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Recent developments on biodiesel in Malaysia

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This paper presents recent developments on biodiesel production from palm oil, its properties and engine test results to evaluate its performance on diesel engine. The potential of palm diesel to be commercially used depends on its price comparison with diesel fuel and its status of reservation. Increasing cost and pollution effects of fossil diesel fuel can be resolved through producing vegetable oil based fuels such as palm diesel. This paper discusses Malaysian palm diesel as well as global biodiesel status, standardization of biodiesel and their commercial price consideration and various engine test results on aspects of brake power, combustion, emissions, engine wear and lubrication performance.

Keywords: Biodiesel, Emissions, Performance, Standardization, Wear

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Introduction

Biodiesel can be produced from various types of vegetable oils (palm, soybean, rapeseed etc). This paper deals with biodiesel (methyl ester of palm oil), commonly known as palm oil diesel (POD). Malaysia[1] is the biggest producer (51% of world palm oil) and exporter (62% of world exports) of palm oil and oil products. The palm oil production area has increased from 38,000 ha in 1950 to 3.5 million ha in 2001 occupying 60 percent agriculture land in the country.

The rapid expansion in oil palm cultivation resulted in a corresponding increase in palm oil production from less than 100,000 tons in 1950 to 11.8 million tons in 2004. The palm oil is the second largest oils (23.6 million tons or 20% of the world oils and fats) produced after soybean oil in 2001 (Table 1). The oil palm yields an average 3.66 ton/ha of oil per year, which is 7 and 2.5 times more than soybean and rapeseed oil respectively. Malaysia exports palm oil (11.26 million tons in 2003) to more than 100 countries; major markets are India, the European Union (EU), China, Pakistan, Egypt and Japan. Malaysian palm oil currently goes into food (80%) and in the non-food sector (20%), which includes making soaps and detergents, toiletries, cosmetics, biodiesel and other industrial usages.

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Biodiesel Production and Marketing Status in Malaysia

Since 1980s, Malaysian Palm Oil Board (MPOB) in collaboration with the local oil giant "Petronas" has begun transesterification of crude palm oil into POD. It has already been successfully demonstrated a 3000 tons per year pilot plant located in the MPOB head quarters. Malaysian government is trying to build-up a biodiesel plant (with budgetary cost about US$ 60.00 million dollars) to produce biodiesel from palm oil. This plant will produce two types of fuels: (1) Blending petroleum diesel with palm diesel; and (2) To convert palm oil into methyl ester, which can be used as fuel. Malaysia produced some 14 million tons of crude palm oil in 2004 and the government is trying to convert 500,000 tons into biodiesel. Currently, 10 percent of palm oil production has been allocated for biodiesel project. It will further stabiles the prices of palm oil in the international market and subsequently, contributes to the Malaysian palm oil industry[2] as well as partial replacement of diesel fuel.

Table 1 — World vegetable oil plantation areas and oil productions in 2001

Oils	Oil production million tons	Lead countries	Area plantation million ha
Soybean	27.8	USA & Brazil	75.8
Palm	23.6	Malaysia and Indonesia	7.0
Rapeseed	13.7	Europe	24.8
Sunflower	8.2	France & Italy	19.5
Coconut	3.5	Philippine	9.4

Consumption of diesel fuel was 3.7 billion litres and 4.84 billion litres in 2003 and 2004 respectively. At present Malaysia exports palm diesel to Korea, Germany and Japan.

World Biodiesel Status

From 1996 to 2002, world biodiesel production and production capacity has increased (Fig. 1) by a factor of four from 591,000 tons to a total of 2 million tons[3]. The EU produces biodiesel from rapeseed oil. Production capacity in the EU more than quadrupled to two million in 2004. All EU members agreed to make at least 2 percent by the end of 2005 and 5.75 percent by 2010[4]. Germany, with a volume estimated at around a million tons for 2004, is the biggest biodiesel market in the world. Biodiesel in Germany is now available at more than 1400 petrol stations with average distance between each biodiesel petrol station at about 30 km[5]. France produces biodiesel from sunflower oil and is the second largest biodiesel market in the world. It produced 390,000 tons in 2004 and had production capacity of about 490,000 tons. USA produces biodiesel from soybean oil. It produced about 160,000 tons in 2004. The World Energy, US premier producer and distributor of biodiesel, supplies biodiesel to petroleum distributors throughout the USA as well as all branches of the US military and hundreds of federal state and local fleets nationwide, helping them meet strict emissions guidelines[6]. Government of Australia has given subsidy on making new plantation to produce biodiesel from rapeseed oil.

