A Rapid Test to Measure Performance, Emission and Wear of a Diesel Engine Fueled with Palm Oil Diesel

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Results of performance, emission and tribological evaluations of palm oil methyl ester and its blends with conventional diesel in an automobile diesel engine test bed are presented. Polymerization and carbon deposits on the fuel injector were monitored. CO, CO_2, O_2, combustion efficiency and temperature of exhaust gases were also measured. Palm oil methyl ester and its blends have great potential as alternative diesel fuel. Performance and exhaust gas emission for palm oil methyl ester and its blends with conventional diesel are comparable with those of conventional diesel fuel. Palm oil methyl ester does not pose a severe environmental problem and will not deteriorate engine and bearing components.

KEY WORDS: Diesel engine, emission, methyl ester, palm oil, performance, wear.

The high cost of energy supplies, as well as the concern over the availability of oil, have brought much pressure on many countries to reevaluate their national energy strategies. Ever since the oil crises of the 1970s, there has been an incentive to increase energy security by seeking substitutes for oil. This incentive has been increasingly reinforced by environmental pollution and global warming effects. Realizing these facts, the Malaysian government has embarked on a strategy to utilize other domestic energy resources to increase self-reliance in energy supply and to save foreign exchange. Energy conservation and alternative fuels research are now given high priority in energy planning.

In the past, many investigations have been carried out on the use of vegetable oils as diesel fuels (1–17). Vegetable oils were tested as early as 1920. Soybean, sunflower, peanut, cottonseed, olive, rapeseed, coconut, jojoba and palm oils were used as is, blended with diesel or converted to their respective alkyl esters. Of the several vegetable oils available as renewable energy sources, palm oil appears promising as an alternative, renewable fuel for diesel engines (18,19).

In 1983, the Palm Oil Research Institute of Malaysia (PORIM) successfully converted crude palm oil (CPO) and crude palm stearin (CPS) to their respective methyl esters (MEs). The properties of MEs of CPO and CPS, also known locally as palm oil diesel (POD), have been characterized (Table 1) by National Petroleum Company of Malaysia (PETRONAS) to be comparable with conventional diesel (CD) (20). The sulfur content is low; causing less emitted pollutants; and the cetane index of 50–52 is slightly lower than that (53) of conventional diesel.

The aim of this paper is to present the performance evaluation of the Isuzu 4FB1 four-cylinder 4-stroke diesel engine (Isuzu Motors Ltd., Tokyo, Japan) when fueled with ME of CPO, CD, and their blends at 25, 50 and 75% POD by volume. It is hoped that research in this area will lead to the most economical use of POD as an alternative fuel to CD. It is also hoped that it will meet both the energy and environmental goals of the nation when a long-term plan for large-scale commercialization of POD, at a competitive price, is realized.

EXPERIMENTAL PROCEDURES

A horizontal, four-stroke, four-cylinder Isuzu 4FB1 diesel engine was used in the experiments without modification. The engine specifications are: type, Isuzu 4FB1, 4-cylinder, 4-stroke, indirect injection; cooling, water; swept vol/stroke (L), 1.817; bore (mm), 84; stroke (mm), 82; compression ratio, 20; nominal power output (kW) at revolutions/min, 39 at 5,000. The variation of loads at different speeds were maintained by the use of a Froude Dynamometer (Froude Engineering, Inc., Livonia, MI). Instrumentations were available to obtain brake load, fuel flow rate, exhaust temperature and gas analysis for this engine. Performance characteristics were studied at speeds between 900–3000 rpm at increments of 250 rpm. The performance of the engine was tested with POD and compared to that of CD. The effect of blending CD with POD was also determined at percentages of 25, 50 and 75% in volume. Lube oil samples were collected every three hours the engine was run and sent to a private laboratory for wear debris, total base number (TBN) and viscosity analyses. Fuel injector polymerization and carbon deposits were inspected after every run.

