Palm Oil Methyl Esters as Lubricant Additive in a Small Diesel Engine

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ABSTRACT: Malaysian crude palm oil has been successfully converted to methyl esters, also known as palm oil diesel (POD), which is readily combustible in diesel engines. This paper presents and discusses the results of current studies on the performance and the effects of POD on the wear characteristics of tribological components of a small, four-stroke diesel engine. Adding POD to commercial lubricating oil has enhanced the performance of such oils. Results obtained from this study show that the power output and brake specific fuel consumption of the engine, lubricated with commercial SAE 40 oil blended with POD, are comparable to those of 100% SAE 40 oil. Wear debris analysis shows that blends of POD and SAE 40 commercial lubricating oil increase the anti-wear characteristics of the engine when compared to 100% SAE 40 lubricating oil.

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KEY WORDS: Additive, diesel engine, methyl ester, palm oil.

Since 1977, the time of the Arab oil embargo, most countries have made a concerted effort to reduce their dependence on imported oil by investigating alternative sources and more efficient use of energy. This effort has been increasingly reinforced by concerns about environmental pollution and global warming effects. The Malaysian government has embarked on a strategy to utilize nonpetroleum, domestic energy resources to increase self-reliance in energy supply. Energy conservation and alternative fuels research are now given high priority in energy planning.

One well-researched form of alternative fuels for diesel engines has been based on vegetable oils. Despite having low cetane numbers, various members of this class, including palm, coconut, cottonseed, peanut, sunflower, soybean, rapeseed, jojoba, linseed, safflower, castor, olive, and corn oils, all from different regions with varying climatic conditions, have been shown to be suitable for this purpose.

Palm oil is Malaysia's leading export crop and is also the country's major export product. Various ways of utilizing this valuable crop into consumable products is one of the tasks of the Palm Oil Research Institute of Malaysia (PORIM), which is actively pursuing research activities related to palm oil production. One of the many successful products of this agency is methyl ester of crude palm oil, also known as palm oil diesel (POD), which is readily combustible in engines and has been characterized as being comparable with petroleum diesel (1).

In the past, Masjuki *et al.* (2,3), Afifi *et al.* (4), PORIM scientists, and Azhar *et al.* (6) have all conducted performance tests on compression ignition engines fueled with POD. However, there is little published work on the effects of POD on the lubricated wear behavior of engine components. The study of wear behavior of engine components is important because the tribological phenomena of the sliding surfaces between piston rings and cylinder liners may be among the most complex in internal combustion engines, and wear could become even more severe with an increase in engine power. Friction between the piston rings and the cylinder liner significantly contributes to the mechanical power losses of the engine (7). Sivasankaran *et al.* (8) have performed lubricated wear experiments with jojoba oil as the base lubricating oil in a two-stroke gasoline engine. Rewolinski and Shaffer (9,10) have conducted lubricated wear experiments with diesel lubricating oil contaminated with sunflower oil fuel. None of these studies has used POD as a lubricant or a lubricant additive.

The aim of this paper is to present and discuss the results of recent studies on the effects of commercial lubricant blended with different percentages of POD on the wear characteristics of diesel engine components when the engine is fueled with pure conventional diesel oil.

EXPERIMENTAL PROCEDURES

A horizontal 7-hp, four-stroke, condenser-cooled, single-cylinder 180N diesel engine was used without modification. The variation of loads at different speeds was measured with a Froude dynamometer (Froude Cosine Ltd., Worcester, England). The test engine specifications were: type, horizontal, single-cylinder, 4-stroke; bore, 80 mm; stroke, 90 mm; displacement, 0.425 L; compression ratio, 21; output, 12-h rating, 7.0 hp, 1-h rating, 7.7 hp; maximum speed, 2,200 rpm; cooling, condenser; specific fuel consumption, 215 g/hp/h; oil consumption, 4 g/hp/h; combustion chamber, swirl combustion-chamber; fuel tank capacity, 7L; lubrication, pressurized splashing; starter, hand-cranked.