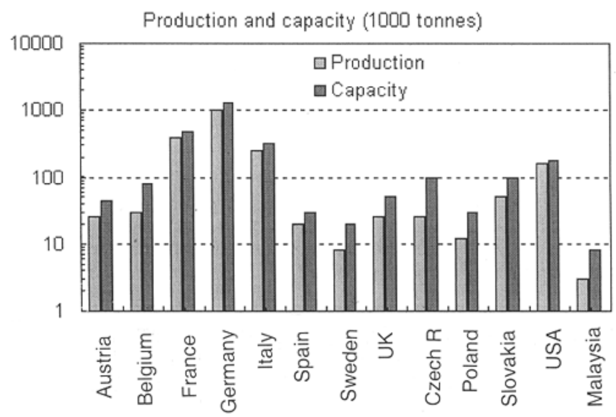

Fig. 1 — Biodiesel production and capacity in the world 2004

Biodiesel Standardization

Germany and EU have done biodiesel standard for rapeseed methyl ester and their biodiesel standard names are DIN V51606 and DIN EN 14214 respectively. The USA has produced biodiesel standard for soybean methyl ester. Japan and Korea have also produced biodiesel standards. The EU standard DIN EN 14214 is often used as the reference for other nations considering adoption of biodiesel standards although the USA has its own biodiesel standard. The field trial of palm diesel project produced promising results and standard for palm diesel compare favourably with the EU and US standards (Table 2).

Table 2 — Standardization of biodiesel

Properties	Malaysia[a]		EU[5]		US[b]	
	Testing procedure	Typical value	Testing procedure	Typical value	Testing procedure	Typical value
Density at 15 °C, g/ml	ASTM D1298	0.870	EN ISO 3675	0.860 to 0.900	—	—
Kinematics viscosity at 40 °C, mm^2/s	ASTM D445	4.44	EN ISO 3104	3.5 to 5.0	ASTM 445	1.9 to 6.0
Flash point, °C	ASTM D93	174	ISO 3679	120 min	ASTM D93	100 min
Sulfur content, wt%	IP 242	0.04	ISO 4260	0.01 max	ASTM 2622	0.05 max
Carbon residue (10% dist.), wt%	ASTM D189	0.11	ISO 10370	0.03 max	ASTM 4530	0.05 max
Ash, wt%	-	-	ISO 3987	0.02 max	ASTM 874	0.02 max
Cetane number	ASTM D613	52	ISO 5165	51min	ASTM 613	40 min

[a] MPOB Technology No. 18, PETRONAS Technical Report on POD; [b]JAOCS, **7** (1996), 829.

Table 3 — Specification of diesel engine being used

Engine	Isuzu
Model	4FB1
Type	Water-cooled, 4 strokes
Combustion	Indirect Injection (IDI)
Number of cylinders	4
Bore x Stroke	84 x 82 mm
Displacement	1817 cc
Compression ratio	21 : 1
Nominal rated power	39 kW/5000 rpm
Maximum torque speed	1800 – 3000 rpm
Dimension (LxWxH)	700 x 560 x 635 mm
Cooling system	Pressurized circulation

