An Alternative Fuel for Automobiles (Vegetable Oils)

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Abstract: - The growing economic risk of relying primarily on fossil fuels with limited reserves and increasing prices has increased the interest on alternative energy sources. Clean and renewable biofuels have been touted as the answer to the issue of diminishing fossil fuels. Countries like Malaysia, the largest producer of palm oil has committed to focus interest on biofuels, namely, palm biodiesel. Since palm oil has a high fossil energy balance, it is a key source of raw material for biodiesel production. This paper presents palm biodiesel as an alternative source of green renewable energy through a survey conducted from previously researched findings. The production of palm biodiesel is discussed by the transesterification reaction of triglycerides of refined palm oil to yield palm methyl ester (palm biodiesel) and glycerin as a by-product. Physical-chemical properties of palm biodiesel are compared to that of petroleum diesel. This survey reveals a conclusion from experiments , in which palm biodiesel blends and crude palm oil (CPO) are injected into compression ignition (diesel) engines to compare performance characteristics with that of petroleum ,diesel. Experimental results reveal that majority characteristics of CPO and palm biodiesel blends meet the combustion requirements of diesel engine combustion, by providing: low fuel consumption, less concentration of exhaust gas emission, higher combustion pressure and longer combustion period. However, contrary to its advantages palm biodiesel produces marginally low performance in terms of torque, thermal efficiency and higher exhaust gas emissions as compared to petroleum diesel. Thus, majority positive results obtained conclude that, palm oil biodiesel can be considered as an alternative source of green renewable energy to meet the energy demands of the future.

Keywords: Biofuels, Palm biodiesel, Palm methyl ester, Crude palm oil, Transesterification, Compression ignition engine, Direct-injection diesel engine.

I.INTRODUCTION

After the energy crisis in the mid 1970s, every country has tried to find a new energy that can replace petroleum specifically, vegetable oil, the most promising alternative fuels. Vegetable oils cannot be used directly in diesel engines because of the problem associated with it of the using pure vegetable oils as fuels in diesel engines. There are more than 350 oil bearing crops identified, among which only sunflower, soybean, cottonseed, rapeseed and peanut oils are considered as potential alternative fuels for diesel engines. The most detrimental properties of these oils are their high viscosity, low volatility, poor atomization and auto-oxidation. Recently considerable attention in developing countries such as Malaysia, Indonesia and Thailand has been drawn to the production of biofuels from domestic, renewable resources. Biofuels are currently being considered from multidimensional perspectives, i.e. depleting fossil fuels, resources, environmental health, energy security and agricultural economy. The two most common types of biofuels are ethanol and biodiesel.

Research on the use of vegetable oils as fuel substitutes in diesel engines have been done in many countries. Peter *et al*. (1982) used degummed soybean mixed with petroleum diesel at the ratio of 2:1 as a fuel in a diesel engine. After 600 hours of running it was found that the engine performance did not alter. Other researchers found that 95% vegetable oil blending with 5% petroleum diesel in a diesel engine gave no problems of carbon deposit on the engine parts or in the fuel injector. Adam *et al*. (1983) tested an agricultural machine with blended oil (soybean oil and petroleum diesel) and found that by using soybean blended with petroleum diesel in the ratio of 2:1, the engine worked well. Kevin *et al*. (1999) concluded that by using semi-refined rapeseed oil (SRO) in a direct injection diesel engine, the power output reduced by 0.06% for every 1% increase in SRO inclusion rate and the brake specific fuel consumption increased by 0.14% per 1% increase in SRO inclusion rate. Chiyuki and Jun-ichi (1998) concluded that de-acidified rapeseed oil could be used in a single cylinder Yanmar IDI diesel engine but degummed and crude rapeseed oil were unsuitable for use as fuel due to the high level of incombustible materials in the oil. Suporn (1987) found that using 100% refined palm oil in a Kubota diesel engine model KND 5B resulted in the best power output and best emission while using 70% refined palm oil blended with 25% diesel resulted in the best specific fuelconsumption.

For vehicles powered with diesel engines, an alternative substitute of diesel fuel has been developed namely, biodiesel. It is produced from the chemical bonding of an alcohol with oils, fats, greases or chemically known alkyl esters. These esters have similar properties as the mineral diesel fuel and even better in terms of its cetane number. In addition, biodiesel is better than diesel fuel in terms of suplhur content, flash point and aromatic content. As a liquid fuel, biodiesel is simple to use and can be used in compression ignition (diesel) engines without modifications. It also can be blended at any level with petroleum diesel to create a biodiesel blend. Regarding these qualities of vegetable oils, Malaysia has committed to investigate the use of biodiesel with blends of palm oil as an alternative fuel for diesel engines. This paper presents palm biodiesel as an alternative green renewable biofuel for diesel engines.