RESULTS AND DISCUSSION

Engine performance. The brake power output at speeds between 900–3000 rpm for various combinations of fuel is shown in Figure 1. Pure POD and its blends developed power similar to pure CD. The maximum power for all fuels occurred at 1250 rpm, with CD fuel producing a maximum power of 9.2 kW, followed by the fuel blend of 25% POD + 75% CD, which showed a maximum power of 8.7

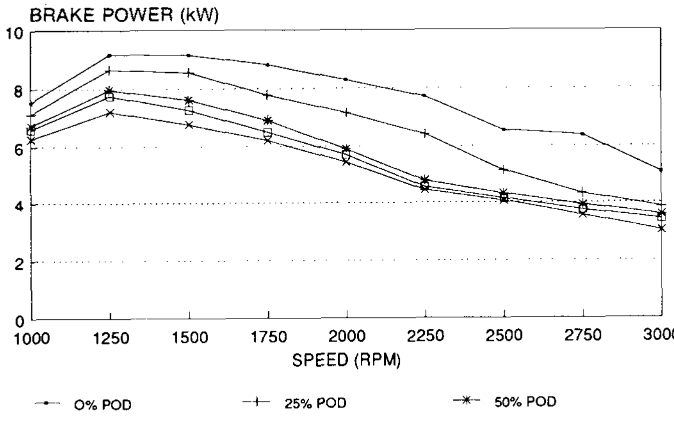

FIG. 1. Brake power developed at various speeds. POD, palm oil diesel.

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TABLE 1

Fuel Characteristics of Methyl Esters of Crude Palm Oil and Palm Stearin[a]

Test conducted	Methyl esters of CPO (POD)	Methyl esters of CPS (POD)	Malaysian diesel (CD)
Specific gravity ASTM D 1298	0.8700 @ 75.6°F	0.8713	0.833 @ 60.0°F
Color (visual)	Reddish	Orange	Yellow
Odor	Castrol smell	—	Normal
Sulfur content (%) WT.IP 242	0.04	0.002	0.10
Viscosity @ 40°C (cSt) ASTM D 445	4.5	4.6	4.0
Pour point ASTM	16.0	17.0	15.0
Distillation D 86 (°C)			
IBP	324.0	320.0	228.0
10%	330.0	331.0	258.0
20%	331.0	332.0	270.0
50%	334.0	335.0	298.0
90%	343.0	343.0	376.0
FBP	363.0	349.0	400.0
Final recovery (mL)	98.0	98.5	
Cetane index ASTM D 976	50.0	52.0	53.0
Gross heat of combustion at 93°C ASTM D	40,135	39,826	45,000
Flash point at 93°C ASTM D	174.0	165.0	98.0
Conradson carbon residue 189% WT. ASTM D	0.02	0.25	0.14

[a]CPO, crude palm oil; CPS, crude palm stearin; POD, palm oil diesel; CD, conventional diesel (Ref. 20); IBP, initial boiling point; FBP, final boiling point; ASTM, American Society for Testing and Materials.

kW. The maximum power of blends of 50% POD + 50% CD, 75% POD + 25% CD and 100% POD were 7.9, 7.75 and 7.25 kW, respectively. Beyond maximum power, the curves showed a consistent trend with the power decreasing rapidly. The maximum power between CD fuel and that of the 25% POD + 75% CD blend represents a difference of 5.43%. The small difference was mainly a result of the reduction of heating value of the fuel blend due to the lower heating value of POD (see Table 1).

Brake-specific fuel consumption is the amount of fuel needed to run the engine to obtain one horse power in one hour. Brake-specific fuel consumption (Fig. 2) showed small differences at the lower indicated rpm values, but they become more obvious at high rpm. Increasing the percentages of POD in POD-CD blend increases the brake-specific fuel consumption. The higher specific fuel consumptions for all blends and 100% POD can be attributed to three factors—higher specific gravity, higher viscosity and lower heating values of these fuels as compared with CD (12,18). Thus, more fuel is needed for the same amount of energy.

In general, blended fuels and pure POD displayed engine performance characteristics that were similar to CD. The engine performed smoothly, did not exhibit starting problems and no audible knock occurred.

