An Accelerated Experimental Investigation on Biofuel Emulsion for an Automobile Engine

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Abstract: Results of performance, exhaust emissions and lube oil analysis of a diesel engine fueled with Malaysian palm oil diesel (POD) and ordinary diesel (OD) emulsions containing 5 % and 10 % of water by volume are compared with those obtained when 100 % POD and OD fuel were used. Very promising results have been obtained. Neither the lower cetane number of POD fuel nor its emulsification with water presented obstacles to the operation of the diesel engine during steady state engine tests and the twenty-hour endurance tests. Polymerization and carbon deposits on fuel injector nozzles were monitored. Engine performance and fuel consumption for POD and its emulsions were comparable with those of OD fuel. Accumulations of wear metal debris in crank-case oil samples were lower with POD and emulsified fuels compared with baseline OD fuel. Both OD and POD emulsions with 10 % water by volume showed promising tendency for wear resistance. The exhaust emissions for POD and emulsified fuels for both OD and POD were found to be much cleaner, containing less CO, CO_2 and HC; the absence of black smoke from the exhaust is an advantage. Theoretical aspects of diesel combustion are used to aid the interpretation of the observed engine behaviour.

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INTRODUCTION

Concern about long term supplies of conventional hydrocarbon based fuels and the growing awareness of environmental pollution from automobile engines and other energy converting devices have motivated the search for suitable alternative fuels and more environmental friendly systems [1, 2].

Vegetable oils are widely available in a variety of sources and they are renewable. They do not add extra carbon dioxide during combustion, instead through the process of photosynthesis they recycle the carbon dioxide given out through the conversion of carbon fixed fossil fuel reserves during combustion. Moreover, vegetable oils contain no sulphur, so this can greatly reduce the existing environmental damage caused by acid rain [3, 4]. If these oils are good enough to substitute hydrocarbon fuel as a means of power production, then, 'home grown' vegetable oil could be a energy source to sustain and build up the standards of living to something approaching comfort, especially for those less developed nations, with scarce indigenous hydrocarbon resources.

Owing to their high viscosities, the injection, performance, combustion and atomization characteristics of vegetable oils and consequently, the combustion and performance in both direct-injection and indirect-injection diesel engines, are significantly different from those of petroleum derived diesel fuels [5]. Having high viscosity, in long term operation, vegetable oils will normally produce gumming, forming injector deposits, and sticking ring. They are also incompatible with conventional lubricating oils [5-9].

One feasible means of overcoming these problems is to emulsify these fuels with water, leading to improved fuel atomization and improved spray characteristics possiblly through the phenomenon of micro-explosion as suggested by Ziejewski [10]. Recent investigations show that the presence of water did not pose significant obstacles to satisfactory engine operation under normal operating conditions [2]. Details of the POD characteristics are given in [4].

The present preliminary study aims to (a) evaluate the effects of emulsions of both POD and OD fuels on engine performance and emission characteristics, (b) study the effects of emulsions on lube oil deterioration and (c) investigate the effects of emulsions on wear rate and injector fouling, and compare them with baseline ordinary diesel fuel.

EXPERIMENTAL SETUP AND PROCEDURE

The tests were conducted at the Tribology Laboratory of Department of Mechanical Engineering, University of Malaya. The test engine used was an Isuzu 4FB1 horizontally arranged four cylinder diesel engine with a rating of 39 kW at 5000 rpm (rev/min). The engine specification and details of instrumentation are described in Masjuki, et al [5]. The procedures for engine performance test, exhaust emissions analysis, wear analysis, smoke particulate agglomerates collection and fuel injector nozzle examination are listed in Masjuki, et al [11].

Fuel properties and emulsion configuration tests were carried out with OD as the baseline fuel system which were followed by POD and their emulsions. Brief qualitative descriptions of the fuels are given in Table 1.

OD was obtained directly from the market in the commercial form whilst POD was provided by PORIM (Palm Oil Research Institute of Malaysia). The lube oil used was PETRONAS MOTOLUB XGD (SAE Grade 30). The Physicochemical characteristics of this crank-case oil are given in Table 3.