Experimental Research using Palm Diesel on IC Engine

Research on the use of palm oil as a diesel fuel alternative had been conducted at MPOB[7], the University of Technology Malaysia[8,9], The University of Malaya[10-12], Proton (National Automobile Industry of Malaysia) and Castrol Malaysia Co. Ltd. The cetane number of POD (52) was slightly lower than that of conventional diesel (53) but within an acceptable range[7]. A field trial[7] concluded that the consumption of palm diesel on the average was 12 km/l compared with 13 km/l for petroleum diesel on 1.8 litre category cars. Moreover, at speed more than 80 km/l, palm diesel gave better fuel economy than conventional diesel. Another study conducted on the use of POD in Yammer TF80 and Isuzu 4FB1 diesel engines[12] showed that the output differed only marginally compared to that of conventional diesel. The fueling rate and the specific mass fuel consumption for both engines were both higher (15-20 %) with POD as compared with conventional diesel. The brake specific energy consumption, of both engines was found to be similar, with POD having a slightly lower thermal efficiency over conventional diesel. In a study of dynamic combustion events in Ricardo engines[7,9] at 2.5 bar brake mean effective pressure, POD gave ignition delay periods between 1 and 2 degrees (crank) earlier than conventional diesel from low to high speeds, which under high load (5.5 BMEP) palm oil gave an ignition delay 1 degree shorter than when run on diesel. This indicated its readiness to burn more rapidly after injection than diesel.

While studying exhaust gas emissions[8,9-11] with POD, percentage of CO_2 although negligible, was found higher compared to conventional diesel due to better combustion. The hydrocarbon (HC) emissions were similar or less than diesel. Using palm diesel and its emulsions in an indirect injection diesel engine, emulsification was found effective in reducing emissions[13] level for CO, CO_2, HC, NOx, SOx and smoke particulates. It also reduced smoke particulate size marginally and exhibited lower exhaust gas temperature. However, pure (100%) palm diesel produced higher NOx than diesel fuel, due to non-volatile ash carbon deposit on piston-cylinder head[14]. POD corrodes and wears the engine components due to oxygen[15], which is also a reason to produce higher NOx than diesel fuel.

In this investigation, POD (7.5-15 % instead of 50-100%) has been blended[10-13] with diesel together with anticorrosion additive to resist wear concentration. The objective of this investigation is to evaluate the effect of anticorrosion additive in POD blend on engine performance, emissions and wear characteristics.

Experimental Setup and Procedures

The specifications of the indirect injection (IDI) diesel engine are shown in Table 3. The dynamometer instrumentation used in this investigation was fully equipped in accordance with SAE standard J1349 JUN90. A variable speed range (800-3600 rpm) with half-throttle setting was selected for performance (brake power) and emissions tests. The same test procedure and practice were followed for all the fuels. A Bosch gas analyzer model ETT 008.36 was used to measure HC and CO emissions. A Bacharach model CA300NSX analyzer (Standard version, k-type probe) was used to measure NOx concentration in vppm (parts per million by volume).

A constant 2000-rpm with half throttle setting was maintained throughout the wear and lubricating oil test period for all the blended fuels. For three test fuels, the engine was operated a total of 300 h at 100 h with each of the test fuels. The sample of lubricating oil was collected through a one-way valve connected to the crankcase sump at 10-h intervals. The first sample was collected immediately after the engine had warmed up. For diesel fuel, the engine was started using new lubricating oil and after 10-h, the engine was stopped for few sec to collect first sample, then the engine was restarted for 10-h to collect the second sample and so on, and ultimately, after 100-h

Table 4 — Test sequence and fuels composition

Test sequence	Fuel	Compositions	Lube oil
Test-1	OD*	100% ordinary diesel	*SAE 40
Test-2	B7.5	50 ppm (corrosion inhibitor) additive +7.5% POD+ 92.5% OD	SAE 40+ 0.1% (Corrosion inhibitor) additive
Test-3	B15	50 ppm (corrosion inhibitor) additive +15% POD+85% OD	SAE 40+ 0.1% (Corrosion inhibitor) additive
	POD	100% palm oil methyl ester	

* No additive

Table 5 — Major properties of fuels

ITEMS	OD	B7.5	B15	POD
High calorific value, MJ/kg	46.80	45.99	45.77	41.30
Kinematic viscosity, cSt @ 40 C	3.60	3.63	3.97	4.71
Cetane number	53	52	51	50-52
Specific density, g/cm^3	0.832	0.840	0.848	0.875