Performance characteristics were studied at speeds between 1500 and 2200 at increments of 100 rpm. The performance of the engine was tested with 100% SAE 40 commercial lubri-

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TABLE 1
Chemical Composition of Palm Oil Diesel

Component	Percentage	Chemical equation
Myristic	1.1–2.5	$CH_3(CH_2)_{12}CO_2H$
Palmitic	40.0–46.0	$CH_3(CH_2)_{14}CO_2H$
Stearic	3.6–4.6	$CH_3(CH_2)_{16}CO_2H$
Oleic	39.0–45.0	$CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H$
Linoleic	7.0–11.0	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7CO_2H$

cant and blends of POD at 5 and 10% by volume with pure SAE 40 lubricant. The chemical composition of typical Malaysian palm oil is shown in Table 1 (11). The engine was fueled with pure conventional diesel and was run for periods of 40 h at a speed of 2200 rpm. Lubricating oil samples were collected at 3, 6, 9, 15, 30, and 40 h and sent to a private laboratory for wear debris analysis by the atomic absorption spectrophotometer method.

RESULTS AND DISCUSSION

Engine performance. The brake power at speeds between 1500–2200 rpm for various combinations of lubricating oil is shown in Figure 1. The maximum power for 100% SAE 40 oil and its blends with POD occurred at 1800 rpm. The 90% SAE 40 oil produced power of 4.4 kW, and 100% SAE oil gave a maximum power of 4.25 kW. The maximum power of 95% SAE 40 oil was 3.95 kW. The maximum power between 100% SAE oil and the highest power of the 90% SAE 40 + 10% POD blend represented a heating value difference of 3.41%. The small difference resulted mainly from reduction of the heating value of the 90% SAE 40 + 10% POD blend due to the lower caloric value by mass of the POD (12).

Another reason may have been the presence of POD in the lube oil. It acted as fuel and it enhanced the performance of the lubricant. The presence of some free fatty acids in POD helped to promote boundary lubrication at the top dead center of the piston ring's travel, thus reducing the possibility of complete piston ring and cylinder liner contact. This helped to reduce the friction and wear rate and resulted in the observed small increase in brake power (13).

When lubricated with 100% SAE 40 oil, the engine gave the lowest brake-specific fuel consumption (Fig. 2). The higher specific consumption for both blends is mainly caused by the lower caloric values by mass of the POD blends and by lower frictional forces between piston rings and cylinder liners, especially at the top dead center. In general, blended lubricating oils displayed engine performance characteristics similar to 100% SAE 40 oil. The engine also performed smoothly, and there was no audible knock.

Engine wear. Generally, in a normal diesel engine, the bearings, piston rings, cylinder liners, pistons, and camshaft are made of the following metals: (i) aluminum—piston and bearings; (ii) lead—piston and bearings; (iii) chromium—cylinder liner and piston rings; (iv) iron—camshaft and piston; and (v) copper—piston rings and bearings. Results of metallic wear debris analysis in the lubricant, sampled during the running hours of the engine, are shown in Figures 3 through 7. We found that, for all metals studied, concentrations in the lubricant sump were comparable with 100% SAE 40 oil when POD was introduced in the lubricating oil. This is due to the fact that POD acted as a lubricant together with the SAE 40 oil be-

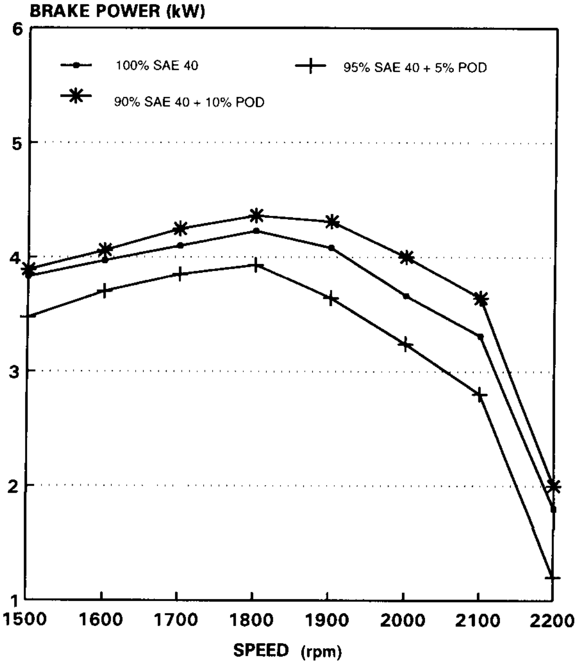

FIG. 1. Power developed with different blend of lubricants at varying speeds. POD, palm oil diesel.