Emission. Exhaust gas emissions were measured with a Max 5 Teledyne Combustion Efficiency Analyzer (Teledyne Analytical Instruments Inc., City of Industry, CA) at an engine speed of 2000 rpm. Carbon monoxide and carbon dioxide emissions are shown in Figures 3 and 4, respectively. Both carbon monoxide and carbon dioxide emissions show a decreasing trend as the percentage of POD increases in the various fuel blends. These observations indicate that POD fuel is environmentally friendly as far as the two gases are concerned. In fact, POD is relatively clean and should not pose severe acid rain

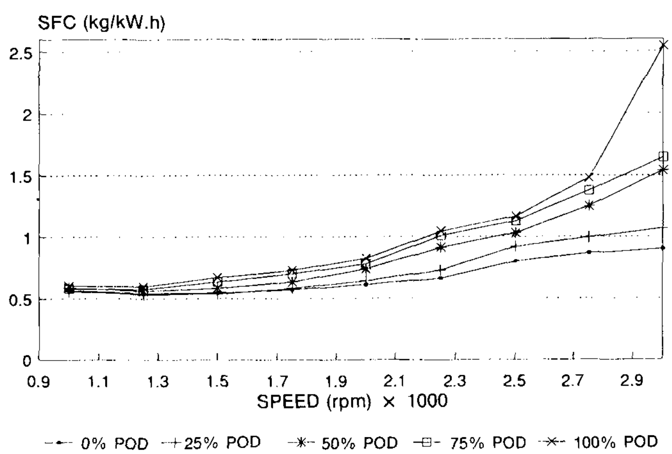

FIG. 2. Specific fuel consumption at various speeds. POD, palm oil diesel.

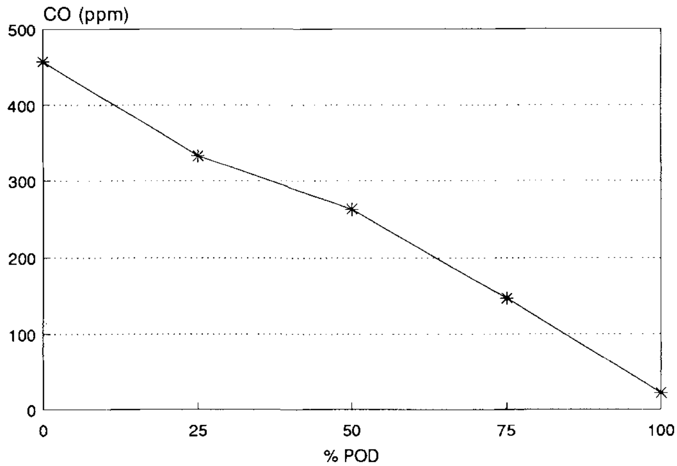

FIG. 3. Gas analysis: carbon monoxide emissions against percentage of palm oil diesel (POD).

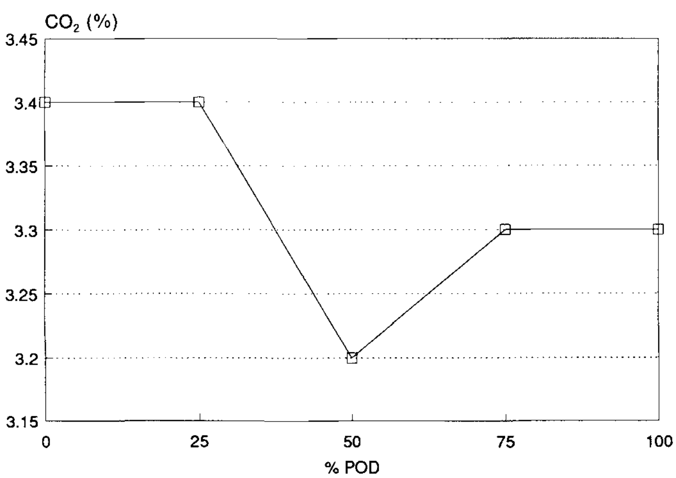

FIG. 4. Gas analysis: carbon dioxide emissions against percentage of palm oil diesel (POD).