BIODIESEL

1.1 Overview

Biodiesel has a major advantage over petroleum diesel, since, it is derived from renewable sources it is a clean burning fuel that does not contribute to the increase of carbon dioxide, being environmentally friendly. Biodiesel is an oxygenate, sulphur-free and biodegradable fuel, and its content of oxygen helps improve its combustion efficiency Therefore, fewer green house gases such as carbon dioxide are released into the atmosphere. Biodiesel has positive performance attributes such as increased cetane, high fuel lubricity, and high oxygen content. Since, biodiesel is more lubricating than diesel fuel, it increases engine life and it can be used to replace sulphur, a lubricating agent, that when burned, produces sulphur oxide; the primary component in acidrain.

1.2 Transesterification Process

Biodiesel is a very versatile transport fuel and can be produced from local raw material or collection of used vegetable or frying oil in rural regions of developing countries. There are three basic routes to biodiesel production from oils and fats.

- Base catalyzed transesterification of the oil
- Direct acid catalyzed transesterification of the oil
- Conversion of oil to its fatty acids and then to biodiesel

Transesterification reaction is a stage of converting oil or fat into methyl or ethyl esters of fatty acid, which constitutes to biodiesel. Biodiesel (methyl ester) is obtained through the reaction of triglycerides of vegetable oils with an active intermediary, formed by the reaction of an alcohol with a catalyst. The general reaction for obtaining biodiesel through transesterificationis.

$$\textbf{\textit{Oil or Fat + Methanol}} \downarrow\!\rightarrow \quad \textbf{\textit{Methyl Esters + Glycerol}} \tag{2.1}$$

or

$$\text{Oil or Fat + Methanol} \downarrow\!\rightarrow \quad \textbf{\textit{Ethyl Esters + Glycerol}} \tag{2.2}$$

Transesterification reactions may employ various types of alcohols, preferably, those with low molecular weight, with the most studied ones being the methylated and ethylated alcohols. Studies have shown that transesterification with methanol is more viable technically than with ethanol. Ethanol may be used as long as it is anhydrous (with a water content of less than 2%), since the water acts as an inhibitor reaction. Another advantage in using methanol is the separation of glycerin (obtained as a by-product of the reaction) from the reactive medium, since, in the case of synthesis of the methylated ester, this separation may be easily obtained through simple decantation. Figure 1 illustrates the simplest procedure of manufacturing biodiesel through transesterification with vegetable oil.

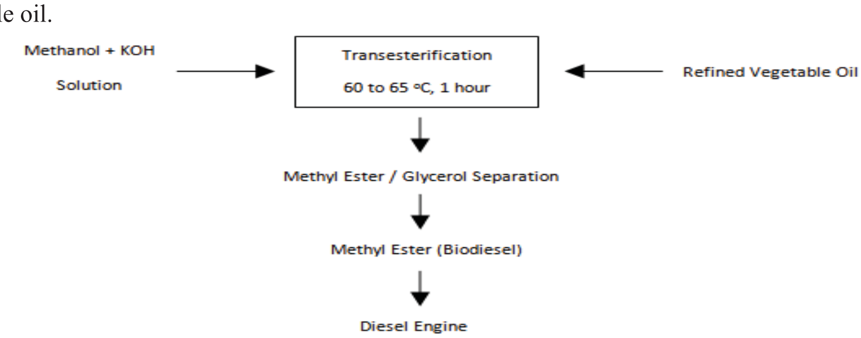

Figure 1. Procedure of manufacturing biodiesel through transesterification with vegetable oil

This reaction can be catalyzed by alkalis, acids, or enzymes. Alkalis include sodium hydroxide, potassium hydroxide, carbonates, and corresponding sodium and potassium alkoxides such as sodium methoxide, sodium ethoxide, sodium propoxide, and sodium butoxide. Sulphuric acid, sulfonic acids, and hydrochloric acid are usually used as acidic catalysts. In the industry, transesterification is generally done with alkali mediums, because they present better yield and lower reaction time. The production of biodiesel by transesterification of vegetable oil uses the following steps

1. *Mixing of alcohol and catalyst:* Potassium hydroxide (KOH) and sodium hydroxide (NaOH) are generally used as alkaline catalysts with methanol (CH3OH) for production ofbiodiesel.

2. *Reaction:* The alcohol/catalyst mix is charged into a closed reaction vessel and the vegetable oil is added. The reaction mixture is heated to the boiling temperature of the alcohol (normally 50 to 60 °C) and is refluxed for a certain length of time under agitation. The reaction mixture has a conversion efficiency of 96% to 99% in relatively short times (around 60 minutes). When agitation is stopped the reaction mixture separates into an upper layer of methyl esters and a lower layer of glycerol diluted with un-reacted methanol.

3. *Separation of glycerin and biodiesel:* Once the reaction is complete, two major products are produced: glycerin and biodiesel (methyl ester). The quantity of produced glycerin varies according to the vegetable oil used, the process used, and the amount of excess alcohol used. Both glycerin and biodiesel products have a substantial amount of the excess alcohol that is used in the reaction.