Table 1: Fuels configuration

a. OD95:	5 % water + 95 % ordinary diesel
b. OD90:	10 % water + 90 % ordinary diesel
c. POD95:	5 % water + 95 % palm oil diesel
d. POD90:	10 % water + 90 % palm oil diesel
e. POD:	100 % palm oil diesel
f. OD:	100 % ordinary diesel

Table 2: Properties of fuels [25]

Properties	POD	OD
Density, kg/L	0.875	0.832
Kinematic viscosity, @ 40° C cSt	4.71	3.60
Cetane Number	50-52	53
Specific energy, MJ / kg	41.3	46.8

RESULTS AND DISCUSSION

Brake power and specific fuel consumption: The results for brake power and specific fuel consumption are shown in Figs. 1 and 2. Brake power was lower with POD when compared to the engine running on OD at higher engine speeds. However, it is higher than emulsified fuels. POD and its emulsions show a slightly higher specific fuel consumption. The detail discussions of engine performance are covered in Masjuki, et al [11].

Table 3: Physiochemical data of Petronas Motolub XGD [Petronas Dadagan]

Characteristics		
Density @ 15° C	kg/l	0.890
Flash Point C.O.C.	°C	246
Pour Point	°C	-9
Viscosity	cSt	
	@ 40° C	106
	@ 100° C	11.9
Viscosity Index		95
Sulphated Ash		0.82
Neutralization Value		
Acid Number		0.05
Base Number		6
Colour (ASTM)		4.0
Elemental Analysis	% wt	
P		0.08
Ba		-
Ca		-
Zn		0.08