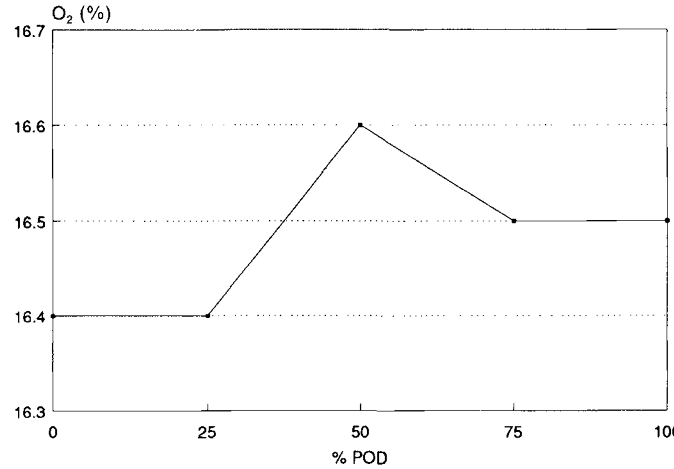

FIG. 5. Gas analysis: oxygen emissions against percentage of palm oil diesel (POD).

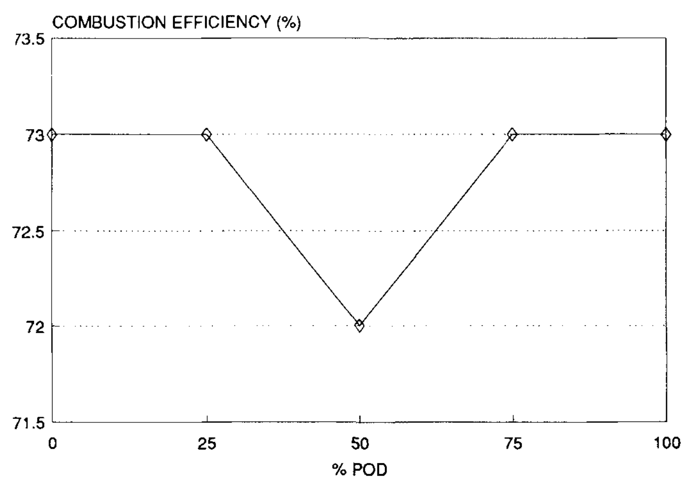

FIG. 6. Gas analysis: combustion efficiency against percentage of palm oil diesel (POD).

problems due to the low content of sulfur in the fuel, which would produce SO_x during combustion. The only pollution is in the process of extracting palm oil, and with more research being carried out on the treatment of palm oil affluents, the pollution problem from palm oil processing can be improved (21).

Measurement of O_2 showed small variation for all fuels (Fig. 5). Except for 50% POD + 50% CD fuel, all fuels have constant combustion efficiencies of 73% (Fig. 6). The 50% POD fuel has a combustion efficiency of 72%. Combustion efficiency can be related to the brake-specific energy consumption (BSEC) or energy delivery per unit time (the unit is MJ/kW.h) in such a way that the lower the combustion efficiency, the higher the BSEC [a lower BSEC is desirable (9,14)]. Exhaust gas temperature measurements showed variation only between 126 and 127°C for the various fuels (Fig. 7). Lower exhaust temperatures for the 50% POD + 50% CD and pure POD were caused by lower intake air temperatures during the test, lower burning temperatures developed in the combustion chamber and lower energy delivery per unit of time (9,18).