4. *Removal of alcohol:* The fatty ester produced in the upper layer is neutralized and vacuum distilled for removal of excessmethano.

5. Glycerin neutralization: The by-product glycerin contains unused catalyst and soaps in the upper layer that are neutralized with phosphoric acid resulting in potassium phosphate, if potassium hydroxide is used as a catalyst. The crude glycerin is sent for storage.
6. Methyl ester washing: The methyl ester produced from the reaction is then washed with hot water and separated out buy configuration.

The transesterification process, involving transformation of the large, branched, triglyceride molecule into smaller, straight chain molecules is shown in Figure 2.

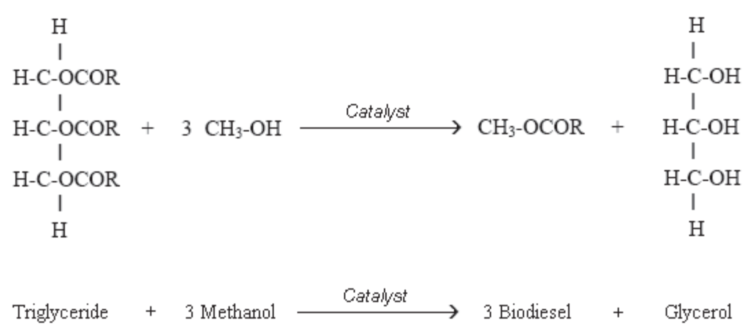

Figure 2. Transesterification reaction of methanol and triglyceride in manufacturing of biodiesel

1.2 *BiodieselDemand*

Transportation fuels are currently the main refinery products around 38% of the world's petroleum products, being used in the transportation sector. It is expected that the demand of petroleum products will increase until 2010 and after that, will reduce due to the commercialization of alternative fuels. The most common alternative fuels currently in use are: compressed natural gas (CNG), liquefied natural gas (LNG), liquefied propane gas (LPG), methanol (M85 or M100) and ethanol (E85 or E100). Currently, the total number of vehicles operated using alternative fuels is 330,000 in the United States, with well over 15 millionworldwide.

II. PALM OIL

i.Overview

Oil palm, an oleaginous tropical plant, has the highest oil productivity per unit of land on earth. In terms of its usage, palm oil has various uses as a food, (oils, margarines, bread, mayonnaise, feeds, ice cream, cookies etc), in industry (soap, lubricants, detergents, plastics, cosmetics, rubber etc), in steel making, the textile industry, pharmacologyetc.

Among other crops for producing fuel, palm oil demonstrates good competitiveness, as can be seen in Table 1. Palm oil blended diesel has emerged as an alternative fuel for an internal combustion engine satisfying certain criteria, such as requiring minimum engine modification, offering uncompromised engine life and not being hazardous to human health and the environment during production, transportation, storage and utilization. Direct use of crude palm oil has been shown feasible in the Elsbett engine. However, a problem of clogging of the filter by impurities is observed, which can be eliminated by using processed liquid palm oil (PLPO) directly or in blends with petroleum diesel to overcome this problem.

Table 1. Sources of fuels of plant origin and their yields in alcohol and oil

Source	Fuel	Yield (kg oil/hectare)
Sugar cane	Alcohol	3,015
Manioc	Alcohol	2,160
Babassu palm	Oil	240
Oil palm	Oil	5,000
Castor plant	Oil	1,600

As shown in Table 1, oil palm appears, together with sugar cane, as the crop with the highest yield as a source of fuel, with sugar cane destined for alcohol production and oil palm for oil production. Depending upon the raw material used for production, methyl ester may contain fewer or more unsaturated fatty acids in its composition, which are more susceptible to an accelerated oxidation reaction due to exposure to oxygen and high temperature, conditions that are relevant to motor operation. Thermal decomposition may also lead to polymeric compounds that are also prejudicial to the motor operation. Approximately 98% of crude palm oil is made up of fatty acids as shown in Table2.

Table 2. Composition of fatty acids in palm oil

Fatty acid	Fuel	% in Palm oil
Saturated	Palmitic (C16)	32-45
	Stearic (C18)	2-7
Unsaturated	Oleic (C18:1)	38-52
	Lineleic (C18:2)	5-11

It is observed that, palm oil has an average composition centered mainly on two fatty acids: palmitic (16:0) and oleic (18:1). The real proportion in fatty acids is maintained constant after the reaction. Thus, it is clear that palm oil promotes optimal impact on the environment and is able to meet a sizeable proportion of the world's energy of oils and fats.

2.2. Palm Biodiesel

Blends of palm biodiesel have become promising renewable fuels for diesel engines, which have been paid more attention in Malaysia. Blends of 20% palm oil with 80% petroleum diesel have been currently used in unmodified diesel engines, and higher blends even crude palm oil (CPO) has been used for experimental purposes in some diesel engines with little or no modification.