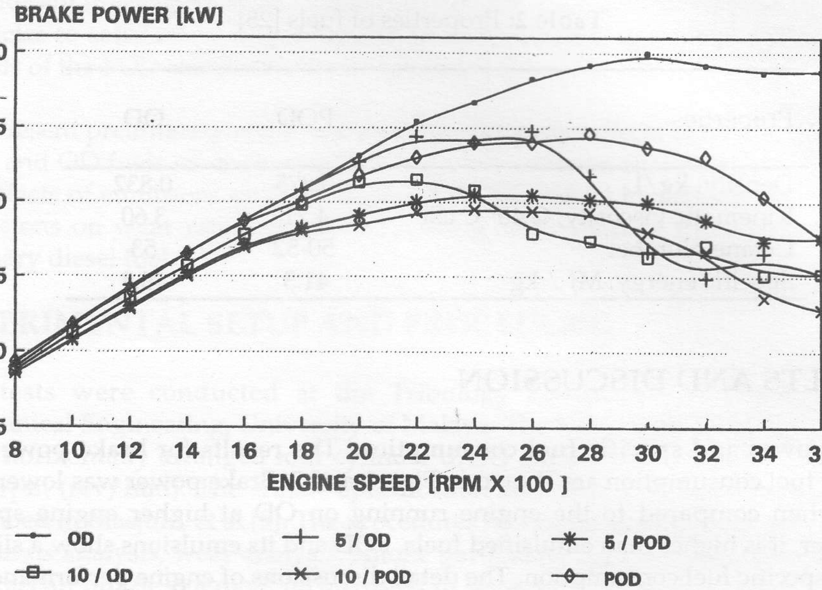

Fig. 1: Brake power vs. engine speed

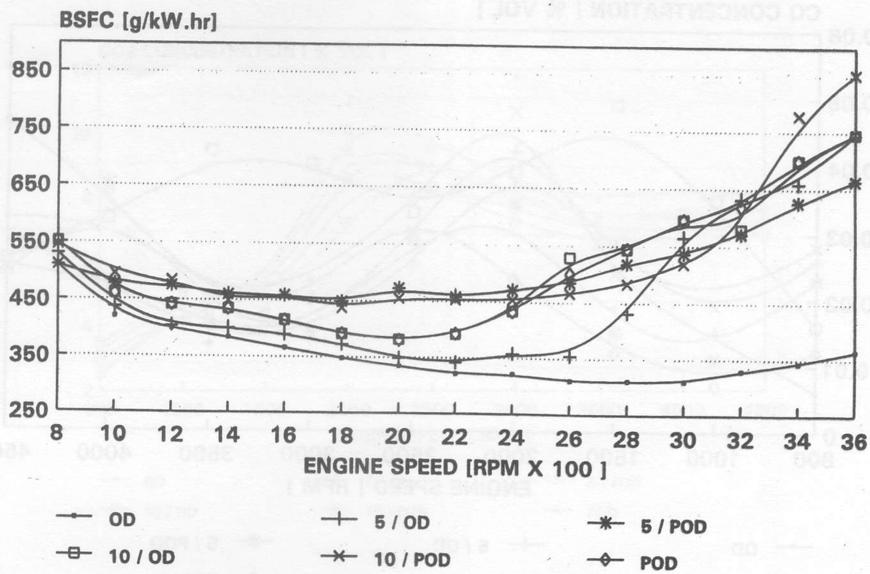

Fig. 2: Brake specific fuel consumption vs. engine speed

Engine exhaust emissions: Figure 3 shows the variation of CO concentration with engine speed. Since the operating conditions are exclusively lean, with an air/fuel ratio of around 1.8, it is observed that all values are below 0.1%. It can be seen that the CO concentration decreased slightly as the water percentage in emulsions increased. POD and its emulsions produced less CO than OD. This probably could be attributed to the presence of oxygen in POD. Figure 4 illustrates the variation of CO_2 concentration with speed. A decrease in CO_2 expressed in % vol. is observed as the content of water in emulsions increases. It is also noted that the CO_2 concentration is reduced as the engine speed increases. Figure 5 shows the variation of HC as a function of engine speed for both fuels and their emulsions. HC values are consistently below 7 ppm. It is observed that the HC concentration decreased as the engine speed increased up to 3000 rpm, at which the lowest HC concentration is found. HC concentration then increased with speed. It can be seen that there is a small reduction in HC concentration when water content is increased in the fuels.

It can be observed that the patterns of CO, CO_2 and HC appear very favourable for POD and its emulsions and they have great potential as diesel fuel substitute as they are much cleaner with reduction of CO, CO_2 and HC contents in the exhaust gas emissions and renewable, therefore they are more environment-friendly.

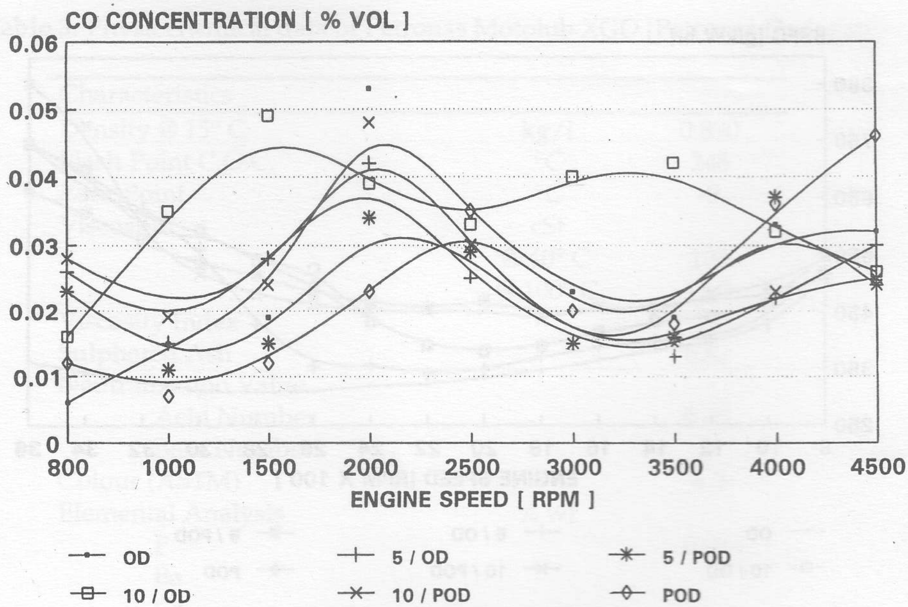

Fig. 3: CO concentration vs. engine speed

Smoke agglomerate's micrographs: Comparing the micrographs between emulsified OD and POD with 5% and 10% water shows a reduction in the mean particle size of the smoke produced as the content of water is increased. This implies that emulsification with water will marginally reduce the particulate size. This finding agrees well with Crookes' [2]. Further observation of the smoke agglomerates in Fig. 6 shows that relatively smaller chains of larger particles are collected with POD emulsions and the primary particulate size of emulsified POD are marginally greater than emulsified OD, although they are denser.