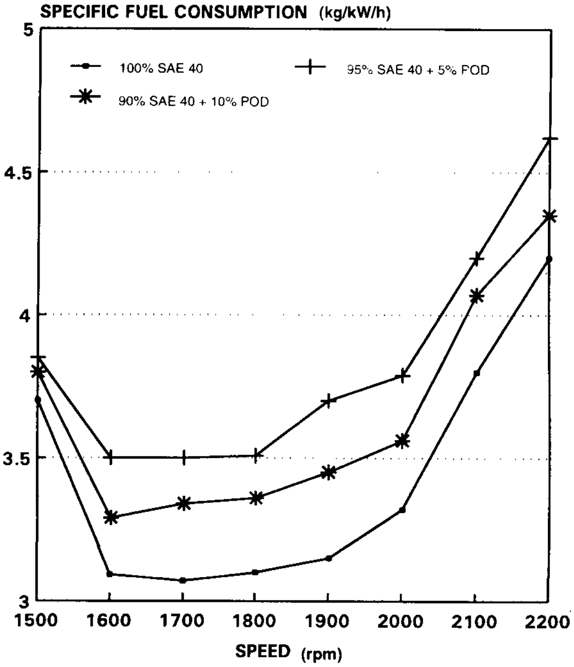

FIG. 2. Specific fuel consumption of different lubricants at varying speeds. Abbreviation as in Figure 1.

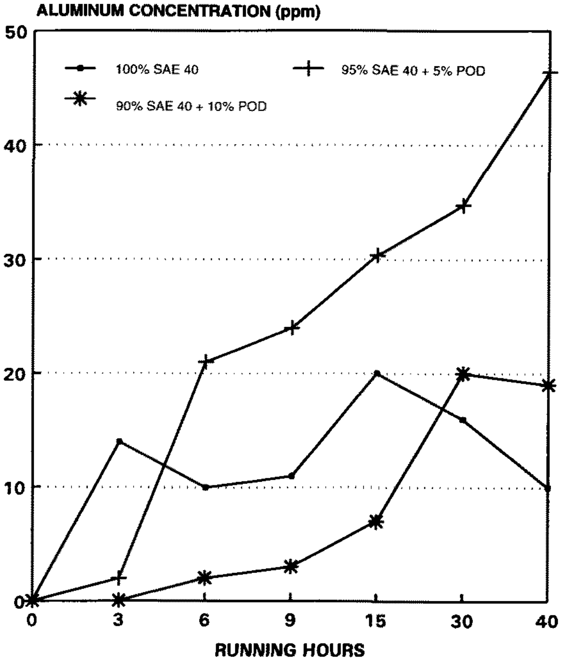

FIG. 3. Variation of aluminum concentration against running hours. Abbreviation as in Figure 1.

tween the cylinder liner and piston rings. It helped to reduce the wear because POD contains fatty acids, which are additives in a commercial engine lubricant.

Figure 4 shows that the lead concentration is greatest in the 100% SAE oil. For the POD blends, lead concentrations increased slightly (to 8.3 ppm) by the end of the test run. This indicates that POD blends gave better antiwear characteristics than 100% SAE oil as far as this metal is concerned. For chromium analysis, the wear rate of 100% SAE was small throughout the engine operation (maximum 6 ppm). On the other hand, the chromium concentration for 90% SAE 40 + 10% POD oil increased to as high as 17 ppm (Fig. 5). However, the concentration in 95% SAE 40 + 5% POD oil was almost constant at 3 ppm.

For iron concentration, for up to 15 running hours, the trends of the curves for the 100% SAE 40 oil and 90% SAE + 10% POD were similar (Fig. 6). Beyond this time, the curve of 90% SAE + 10% POD increased to 140 ppm while the 100% SAE oil curve decreased to as low as 23 ppm. A fluctuation between 60–120 ppm was observed for the 95% SAE + 5% POD blend. In the copper analysis, the wear rates for all the lubricants studied varied between 85–118 ppm (Fig. 7). Clearly, Figures 5 and 6 indicate that blends containing POD produced higher level of chromium and iron, which was mainly the result of extreme conditions at the upper cylinder lubrication, as explained later in the text.

It is generally assumed that adsorption layers are responsible for the improved lubricating properties of oils containing long-chain fatty acids and alcohols with the major axis perpendicular to the surface. Among acids, alcohols, and esters, acids are the most strongly adsorbed, alcohols are adsorbed with intermediate strength, and esters are the least strongly adsorbed. Generally, the ease of adsorption increases with increasing chainlength as it influences the lateral cohesion of the monolayers (14).