Commercial production of palm biodiesel in the Malaysian biodiesel industry uses refined, bleached and deodorized palm oil in the presence of excess methanol and alkaline catalyst, which is heated to the transesterification reaction temperature and is passed through multi- stage continuous reactors. These reactors are used in a series to maximize the reaction conversion. Glycerol is removed after each reactor. After the reaction is completed, the excess methanol is recovered by flashing through the flash vessels and is distilled by using a methanol purification column with structured packing. The recovered methanol is then recycled and reused in the reaction process. The crude biodiesel is washed using hot water and is separated by centrifugal separation. The biodiesel is then dried under vacuum to achieve low moisture content of the final product, and is sent to the storage tanks. The glycerol is flashed to recover methanol and is sent to the storage tanks as crude glycerol. A flowchart of the commercial production of palm biodiesel in the Malaysian biodiesel industry is shown in Figure 3.

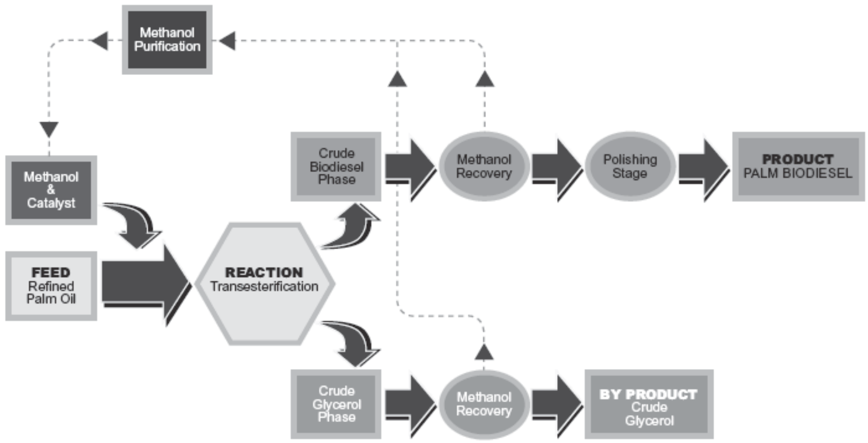

Figure 3. Flowchart of commercialized palm biodiesel production

Evaluation of the carbureting quality of vegetable oils requires the determination of their physical and chemical properties, such as: calorific value, cetane level, distillation curve, viscosity, cloud point etc. Table 3 compares the physical-chemical properties of palm biodiesel to that of petroleum diesel. It is observed that the transesterification reaction reduces the calorific value of palm biodiesel, as well as its density, cloud point, sulphur content and carbon residue as compared petroleum diesel. Palm biodiesel has a lower calorific value, however, the higher cetane level compensates for this disadvantage, i.e., palm biodiesel has higher quality combustion, making better use of its energy content. In addition, distillation of palm biodiesel indicates that the fuel is volatile with the dynamic viscosity, increasing with the palm oil content. However, the tendency of palm biodiesel to form carbon during combustion is observed to be less compared to petroleumdiesel.

Table 3. Physical-chemical properties of palm biodiesel and petroleumdiesel

Characteristics	Palm biodiesel (palm methyl ester)	Petroleum diesel
Typeofsource	Renewable	Fossil
Calorificvalue(MJ/kg)	41.3	46.8
Gross heat of combustion (KJ/kg)	40.135	45.8
Cetane level	65	53
Flash point (°C)	174.0	98.0
Pour point (°C)	16.0	15.0
Cloud point (°C)	16.0	18.0
Density at 40 °C (kg/L)	0.855	0.823
Viscosity at 40 °C (cST)	4.5	4.0
Sulphur content (wt. %)	0.04	0.10
Carbon residue (wt. %)	0.02	0.14

III. EXPERIMENTAL RESULTS FROMSURVEY

3.1 Diesel Engine Performance using PalmBiodiesel

A survey carried out on performance of a diesel engine using palm biodiesel has been mentioned here. The engine is a 4 cycle diesel engine, with 4 cylinders, 83mm cylinder diameter, 100mm stroke length, and has a 22:1 compression ratio. The diesel engine has a maximum torque resulted at 3200 rpm.

The diesel engine is initially warmed up for 15 minutes, after which it is subjected to the first test using petroleum diesel at an engine speed of 650 rpm. After a certain time a breaking force is applied and the load is measured. This load data is taken five times for each test, and the time required for consumption of every 100 ml of fuel is also measured. The test is then continued for engine speeds of 1000 rpm, 1350 rpm, 1700 rpm and 2050 rpm respectively. When the test using the petroleum diesel is completed, the same test is carried out again using palm biodiesel with the same engine speeds.