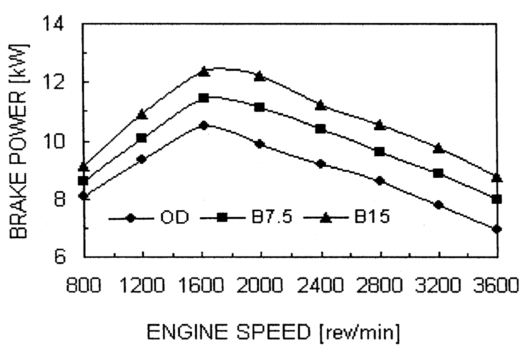

Fig. 2 — Brake power vs engine speed

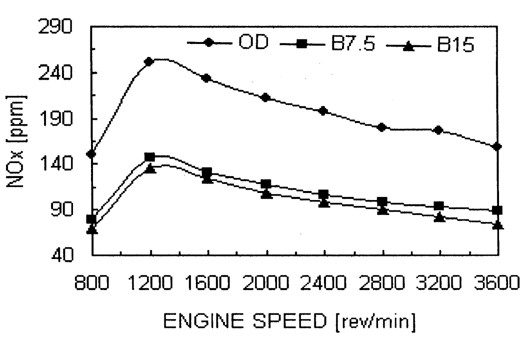

Fig. 3 — NOx concentration vs engine speed

operation, the fuel and lubricating oil were replaced by new one, and the same procedure was followed for all the test fuels (Table 4). The same conventional diesel compatible lubricant was used for all the test fuels. After collecting, the sample was immediately analyzed to obtain wear, additive and TBN results. The physicochemical data of pure lubricating oil and the analysis method of used lubricating oil characteristics can be found elsewhere[13].

Tested Fuels

POD (Table 5) is just like diesel fuel but reddish and its blends does not create any separation or any layer on the inside wall of the fuel tank. In this investigation, B7.5 and B15 have been used to measure overall engine performance. The lube oil[14] was PETRONUS MOTOLUB XGD (SAE 40). IRGANOR NPA (product name) was used as the corrosion inhibitor, which is claimed to improve the corrosion control in lube oil. When it is added to fuels, metal protection limits the formulation of ions, which catalyze oxidation processes to gum formation. It is also known as corrosion inhibitor. It is used in this experiment in blending with fuel and lubricant with different compositions.

Results and Discussion

All tests and data analysis were performed for different fuels in the Tribology Laboratory, Department of Mechanical Engineering, University of Malaya. The data were used to evaluate differences in these fuels and to serve as a basis of comparison of blended fuels with OD.

Engine Performance

The brake power (Fig. 2) increases with increasing POD blend concentration over the speed range compared to OD. Fuel B15 produced the maximum brake power (12.4 kW) at 1600 rpm followed by fuel B7.5 (11.44 kW) and fuel OD (10.48 kW). The reason of increasing brake power with increasing POD in blends is the effect of addition of corrosion inhibitor in POD blends that influences conversion of heat energy to work or increases fuel conversion efficiency through the complete combustion. On average, fuel B15 produced higher (10-15%) brake power than OD. This is the effect of additive that enhances POD in producing higher power.

Exhaust Emissions

Raising POD blend (7.5-15%), the exhaust NOx level decreased from 147 ppm to 135 ppm at 1200 rpm (Fig. 3). The difference was mainly due to the