Wear debris analysis: A crank-case lube oil may be considered as much an integral part of an engine as any of its components and it must perform various vital tasks over extended periods of operation. Sliding contact between metallic components of any mechanical system is always accompanied by wear which results in the generation of minute particles of metal. In the diesel engine, the components normally subjected to wear processes are piston, piston ring, cylinder liner, bearing, crankshaft, cam, tappet and valves [12]. In a lubrication system, wear particles are in suspension in the oil. By testing a sample of lube oil from the engine after certain running duration it is possible to measure the lubricant's ability to continue to perform its original function, and also to gain information on the operation and condition of the engine.

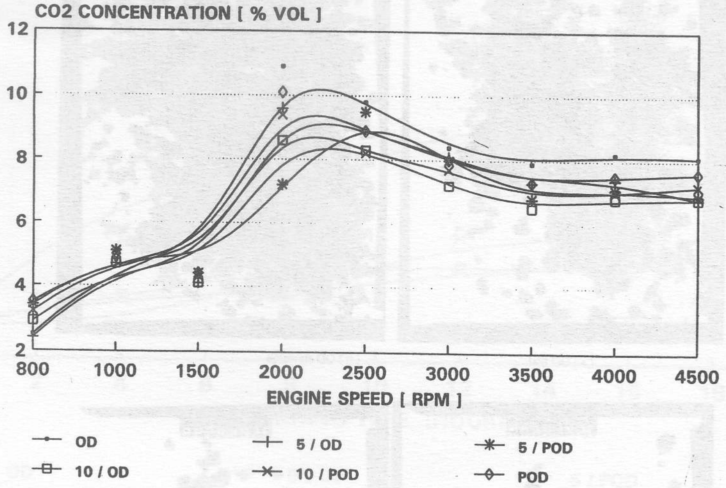

Fig. 4: CO_2 concentration vs. engine speed

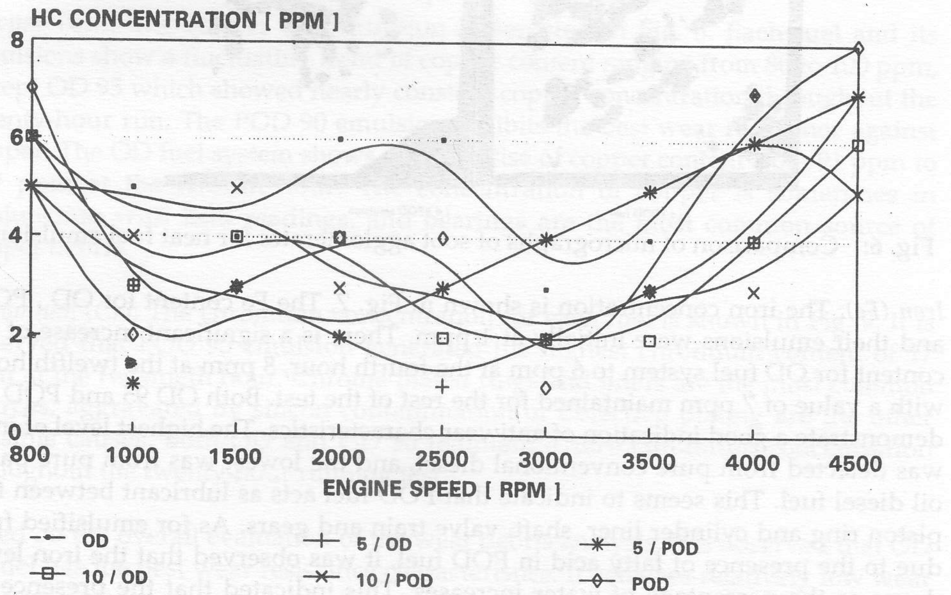

Fig. 5: HC concentration vs. engine speed

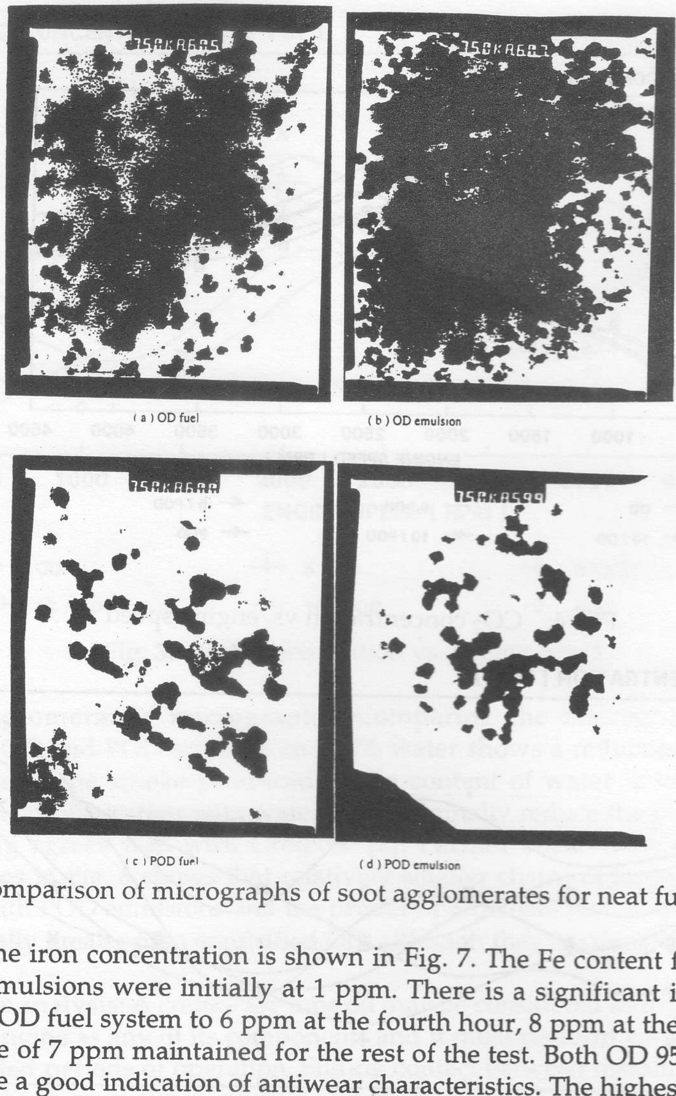

Fig. 6: Comparison of micrographs of soot agglomerates for neat fuel emulsions

Iron (Fe): The iron concentration is shown in Fig. 7. The Fe content for OD , POD and their emulsions were initially at 1 ppm. There is a significant increase of Fe content for OD fuel system to 6 ppm at the fourth hour, 8 ppm at the twelfth hour with a value of 7 