Table 4. Load applied and time for fuel consumption on diesel engine

Engine revolution (rpm)	Fuel			
	Petroleumdiesel		Palmbiodiesel	
	Load applied (kg)	Time required	Load applied (kg)	Time required
650	0.54	0.07’.05.6”	0.52	0.10’.16.4”
1000	12.6	0.02’.10.4”	0.52	0.03’.33”
1350	13.0	0.02’.42.4”	6.78	0.02’.53.2”
1700	14.4	0.01’.08.8”	7.0	0.00’.55.8”
2050	24.48	0.00’.35”	8.82	0.00’.43.6”

From the diesel engine test, data for the load applied and the time required for fuel consumption is shown in Table 4. The engine performance parameters measured from the various loads applied (in Table 4) are: torque, fuel consumption and thermal efficiency, as shown in Table 5.

Table 5. Results obtained from performance test on diesel engine

Engine revolution (rpm)	Fuel					
	Petroleumdiesel			Palmbiodiesel		
	Torque (kg.m)	Fuel Consumption (kg/hr)	Thermal Efficiency (%)	Torque (kg.m)	Fuel Consumption (kg/hr)	Thermal Efficienc (%)
650	0.193	0.710	1.48	0.186	0.508	2.12
1000	4.511	2.322	16.31	1.518	1.472	8.35
1350	4.654	1.862	28.34	2.427	1.808	16.2
1700	5.115	2.348	31.34	2.506	5.618	6.78
2050	8.764	8.640	17.47	3.157	7.191	8.05

Exhaust Gas Emissions of Diesel Engines using Palm Biodieselblends

In this survey, biodiesel fuels were provided by the Malaysian Palm Oil Board (MPOB). For the test, four fuels were used, including petroleum diesel (D2). The other fuels were biodiesels, with blends of palm oil and petroleum diesel at various volumetric proportions. Fuel composition properties of the fuels used are shown in Table6.

Table 6. Fuel compositions for exhaust gasemissionmeasurement

Fuel	Fuels blended(%vol)
D2	100% Petroleumdiesel
B10	10% CPO + 90%D2
B20	20% CPO + 80%D2
B50	50% CPO + 50%D2

The experiment was carried out using a single cylinder direct-injection diesel engine with a bore of 78 mm, stroke 62 mm and compression ratio of 19.5. It is air- cooled, low speed diesel engine with maximum power output rated at 4.9 kW at 3400 rpm. The engine was directly coupled to an eddy-current brake dynamometer equipped with a load controller. The overall experimental setup is shown in Figure 4..

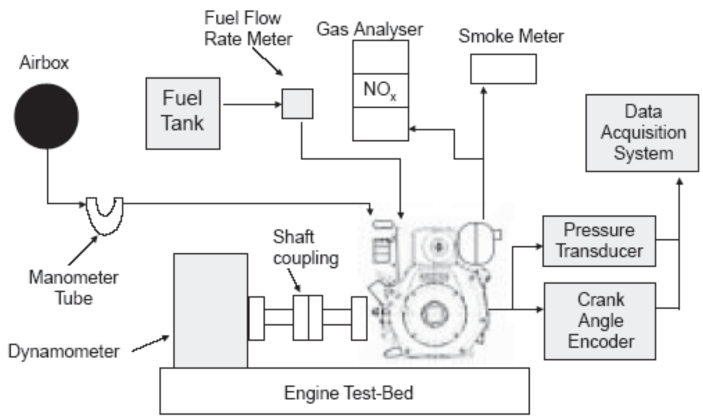

Figure 4. Schematic engine diagram test setup

The engine exhaust gas emissions measured for this experiment are the brake specific basis (g/kWh): carbon monoxide (CO), carbon dioxide (CO2), unburned hydrocarbons (HC), nitrogen oxides (NOx) and concentration of black smoke, respective to the brake mean effective pressure (BMEP) as shown in Figures 5.

