si K | 0.46 |
| | | O K | 5.26 | O K | 10.12 | | | | | | |
| | | Mg K | 1.71 | Mg K | 6.04 | | | | | | |
| | | S K | 1.09 | | | | | | | | |
| | | Zn L | 2.87 | | | | | | | | |
| Total | 100 | | 100 | | 100 | | 100 | | 100 | 100 | |

with steel surface to form soapy layers that provide wear protective mechanism to the metal surface. This factor also considered as a possible explanation for better performance of the 75% MO-25% JO oil blend compared to 100% MO and 100% JO. When the percentage of JO increased to 50%, effectiveness of the wear protection property reduced. Similar occurrence also found with 25% MO-75% JO oil blend.

Wear of bearing material may take place by several mechanisms such as: (i) abrasive, (ii) adhesive, (iii) chemical/corrosive, and (iv) fatigue mechanism. These mechanisms are considered as common mechanisms found in lubricated wear (Godfrey, 1980). The occurrence of adhesive wear symptom indicates that the oil was not fully separate the surfaces and material transfer or micro welding taken place during the sliding. This finding also suggests that the lubricating layer was completely broken down (Masjuki, and Maleque, 1997). Figure 5d shows a sample of hard particle which penetrate and produce micro cutting on the worn surface. In Fig. 5e, a typical surface crack was observed. This crack is believed was generated from cumulative metal adhesion which produce typical surface layer and by repeating sliding contacts, the layer cracked and wear occurs. The darker and rougher wear surfaces on the bearing lubricated with higher MO indicating that the additives contained in MO has attached to the surface. This result also proved by EDX analysis results. However, the smoother and shiny worn surface of bearing lubricated with higher content of JO is assumed as result of polar head attachment to the surface.

Both of this finding suggesting the dissimilarity reaction effect of unsaturated polar head in JO and additives contained in MO to metal surface.

EDX analysis of the worn surfaces is shown in Table 2. Basic element of the steel ball such as Fe, C and Cr were found at all worn surfaces. Si was found at sample lubricated with 100% JO. Other elements such as P, O, Mg, S and Zn were found at sample lubricated with 100% MO and blend of 75% MO-25% JO. However, these elements were not found when the addition of jatropha oil was further increased to 50%. This finding shows that the additives in MO effect had gone at 50% MO-50% JO, which affecting wear prevention properties of mineral oil. It also concluded that steel lubricated with higher mineral oil forms a typical layer consisting of strong organoiron compound, contained of phosphor, sulfur and zinc, while higher jatropha oil form a typical metallic iron carbon layer (Cavdar and Ludema, 1991). Further analysis is still required to study this matter in details.

## CONCLUSION

The utilization of Jatropha oil as lubricant shows comparable wear preventive performance to mineral oil. It also acts as good substituent when 25% of jatropha oil added to mineral oil. We conclude that jatropha oil has potential to be used as both lubricant base stock and substituent.

## ACKNOWLEDGEMENT

The authors would like to thank Universiti Teknologi Petronas for funding this work under STIRF grant No 38/09.10

## REFERENCES

Achten, W.M.J., L. Verchot, Y.J. Franken, E. Mathijs, V.P. Sigh, R. Aerts and B. Muys, 2008. Jatropha bio-diesel production and use: Review. Biomass Bioenergy, 32: 1063-1084.

Adhvayu, A., S.Z. Erhan and J.M. Perez, 2004. Tribological studies of thermally and chemically modified vegetable oils for use as environmentally friendly lubricants. Wear, 257: 359-367.

Akbar, E., Z. Yaakob, S.K. Kamarudin, M. Ismail, J.M. Jahim and J. Salimon, 2008. Characteristics of jatropha seed oil from Malaysia, Indonesia and Thailand. Proceeding of 15th Regional Symposium on Chemical Engineering-SOMCHE, Dec. 2-3, Kula Lumpur, pp: 585-591.

Biresaw, G., A. Adhvaryu, S.Z. Erhan and C.J. Cariere, 2002. Friction and adsorption of normal and high oleic soybean oils. J. Am. Oil Chem. Soc., 79: 53-58.

Budinski, K. and M.K. Budinski, 2002. Engineering Materials: Properties and Selection. Pearson Education, New York.

Cavdar, B. and K.C. Ludema, 1991. Dynamics of dual film formation in boundary lubrication of steels: Part I: Functional nature and mechanical properties. Wear, 148: 329-346.

Erhan, S.Z., A. Adhvaryu and B.K. Sharma, 2006. Chemically Functionalized Vegetable Oils. In: Synthetic, Mineral Oils and Bio-Based Lubricants, Rudnick, L.A. (Ed.). CRC Press, New York.

Gawrilow, I., 2003. Palm oil usage in lubricants. Proceedings of the 3rd Global Oils and Business Forum, USA.

Godfrey, D., 1980. Diagnosis of Wear Mechanism. In: Wear Control Handbook, Peterson, M.B. and W.O. Wine (Eds.). ASME., New York.

Gunam Resul, M.F.M., T.I.M. Ghazi, A.M. Syam and A. Idris, 2008. Synthesis of biodegradable lubricant oil with high content of free fatty acid. Proceeding of RSCE-SOMCHE, Dec. 2-3, Kula Lumpur, pp: 603-608.

Henning, R.K., 2000. Use of *Jatropha curcass* oil as raw material and fuel: An integrated approach to create income and supply energy for rural development. Presented at International Meeting Renewable Energy-A Vehicle for Local Development II. http://www.angelfire.com/ks3/go_diesel/files042803/jathropa2.pdf.

Hwang, H.S., A. Adhvaryu and S.Z. Erhan, 2003. Preparation and properties of lubricant basestocks from epoxidized soybean oil and 2-ethylhexanol. J. Am. Oil Chem. Soc., 80: 811-815.

Lea, C.W., 2002. Europen development of lubricant derived from renewable resources. Ind. Lubrication Tribol., 54: 268-274.

Maleque, M.A. and H.H. Masjuki, 2002. Wear surface characteristics study of tribo-materials under palm oil methyl ester added lubricant. Ind. Lubricat. Tribol., 54: 177-182.

Masjuki, H.H. and M.A. Maleque, 1997. Investigation of the anti-wear characteristics of palm oil methyl ester using a four ball tribometer test. Wear, 206: 179-186.

Rowe, C.N., 1980. Lubricated Wear. In: Wear Control Handbook, Peterson, M.B. and W.O. Wine (Eds.). ASME., New York.

Rudnick, and S.Z. Erhan, 2006. Natural Oils as Lubricants. In: Synthetic, Mineral Oils and Bio-Based Lubricants, Rudnick, L.A. (Ed.). CRC Press, New York.

Sharma, B.K., A. Adhvaryu, Z. Liu and S.Z. Erhan, 2006. Chemical modification of vegetable oils for lubricant application. J. Am. Oil Chem. Soc., 83: 129-136.

Stachowiak, G.W. and A.W. Batchelor, 2001. Engineering Tribology. Butterworth-Heinemann, USA.

Stefanescu, I.I., C. Calomir and G. Chirita, 2002. On the future of biodegradable vegetable lubricants used for industrial trybosystems. Ann. Univ. Dunarea De Jos Galati Fascicle, 8: 94-98.

Weller, Jr. D.A., 2000. Study of the effect of chemical structure of esters and vegetable oils on friction and wear with and without additives. Ph.D. Thesis, Pennsylvania State University.