ppm maintained for the rest of the test. Both OD 95 and POD 90 demonstrate a good indication of antiwear characteristics. The highest level of iron was detected from pure conventional diesel, and the lowest was from pure palm oil diesel fuel. This seems to indicate that POD fuel acts as lubricant between the piston ring and cylinder liner, shaft, valve train and gears. As for emulsified fuel due to the presence of fatty acid in POD fuel, it was observed that the iron level drops as the percentage of water increases. This indicated that the presence of water in fuel could lower the combustion temperature, this was obviously indicated by the exhaust temperature difference, and hence reduce the wear rate between engine rubbing components.

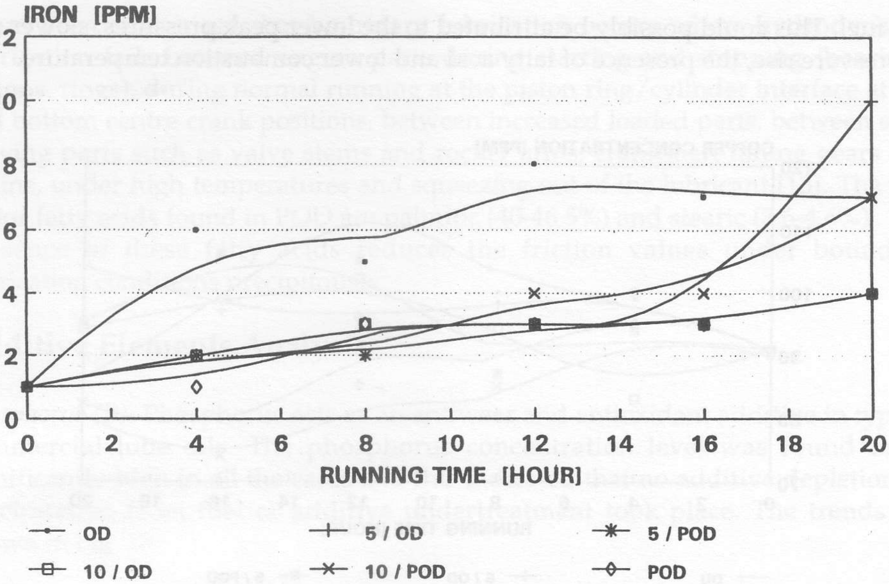

Fig. 7: Variation of iron concentration vs. running hour

Copper (Cu): The copper concentration is depicted in Fig. 8. Each fuel and its emulsions show a fluctuating trend of copper content ranging from 80 to 100 ppm, except OD 95 which showed nearly constant copper concentration throughout the twenty-hour run. The POD 90 emulsion exhibits the best wear resistance against copper. The OD fuel system shows a drastic rise of copper content from 91 ppm to 119 ppm at the twelfth hour. The concentration of copper is sometimes in conjunction with lead readings, and bearings are the most common source of copper debris.