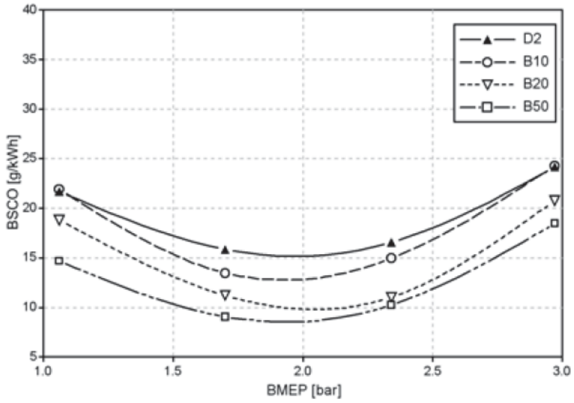

Figure 5. Effect of BMEP on CO of tested fuels

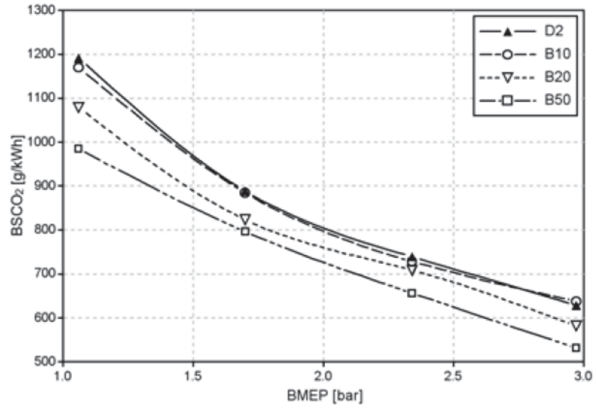

Figure 6. Effect of BMEP on CO2 of tested fuels

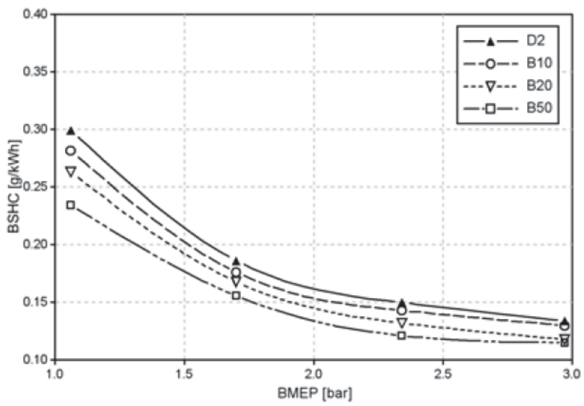

Figure 7. Effect of BMEP on BSHC of tested fuels

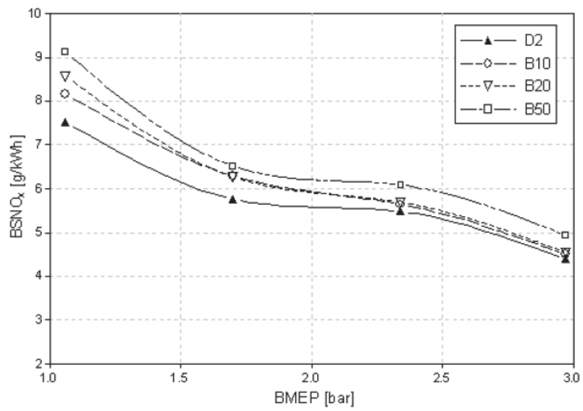

Figure 8. Effect of BMEP on BSNOx of tested fuels

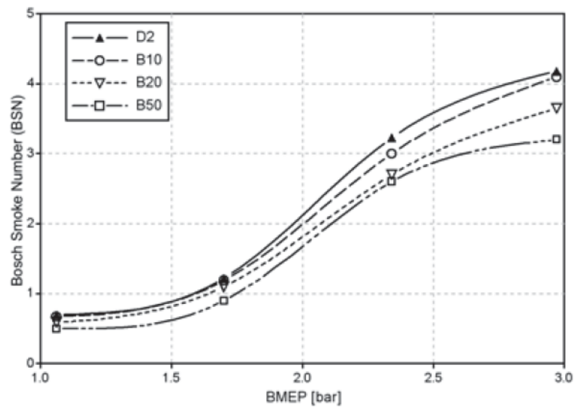

Figure 9. Effect of BMEP on black smoke density of tested fuels

3.2 Deposit Compositions of Exhaust Gas Emission from a Diesel Engine usingCPO

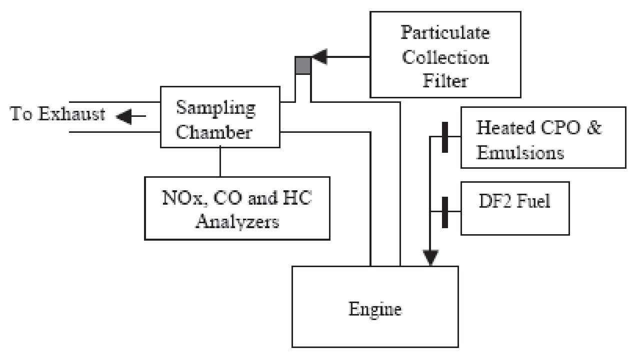

Figure 10. Layout of experimental setup

Characterization of deposit formation can be classified as the amount of: volatile matter and non-volatile fraction. Non-volatile fraction can be divided into fixed carbon and ash. Deposit composition parameters of exhaust gas emission measured from this experiment are the ratio of: volatile content, fixed carbon and ash content for all test fuels shown in Figure 11.

Table 7. Fuel compositions for deposit composition measurement

Fuel	Fuels blended (%vol)
OD	
	100%PetroleumdieselCP
O	100%CPO
CPO99	99% CPO + 1%water
CPO98	98% CPO + 2%water
CPO97	97% CPO + 3%water