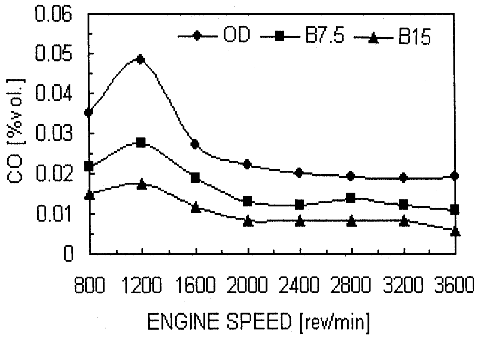

Fig. 4 — CO concentration vs engine speed

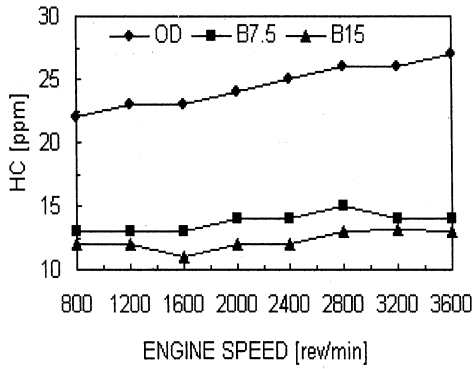

Fig. 5 — HC concentration vs engine speed

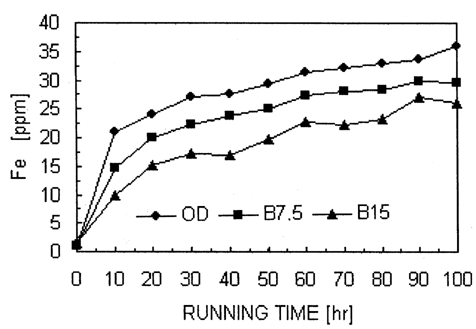

Fig. 6 — Fe concentration vs running time

reduction in combustion temperature caused by POD blends with additive. It can be attributed to the fact that POD blend (with additive) reduces heat release rate at premix combustion phase, which lowers the peak combustion temperature, hence reduces NOx emissions. The reason[16] for producing lower combustion temperature by vegetable oil and POD is their chemical bond/properties (in saturated fatty acid) together with the effect of fuel additive that limits the formulation of ions, which catalyse oxidation processes. POD blended fuel has positive effect on CO concentration because a naturally aspirated or turbo-charged diesel engine uses more oxygen (excessive air) to burn the fuel. Since the operating conditions are exclusively lean, with an air/fuel ratio of around $1.8 \times$ stoichiometric, CO concentration values for all fuels is low (Fig. 4) as even less than 0.1 percent (maximum tolerable 1%). Increasing POD concentration in blends has a beneficial effect in reducing HCs emissions (Fig. 5). The reduction in HC is mainly the result of complete combustion of POD blends within the combustion period as confirmed by combustion characteristics[13,16] such as net heat release rate and mass burn fraction. Around 60 percent mass (of each test fuels) was burnt within 0 to 20 deg. ATDC (after top dead center) and the remaining fuel mass was burnt within 20 to 50 deg. ATDC. The HC species during POD fuel oxidize better than OD fuel, due to higher heat release rate and higher cylinder pressure at the expansion stroke. On average, a reduction in HCs (45%) was obtained with fuel B15 in comparison to OD fuel. Hence, POD blended fuels with the corrosion inhibitor additive could be effective as alternative fuels for diesel engines because they reduce emissions levels of NOx, CO and HC.

Engine Wear

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 diesel engines, components that are normally subjected to the wear and tear process are piston, piston ring, cylinder liner, bearing, crankshaft, cam, tappet and valves[17]. In a lubrication system, wear particles remain in suspension in the oil. By analyzing and examining the variations in concentration of the metallic particle in the lubricant oil after certain running duration, sufficient information about wear rate, source of element and engine condition can be predicted.

Wear Metals and Additives

Multi element oil analyzer (MOA) was used to measure wear metals debris (Fe, Cu, Al, Pb) and additives (Zn, Ca) depletion (Figs 6-11). Wear metals debris reduced with increasing POD in to blends. Fuel B15 produced the lowest level of wear concentration followed by fuel B7.5 and OD. Fuel B15 produced Fe concentration of 26 ppm followed by fuel B7.5 (29 ppm) and OD (36 ppm) at the end of 100-h (Fig. 6). Similar trends of reduction of wear were found in metal concentration for Cu (Fig. 7), Al (Fig. 8) and Pb (Fig. 9). The reason to decrease wear metals when using blended fuels is the effect of the