Chromium (Cr): The chromium concentration for each fuel is shown in Fig. 9. It is observed that POD 95 emulsion generated the highest chromium content of 17 ppm at the twentieth hour. Chrome plated rings and liners are the most common sources, aggravated by silicon contamination or defective plating are the other possible causes. Both OD and OD 90 maintain a zero chromium concentration throughout the twenty-hour running test.

Based on the overall evaluation of the wear debris analysis, it is observed that OD 90 fuel has the best wear resistance characteristics. It achieves relatively low wear rates in almost every type of elements. Conversely, OD fuel system shows the worst performance in wear resistance. However, it has a good wear resistance against silicon and chromium. In general, an engine fueled with POD and its emulsions have relatively lower wear metal concentrations than that running on

OD fuel. This could possibly be attributed to the lower peak pressures, slower rate of pressure rise, the presence of fatty acid and lower combustion temperature.

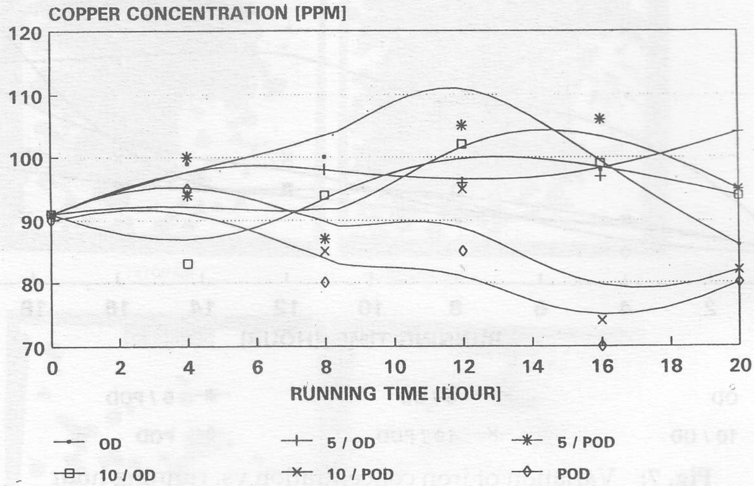

Fig. 8: Variation of copper concentration vs. running hour

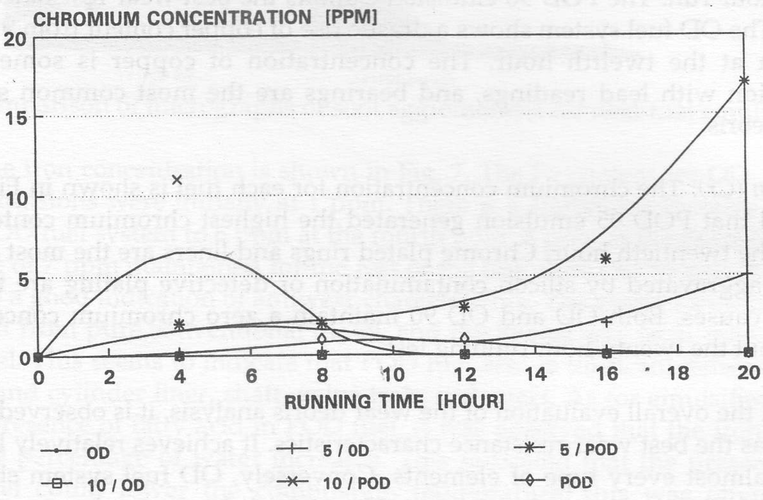

Fig. 9: Variation of chromium concentration vs. running hour

It has been recognised that boundary lubrication occurs where hydrodynamic lubrication fails between engine parts during starting and stopping (bearings, pistons, rings), during normal running at the piston ring/cylinder interface at top and bottom centre crank positions, between increased loaded parts, between slow moving parts such as valve stems and rocker arms, crankshaft timing gears and chains, under high temperatures and squeezing out of the lubricant [13]. The two major fatty acids found in POD are palmitic (40-46 5%) and stearic (3.6-4.6%) . The presence of these fatty acids reduces the friction values under boundary lubrication conditions precipitously.