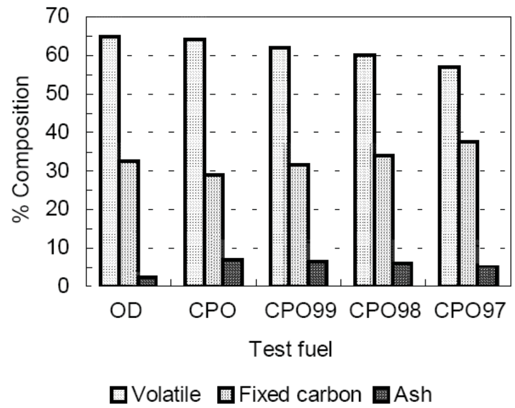

Figure 11. Deposit composition for test fuels

3.3 Injection System of a Diesel Engine using Preheated CPO

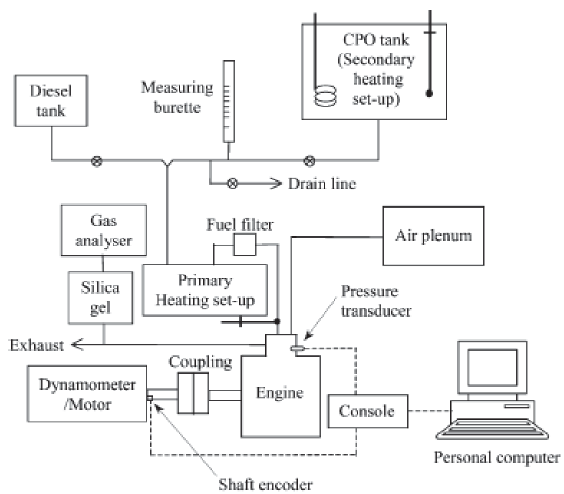

Figure 12. Basic experimental setup

The injection system parameters measured from this experiment are: the peak combustion pressure shown in Figure 13, the maximum heat release rate shown in Figure 14 and the combustion period shown in Figure 15.

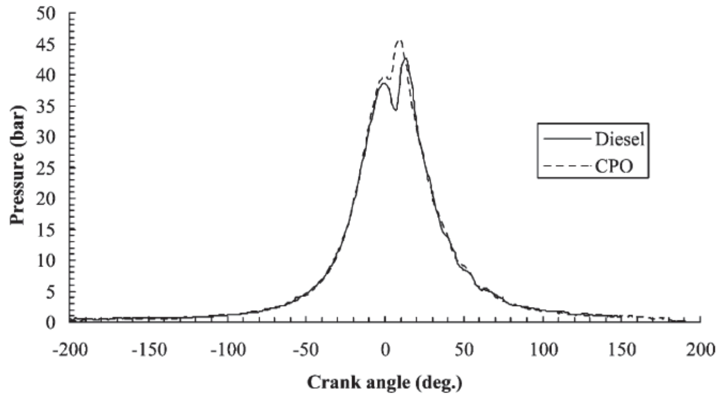

Figure 13. Pressure vs. crank angle diagrams for CPO and petroleum diesel combustions