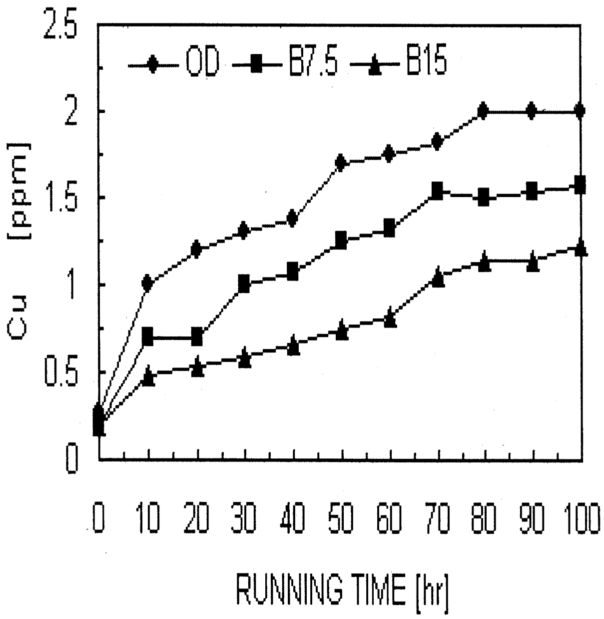

Fig. 7 — Cu concentration vs running time

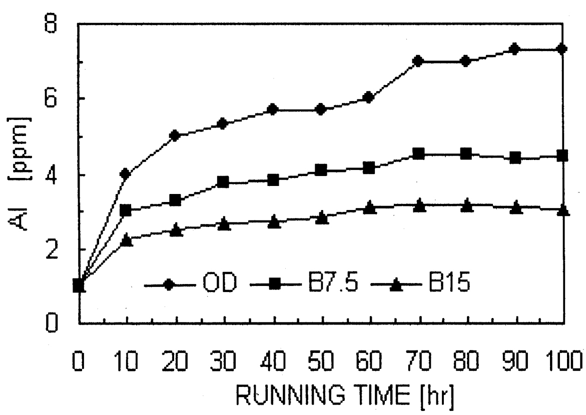

Fig. 8 — Al concentration vs running time

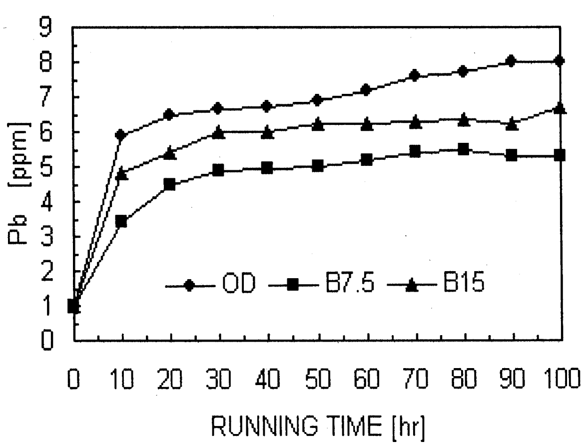

Fig. 9 — Pb concentration vs running time

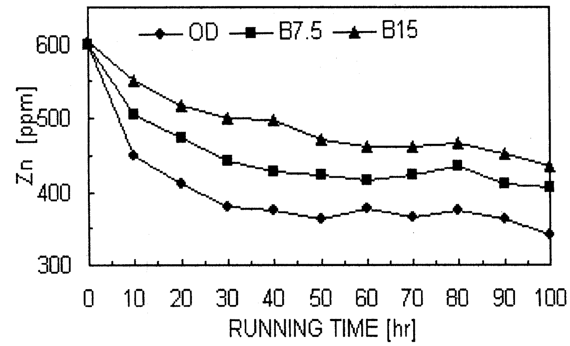

Fig. 10 — Zn concentration vs engine operation time

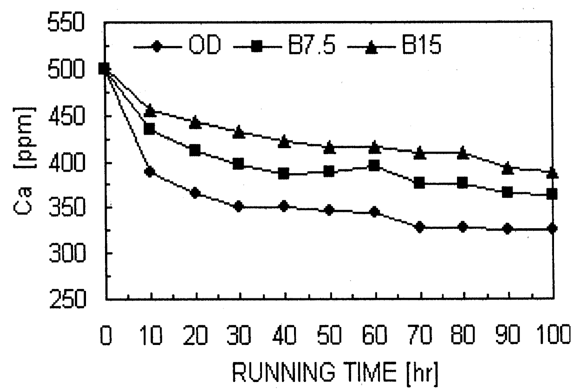

Fig. 11 — Ca concentration vs engine operation time

corrosion inhibitor in fuel and lube oil that control corrosion as well as oxidation in lubricating oil. Additive compounds (Zn, Ca), used as detergents in typical commercial lube oil, provide an alkaline reserve to neutralize acidic by-products of combustion. Detergents react with oxidation products to reduce the formation of insoluble and provide some measure of corrosion protection[18]. The depletion of lubricant additives (Zn, Ca) decreased with increasing POD in blends. The lowest level of depletion occurred by fuel B15 followed by fuel B7.5 and OD. After 100-h of engine operation, depletion of Zn for fuel B15 was 435 ppm followed by fuel B7.5 (406 ppm) and OD (341 ppm). Addition of 50 ppm corrosion inhibitor of Zn (Fig. 10) and Ca additive (Fig. 11) with POD was effective in lowering depletion levels.

Viscosity

Viscosity of lubricating oil affects the wear rate of engine components. Very high viscosity lubricating oil increases the friction loss through the shearing forces of the lubricant preventing the formation of a protective film. During engine operation at normal temperature, a small amount of fuel is normally diluted in the lubricating oil. During engine starting, rich mixtures of fuel and air, and low ambient