Engine wear and deposits. The major sources of metallic wear particles in the circulating lubricating oil of a normal diesel engine are as follows (22): cylinder liner, cast iron (Cr); piston rings, cast iron (Cr, Mo, Cu); piston, Al, Si alloy, malleable cast iron, Sn- or Pb-coated; crankshaft, low-carbon alloy steel; main, big end and small end bearings, Pb-Sn, Cu-Pb-Sn, Al-Si, Al-Sn, Cd; thrust bearings, phosphor bronze, Al-Sn, Cu-Pb; camshaft, cast iron; valve train, high alloy steel, Ni; auxiliary drive, phosphor bronze, low-carbon alloy steel. Engine wear was monitored by analyzing the lubricating oil for wear-metal levels. The iron concentration is shown Figure 8. The highest level of iron comes from pure conventional diesel. As the percentage of POD increases in the fuel, the iron level decreases throughout the 28-h test. This seems to indicate that POD acts as lubricant between the piston ring and cylinder liner because most of the iron particles come from the combustion chamber. The copper concentration is depicted in Figure 9. CD fuel seems to generate the lowest concentration, whereas 50% POD + 50% CD generates the highest, although measurement at about 6 h of the engine

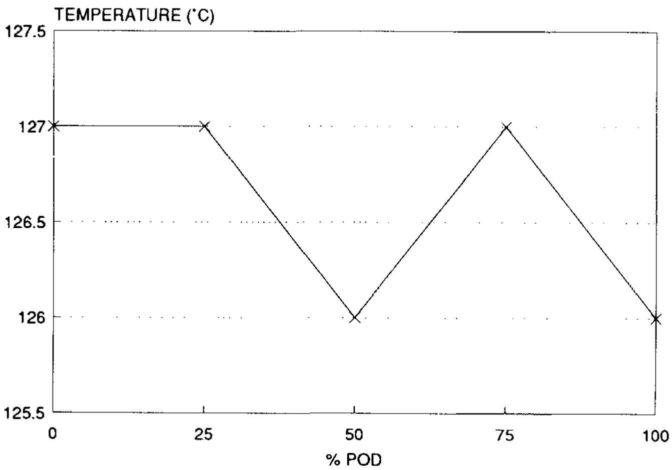

FIG. 7. Gas analysis: exhaust gas temperatures against percentage of palm oil diesel (POD).

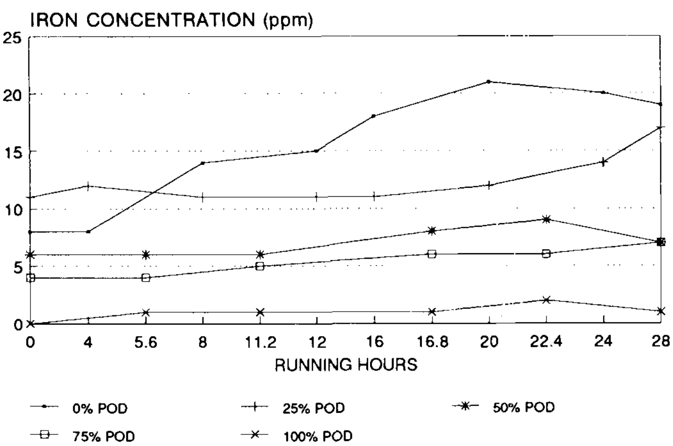

FIG. 8. Variation of iron concentration as a function of running hours. POD, palm oil diesel.

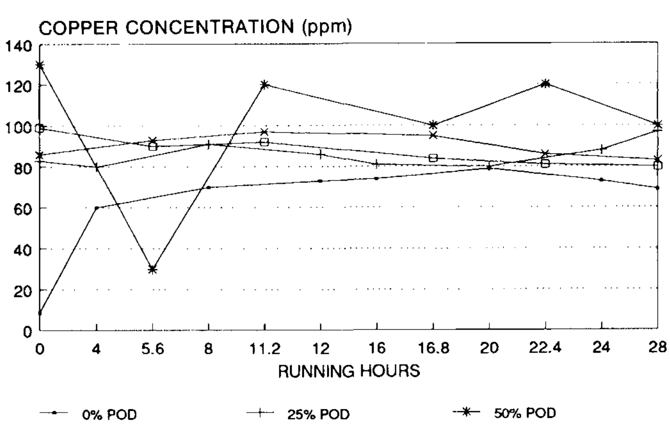

FIG. 9. Variation of copper concentration against running hours. POD, palm oil diesel.