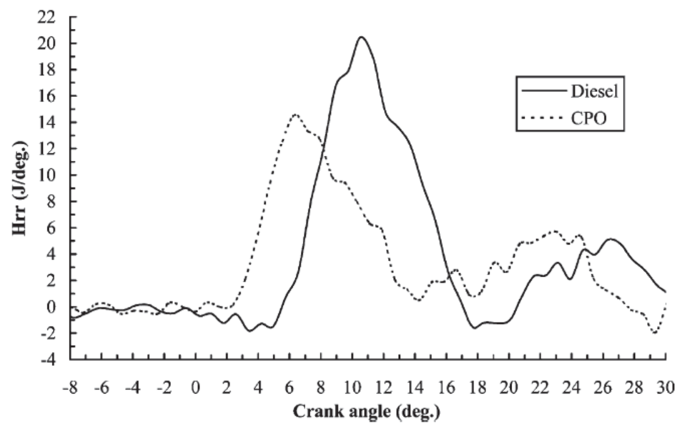

Figure 14. Heat release rates for CPO and diesel combustions

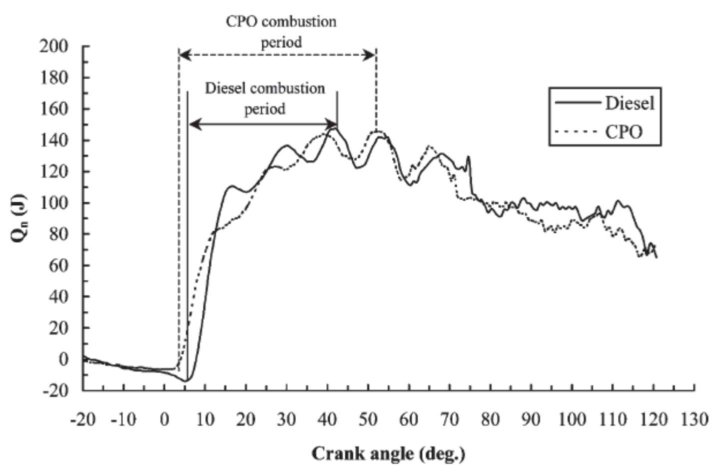

Figure 15. Net heat release values for CPO and diesel combustions

IV. DISCUSSION OF SURVEY RESULTS

The first experiment compares the performance of a diesel engine using palm biodiesel and petroleum diesel, as shown in the performance test results in Table 5. It is observed that, palm biodiesel gives lower performance on diesel engines for torque and thermal efficiency, compared to petroleum diesel. This is caused by the lower heat value of palm biodiesel to that of petroleum diesel, which produces a lower work to reach a higher torque. When the engine revolutions keep on increasing the torque produced from palm biodiesel tends to decrease. At lower engine revolutions, palm biodiesel produces a close torque compared to petroleum diesel, while at higher engine revolutions the torque resulted for palm biodiesel drops sharply than petroleum diesel. This is caused due to the density of palm biodiesel, as it is higher than petroleum diesel. Since palm biodiesel is burned imperfectly, it has a rapid injection in the combustion chamber, which decreases the torque produced. However, on the other hand, from the lowest engine revolution to the highest engine revolution, palm biodiesel has lower fuel consumption than that of petroleum diesel. This indicates that the use of palm biodiesel in diesel engines gives more fuel saving than petroleum diesel. The lower fuel consumption of palm biodiesel is caused by its higher flash point and viscosity than the petroleum diesel. The higher the flash point of palm biodiesel, the better atomization process will be performed which will minimize the droplet size of palm biodiesel and decrease its pre- combustion time, so that it will burn at the time the cylinder passes at its top dead center. The effective thermal efficiency of palm biodiesel was also observed to be lower than the petroleum diesel, which is caused due to the lower calorific value of palm biodiesel.

For the second experiment, exhaust gas emissions using palm biodiesel blends and petroleum diesel were measured for a diesel engine. It was observed that palm biodiesel blends produced lower CO emissions than petroleum diesel for the entire engine load range, as shown in Figure 5.

The palm biodiesel blends had a tendency to reduce CO2 emissions compared to petroleum diesel, as shown in Figure 6. The reduction of CO2 emissions is logical because of the oxygenated nature of palm oil and the lower amount of carbon in the palm biodiesel blends. All blends of palm biodiesel produced lower emissions of unburned hydrocarbons (HC), as shown in Figure 7. However, palm biodiesel blends increased the concentration of NOx emissions especially at the higher engine loads as shown in Figure 8. The additive oxygen content in palm biodiesel is the cause of this, as more oxygen during combustion will raise the combustion bulk temperature. Higher NOx emissions of palm biodiesel are also resulted from its other properties or by interaction with the fuel injection process and combustion chamber dynamics. Furthermore, the biodiesel fuels produced lower concentration of black smoke than petroleum diesel under similar engine operating conditions, as shown in Figure 9. This is because palm oil contains inherent oxygen which helps to oxidize the number of gaseous by-products.

The third experiment studies the deposit compositions formed during exhaust gas emissions of a diesel engine operated on CPO and emulsified fuels. carbon, but decreases volatile ash content. These emulsified fuels also tend to reduce NOx emissions due to the reducing ash content, when compared to petroleum diesel.

The last experiment concentrates on the combustion characteristics of CPO and petroleum diesel. It was found that the performance of heated CPO as a fuel was better compared to petroleum diesel. Heating of the CPO was necessary for the fuel to slow smoothly in the fuel system. Still, there were differences observed from the combustion analysis results. Comparing CPO combustion to petroleum diesel combustion, a higher peak pressure was obtained with CPO as shown in Figure 13, which agrees to the increasing NOx emissions when the engine load is increased. A shorter ignition delay of CPO compared to petroleum diesel was noticed. Due to shorter ignition delay less fuel is injected during the delay period resulting in a lower maximum heat release rate, as shown in Figure 14. Since CPO consists of roughly 50% saturated and 50% unsaturated fatty acids, chemical reactions, such as cracking of the double bond of the carbon chain, produce light volatile compounds, which result in a shorter ignition delay compared to petroleum diesel. A longer combustion period of CPO compared to petroleum diesel was the other characteristic that was noticed, as shown in Figure 15. This is due to the fact that another chemical reaction, polymerization of vegetable oil at the high temperature spray core produces heavy low-volatility compounds. These heavy compounds are difficult to combust and cannot completely burn in the main combustion phase, therefore, they continue to burn in the late combustionphase.

V. CONCLUSION

The results obtained from the survey reveal that palm biodiesel meets the combustion requirements of diesel engine combustion; however, it produces marginally low output characteristics compared to petroleum diesel. The case-study from the survey reveals that palm biodiesel has a number of advantages over petroleum diesel, namely: low fuel consumption, less concentration of exhaust gas emission, higher combustion pressure and longer combustion period. However, contrary to its advantages, palm biodiesel gives marginally low performance in terms of torque, thermal efficiency, and produces higher NOx emissions as compared to petroleum diesel. In the view of majority positive results obtained from the experiments, it is rational to say that palm biodiesel can be used as a substitute for petroleum diesel in diesel engines. Hence, palm biodiesel contributes to be an alternative source of green renewable energy to meet the energy demands of the f uture.

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