In the lubrication of piston ring and cylinder liner, a region is encountered where hydrodynamic lubrication fails, a region of increased load, high temperatures, decreased speeds, and

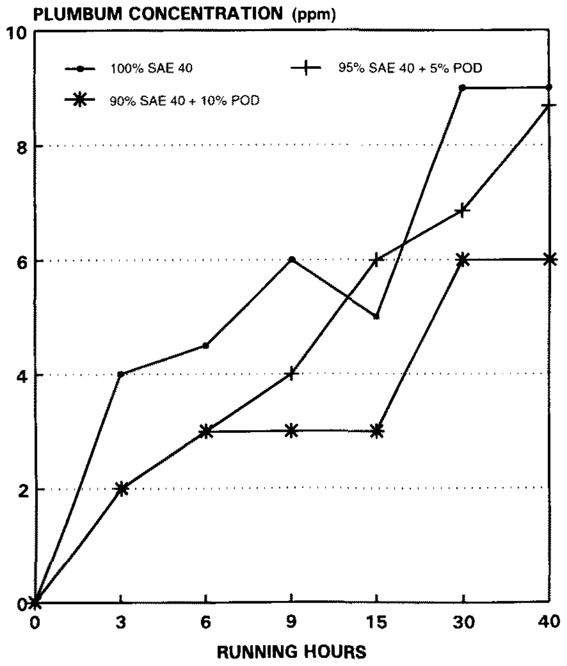

FIG. 4. Variation of lead concentration against running hours. Abbreviation as in Figure 1.

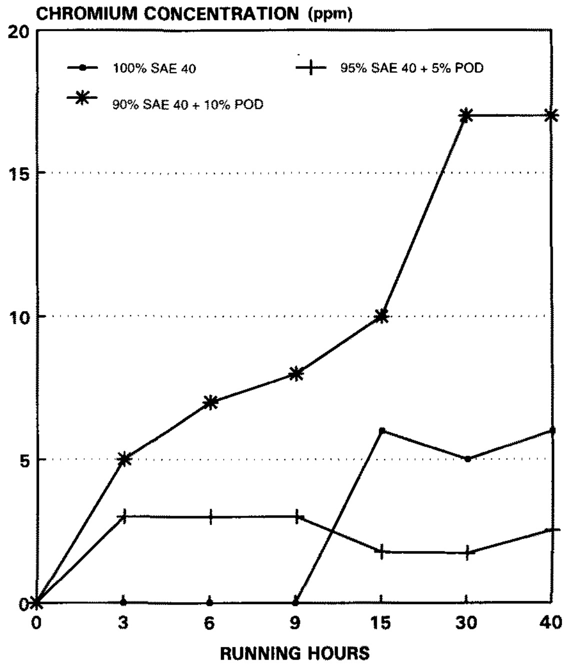

FIG. 5. Variation of chromium concentration against running hours. Abbreviation as in Figure 1.

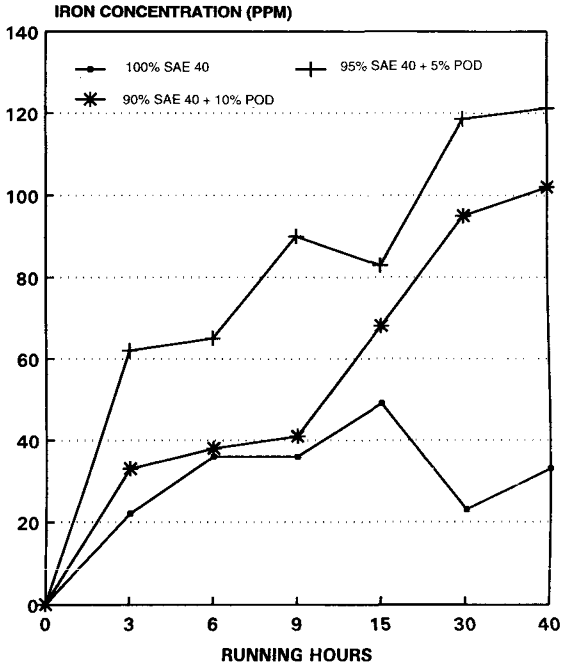

FIG. 6. Variation of iron concentration against running hours. Abbreviation as in Figure 1.