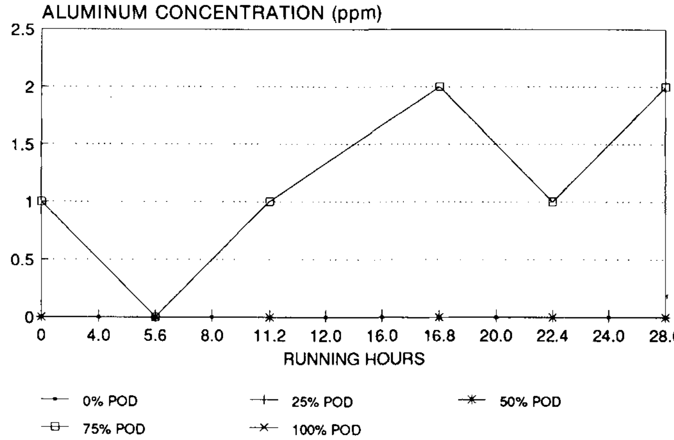

FIG. 10. Variation of aluminum concentration against running hours. POD, palm oil diesel.

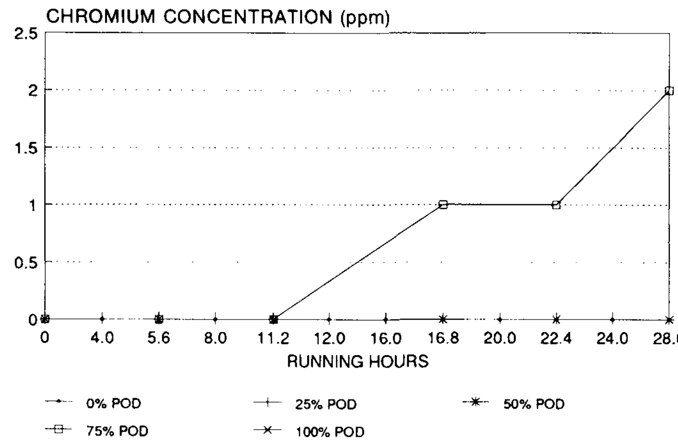

FIG. 11. Variation of chromium concentration against running hours. POD, palm oil diesel.

being run indicates a sudden drop in the copper concentration.

The results for the aluminum concentration are shown in Figure 10. The 75% POD + 25% PD is the only fuel that shows the presence of aluminum. The rest of the fuels have zero aluminum concentrations. In Figure 11 a zero chrominum level is observed at up to approximately 11-1/2 h of the engine being run. However, beyond this, the chromium concentration in 75% POD + 25% CD increases up to 2 ppm, while the rest of the fuels maintain a zero chromium concentration. The lead concentration is shown in Figure 12. A variation between 1–3 ppm in the lead concentration is seen in the 25% POD + 75% CD, 50% POD + 50% CD and 75% POD + 25% CD blends. However, for the first 6 h, in 50% POD + 50% CD, a sharp increase, from 0 to 3 ppm, is observed. The lead concentrations are zero for the pure POD and the CD. All wear metals were observed when the engine was fueled by 75% POD + 25% CD. In general, wear metal levels for the blended fuels and pure POD fuel were considered to be normal throughout the 28 h test.

The TBNs and the viscosities of the lubricating oil samples at 40°C, monitored over the 28-h test, are shown