Additive Elements Analysis

Phosphorus (P): Phosphorus acts as an antiwear and antioxidant additive in typical commercial lube oils. The phosphorus concentration level was found to be significantly high in all the cases and this indicated that no additive depletion by precipitation from fuel or additive undertreatment took place. The trends are shown in Fig. 10.

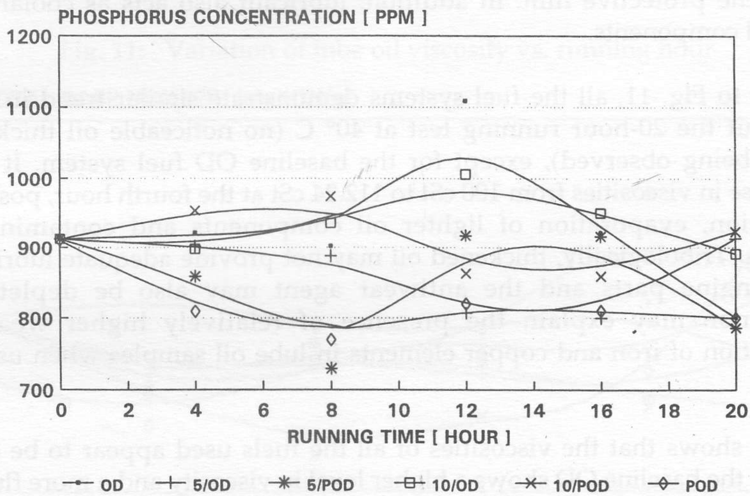

Fig. 10: Variation of phosphorus concentration vs. running hour

Injector observation: Visual inspection of the injector nozzles at the end of each running test (for a period of 20 hours) for all the various fuel systems shows that little polymerization of the fuels took place. Deposits of carbon were comparable in amount, but slight differences in color and texture were observed. Using OD fuel system , greater carbon deposit and varnish were noticed around the injector tip.

The surface of the injector using OD emulsions is generally dirtier than using POD emulsions. The percentage of water in fuel seems to influence the operation of the fuel injector. The findings here show that increasing the water content will reduce the alcohol content in the fuel system, thus resulting in heavier carbon deposit. This is due to the loss of dispersancy in lube oil since alcohol has a good solvent action [14] and has a strong affinity for dirt particles thus surrounding each with oil soluble molecules which keep sludge and varnish from agglomerating, so keeping the debris in suspension in a very fine state of dispersion in the lube oil.

Lubricating oil viscosity: Viscosity is the most important single property of a lube oil, since it is the sole property which determines the load carrying capacity at a specific load and speed. Thus, it is an important criterion of diesel engine operation as it affects the wear rate of engine components. Very high viscosity lube oil will increase the friction loss through the shearing forces of the lubricant and too low viscosity will prevent the formation of a protective film and this may even evaporate the oil under high temperature, following the mechanical reaction during combustion. Hence, at high temperatures, e.g., the surface of the combustion cylinder, lubricant with high viscosity is needed to prevent failure in forming the protective film. In addition, lubricant also acts as coolant for the lubricated components.

Referring to Fig. 11, all the fuel systems demonstrate similar trend in viscosity throughout the 20-hour running test at 40° C (no noticeable oil thickening or thinning being observed), except for the baseline OD fuel system. It shows a sudden rise in viscosities from 100 cSt to 112.24 cSt at the fourth hour, possibly due to oxidation, evaporation of lighter oil components and contamination by insolubles. Tribologically, thickened oil may not provide adequate lubrication to critical engine parts and the antiwear agent may also be depleted. This phenomenon may explain the presence of relatively higher wear debris concentration of iron and copper elements in lube oil samples when using pure OD fuel.

Figure 11 shows that the viscosities of all the fuels used appear to be constant. However, the baseline OD shows a higher level in viscosity and a more fluctuating trend. Results obtained from chemical analysis of lube oil samples also show that emulsified fuels for both POD and OD have a better viscosity performance than the baseline OD fuel since emulsified fuels are capable of maintaining a more uniform viscosity level than OD fuel.