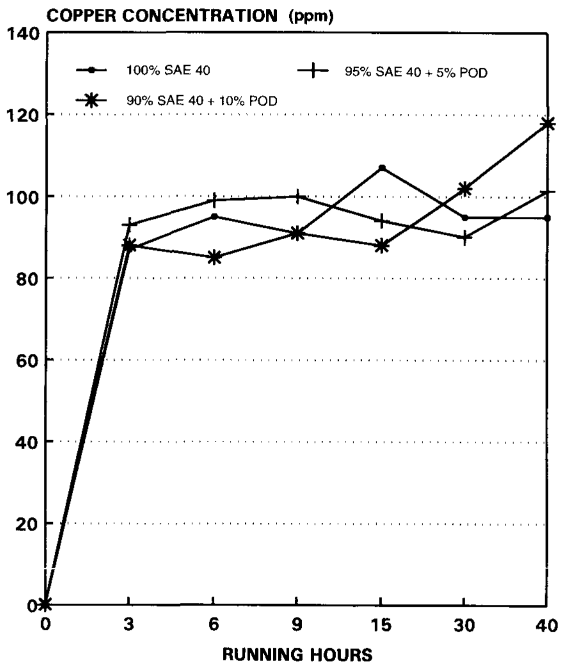

FIG. 7. Variation of copper concentration against running hours. Abbreviation as in Figure 1.

squeezing out of lubricant. These effects happen under boundary lubrication. The high content of some metals in the lubricant should not be a cause for worry because they did not exceed the unsafe level of 350 ppm. These include predominantly iron and copper, which enter the oil from the wear and tear of machinery during processing, and also (in the case of iron) during oil storage. Initially they are present as minute particles, but during storage they react with the chemicals (free fatty acids) present and form metallic soaps, which dissolve in the oil. Iron and copper are capable of producing peroxides, which break down into many taste and flavor compounds.

It is possible to select samples from the top, middle, and bottom dead center positions of the liner, which has exhibited a low wear rate. At the top dead center position, wear was primarily by abrasion, and the rubbing action revealed what appeared to be hard phases. There is no evidence of abrasion at the mid-position, but microstructures of the pearlite and phosphide hard phase are clearly evident (14).

POD attacks metals, and in this experiment it reacted strongly with aluminum. The POD used in this experiment had a total acid number of 1.89. During the 40 h of running the engine, the piston, which is made of cast aluminum, was corroded by POD. This increased the aluminum content for the mixture of 95% SAE 40 + 5% POD (Fig. 3).

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REFERENCES

1. Ong, A.S.H., Y.M. Choo, A.H. Hitam and S.H. Goh, *Proceedings of 3rd ASCOPE Conference,* Dec. 2–5, 1985, Kuala Lumpur, 1985, pp. 441–458.
2. Masjuki, H., and M. Sohif, *J. Energy, Heat and Mass Transfer 13*:125 (1991).
3. Masjuki, H.H., A.M. Zaki and S.M. Sapuan, *2nd International Seminar on Fuels for Automotive and Industrial Diesel Engines,* April 6–7, 1993, London, 1993, pp. 129–137.
4. Afifi, M.A.M., M.M.Y. Zainal and A.A. Rahim, *PORIM Bulletin 9*:22 (1984).
5. Azhar, A.A., A.A.A. Zainol and A.N. Darus, *Proceedings 2nd ASEAN Science and Technology Week,* Jan. 30–Feb. 4, 1989, Manila, Philippines, 1989, pp. 430–448.
6. Anon., *Performance Test on Engine Fuelled by Methyl Ester (Palm Oil Diesel),* PORIM Report BD3-5.3, PORIM, Kuala Lumpur.
7. Wakuri, Y., T. Hamatake, M. Soejima and T. Kitahara, *Tribology International 25*:299 (1992).
8. Sivasankaran, G.A., R.P.S. Bisht, V.K. Jain, M. Gupta, A. Sethuramiah and B.K. Bhatia, *Ibid. 21*:327 (1988).
9. Rewolinski, C., *J. Am. Oil Chem. Soc. 62*:1120 (1985).
10. Rewolinski, C., and D.L. Shaffer, *Ibid. 62*:1598 (1985).
11. Henham, A.W.E., *Proceedings Seminar on Fuels for Automotive and Industrial Diesel Engines,* International Seminar on Fuels for Automotive and Industrial Diesel Engines, Institution of Mechanical Engineers, Nov. 19–20, 1990, London, pp. 117–122.
12. Studt, P., *Tribology International 22*:111 (1989).
13. Nautiyal, P.C., Singhal, S. and Sharma, J.P., *Ibid. 16*:43(1983).
14. Nadeland, T.S.E., *Ibid. 16*:267 (1978).

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