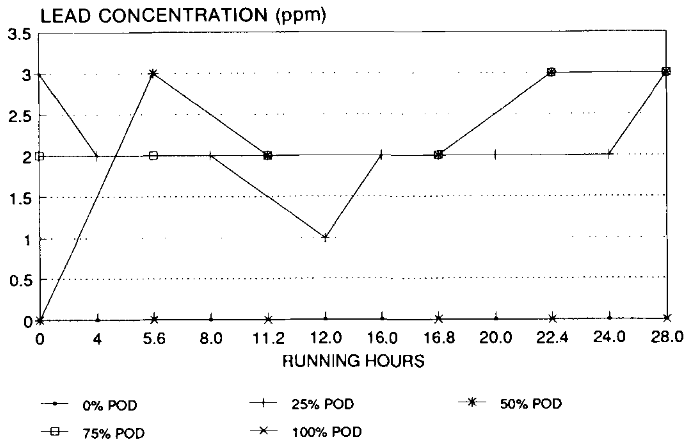

FIG. 12. Variation of lead concentration against running hours. POD, palm oil diesel.

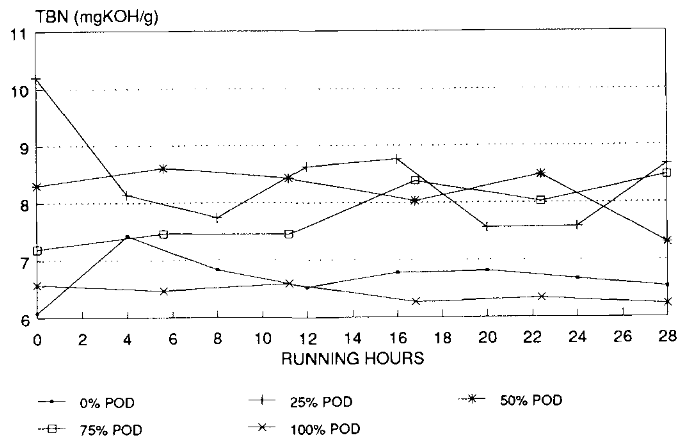

FIG. 13. Lubricant total base number against running hours. POD, palm oil diesel; TBN, total base number.

in Figures 13 and 14, respectively. The TBN for pure POD and CD are slightly lower than in the POD blends. The 50% POD blend shows constant viscosity throughout the test. Variations between 126 to 142 cSt and 133 to 144 cSt are observed in 75% POD + 25% CD and 100% POD, respectively. A sudden drop in the viscosity of 75% POD fuel from 142 to 126 cSt after 16 h of the engine being run suggests that lube oil dilution was taking place. Higher viscosities are observed in 25% POD + 75% CD and pure CD. Generally, however, no substantial changes were found for lube oil viscosity when burning either pure CD, pure POD or any of the blends. The figures indicate no serious deterioration in the lubricating oil.

Inspection of the injector nozzles at the end of each test run for all the various fuels showed little polymerization of the fuels. However, much carbon was deposited when 25% POD + 75% CD fuel was used. This is followed by 100% CD and 100% POD fuels. Lesser and the least carbon deposits were observed when 75% POD + 25% CD and 50% POD + 50% CD fuels were used.

The above observations on engine performance, emission and engine wear, deposits and lube oil viscosity indicate the positive nature of palm oil methyl ester as an alternative diesel fuel.

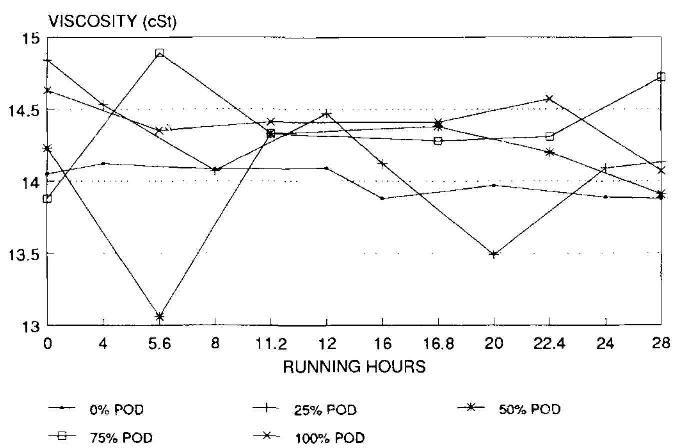

FIG. 14. Lubricant viscosity at 100°C against running hours. POD, palm oil diesel.

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