Total base number (TBN): TBN is a measure of the lube oil's alkalinity which is an indication of its ability to counter the corrosive effects of high sulphur diesel fuels. Figure 12 shows that TBN depletion is negligible as all lies within the allowable limits for SAE 30 motor oil. Based on the wear debris and chemical analysis, it is noted that there is no direct correlation of TBN with wear rate. This agrees well with the findings of Shukla, et al, though they used methanol fuel [15].

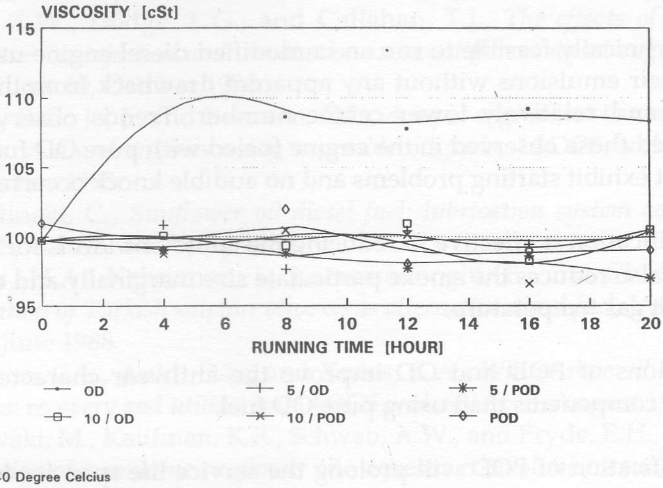

Fig. 11: Variation of lube oil viscosity vs. running hour

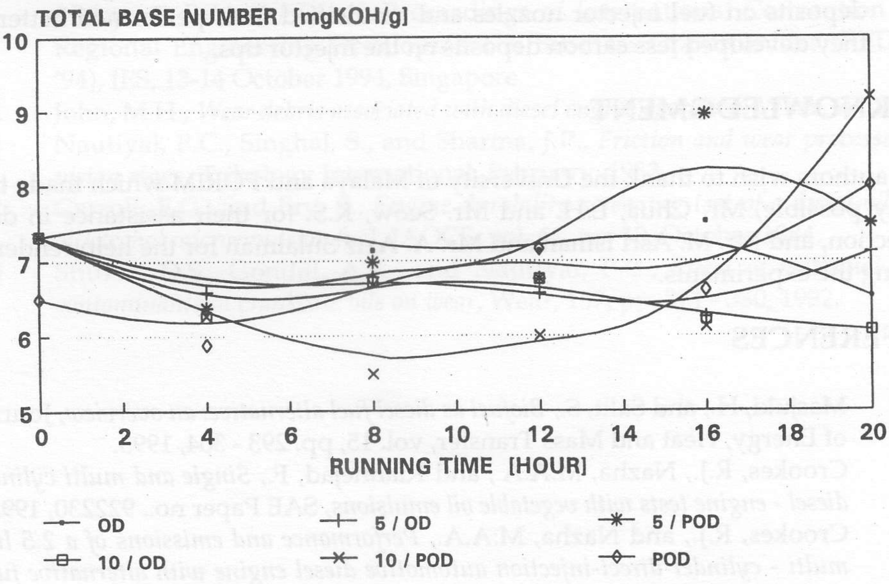

Fig. 12: Variation of total base numbers vs. running hour

CONCLUSIONS

The following conclusions may be drawn as a result of the present study:

(a) It is technically feasible to run an unmodified diesel engine using OD, POD and their emulsions without any apparent drawback from the presence of water and relatively lower cetane number. Trends observed generally followed those observed in the engine fueled with pure OD fuel. The engine did not exhibit starting problems and no audible knock occurred.

(b) Emulsification is effective in reducing the emissions levels for CO, CO_2 and HC. It also reduces the smoke particulate size marginally and exhibits lower exhaust gas temperature.

(c) Emulsions of POD and OD improve the antiwear characteristics of the engine components than using pure OD fuel.

(d) Emulsification of POD will prolong the service life span for lube oils since the lube oils are capable of maintaining a constant viscosity and TBN levels.

(e) Emulsified POD with water seemed to be effective in reducing the carbon deposits on fuel injector nozzles and emulsified fuels performed better as they developed less carbon deposits on the injector tips.

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