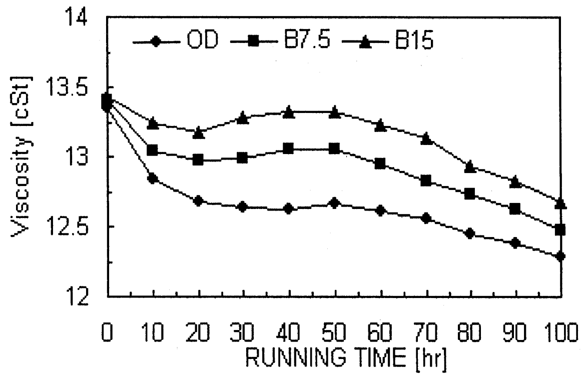

Fig. 12 — Viscosity vs running time

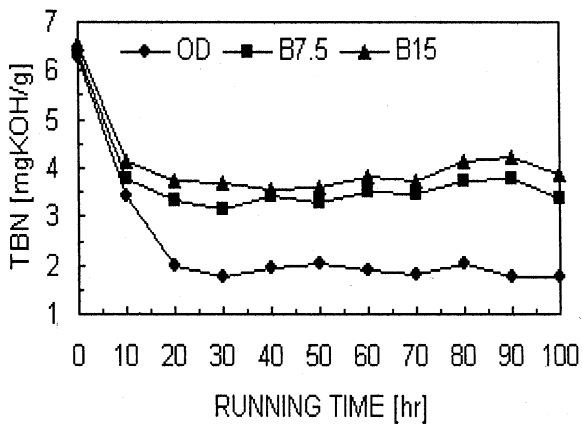

Fig. 13 — TBN concentration vs running time

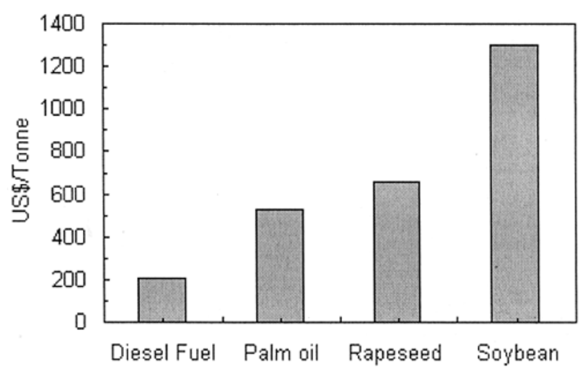

Fig. 14 — Prices of diesel fuel and vegetable oils

temperature promote fuel dilution. High dilution reduces oil viscosity, pour point, and flash point and diminishes the oil load-carrying ability. Viscosity at 100 °C (Fig. 12), indicate that there is no significant variation between POD blends and the base fuel OD. Viscosity of used lube oil during operation on POD blends decreased lower to the addition of the anticorrosion additive and lubricating oil in comparison to base fuel OD. At the start of the test, viscosity value for all the fuels was 13.4 cSt, and after 100-h engine operation, viscosity value for fuel B15 was 12.68 cSt followed by fuel B7.5 (12.47 cSt) and fuel OD (12.28 cSt). However, viscosity variation did not exceed the limits (lower 12 cSt, upper 14 cSt) for SAE40 lube oil[18] during the engine operation on POD blends as well as OD.

Total Base Number (TBN)

TBN is a measure of oil alkalinity, which is an indication of its ability to counter corrosive effects due to oxidation. Higher TBN values mean more stability of lubricating oil. Positive TBN value indicates the absence of free strong acids[18]. TBN depletion of fuel B15 was lower followed by fuel B7.5 and base fuel OD (Fig. 13). This is because corrosion inhibitor, which was added with POD blends and lube oil during engine operation on POD blends, reduced TBN depletion through controlling corrosion (caused due to oxidation). Original TBN value for all the fuels system was 6.5 mgKOH/g. At the end of 100-h engine operation, TBN value was: B15, 3.88; B7.5, 3.38; and OD, 1.76 mgKOH/g.

Future Demand of Biodiesel Fuels

Around 38 percent of world petroleum products are being used in the transportation sector[19,20]. The demand of petroleum products is expected to increase until 2010 and after that, will reduce due to the commercialization of alternative fuels. The most common alternative fuels are compressed natural gas (CNG), liquefied natural gas (LNG), liquefied propane gas (LPG), methanol (M85 or M100), ethanol (E85 or E100), electricity and hydrogen (usually a fuel cell vehicle). None of these fuels is ideally suited for use in diesel engines. However, currently the total number of vehicles operated using those alternative fuels is 360,000 on the roads in America with well over 1.8 million worldwide[21]. In some European countries, biodiesel is sold commercially. Some US demonstration programs are using biodiesel with more than 300 vehicles, including buses, trucks, construction/maintenance equipment, and motorboats, etc. In France, there are 2,000 vehicles including buses and trucks running on rapeseed methyl ester. Malaysia is producing palm oil diesel (3000 million tons/y) that is used in transit fleet, bus and cars[22]. Therefore, the demand of biodiesel movement to the market is fully dependent on the availability of diesel oil and its official prices. After 5-10 years, demand of biodiesel will be increased in Europe, USA and some countries in Asia like Thailand and Malaysia.

The production cost of biodiesel is dependent on the regional prices of biofuel, labour, land and processing plant cost etc. In Malaysia, price for net biodiesel production per litre is about 60 cent (US$) and the same for diesel is about 21 cent (Fig. 14).

Conclusions

Vegetable oil as well as biodiesel production is increasing worldwide and at present Germany holds leading position in biodiesel production and utilization followed by France, Italy and USA. Physico-chemical properties of POD meet requirements of diesel engine combustion and are comparable with other biodiesels such as soybean and rapeseed oils. Fuel B15 increased brake power and reduced exhaust emissions compared to base fuel OD. It decreased wear metals (Fe, Cu, Al and Pb) and additives (Zn, Ca) depletion as compared to OD. Viscosity changes are normal for both the POD blends. TBN decreases with increasing POD in blends. Hence, an anticorrosion additive is effective with POD blends. Vegetable oil price is higher than diesel fuel; hence government subsidy and production need to be increased to move the biodiesel markets.

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