USING CRUDE PALM OIL (CPO) AS DIESEL ENGINE FUEL

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ABSTRACT

In this study, heating was used to lower the viscosity of CPO to an acceptable level. 60°C was found to be the optimum heating temperature for CPO to ensure smooth flow in the fuel system, but heating further up to 100°C did not improve the engine performance. A comparison between CPO and diesel in terms of engine performance, combustion characteristics and emission showed that the brake specific fuel consumption (bsfc) for CPO was 13% higher at 400 kPa brake mean effective pressure (bmep), and the highest bmep achieved was 13.5% lower. However, CPO fuel gave a better brake thermal efficiency. Combustion analyses indicated that CPO combustion produced a 7% higher peak pressure, a 3.3-degree earlier ignition and an 11.6-degree longer burning duration, but a 26% lower peak heat release rate. After 500 hours of running with CPO, performance and power of the engine dropped even while running with diesel, with a 26% higher bsfc and a 20% lower maximum bmep. Visual inspection of the dismantled engine parts discovered heavy carbon deposits but normal wear. Overhaul of the engine restored the power and performance.

1. INTRODUCTION

Crude palm oil (CPO) is a vegetable oil that is produced by the most popularly cultivated oil crop in Malaysia, the oil palm; and the country is the largest producer of CPO in the world¹. Currently most of the CPO after processing is used in the food and oleochemical industries. The interest in using CPO as an alternative fuel in diesel engines was originally initiated by the Palm Oil Research Institute of Malaysia (PORIM) in its effort to find new applications for palm oil. Previous studies by Ahmad and Salmah²⁻³ showed that CPO is useable in diesel engines, although some difficulties and problems were encountered, including clogging of CPO in the fuel line and fuel filter, bubbles in the fuel line and wear of the piston rings. Some selected fuel properties of CPO and Malaysian diesel are presented in Table 1.

The use of vegetable oils in diesel engines was first demonstrated by Rudolph Diesel, when he used peanut oil in the engine he invented⁴⁻⁵. Vegetable oils in their crude form

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Table 1 : *Properties of crude palm oil and Malaysian diesel*².

Fuel Characteristic	Crude Palm Oil (CPO)	Malaysian Diesel
Specific gravity	0.8990 @ 50°C	0.8330 @ 15.6°C
Kinematic viscosity (cSt)	24.3 @ 55°C	4.0 @ 37.8°C
Gross heat of combustion (kJ/kg)	39,600	45,800
Pour point (°C)	12.8	15.0
Flash point (°C)	240	98
Sulphur content (% wt)	0.02	0.50
Free fatty acid (% wt)	3.26	-

can be used directly in diesel engines⁶⁻⁸, but some problems occur due to their high viscosity, low volatility and the presence of unsaturated fatty acids². These problems include clogging of the fuel lines and fuel filter at low temperatures, heavy carbon deposits in the combustion chamber and on the injector tip, wear on the piston and on the injection pump plunger, valve sticking, and engine oil gelling⁹.

To minimise these problems, two approaches can be taken: adapt the fuel to the engine, or the other way round. Under the first approach, a proven method is to convert vegetable oil into biodiesel through a process called transesterification. Biodiesel is a common name for fatty acid mono alkyl ester⁴, which is commonly produced during transesterification by reacting vegetable oil with methanol in the presence of an alkaline catalyst such as sodium hydroxide¹⁰. The physical and chemical properties of biodiesel are very similar to those of mineral diesel, so the application of biodiesel in diesel engines encounters no difficulties, except that biodiesel attacks rubber-based materials, requiring a change of materials for parts that come into contact with biodiesel fuel, such as the fuel tank, fuel lines and injection pump¹¹. The second approach is to design an engine that can use crude vegetable oil directly. One such engine is the Elsbett engine, manufactured by Elsbett GmbH of Germany, which can run on virtually any liquid fuel^{13,12-13}. Field trials and bench tests have showed that the Elsbett engine can be fuelled with crude palm oil.

Although technically the problems of using CPO can be solved using the two methods described above, they are expensive to implement. Finding ways to utilise CPO in conventional diesel engines appears to be a possibly cheaper alternative. The obstacles that need to be overcome include the high viscosity and thermal reactivity of the unsaturated chemical bonds. The viscosity of CPO is 20 times higher than the viscosity of diesel at room temperature (around 28°C)¹⁴. This is evident as CPO is a very thick mixture of liquid and solid phases at 28°C. Heating is one of the ways to lower CPO's viscosity, and is also necessary to keep CPO in liquid form so that it can flow smoothly in the fuel lines^{2,15}.

This study intended to find the optimum CPO heating temperature in terms of engine performance and smooth flow in the fuel lines, fuel filter and injection system; to compare the engine performance, combustion and emission of heated CPO with those of diesel; and to examine the various engine parts when the performance of the engine had deteriorated noticeably from running with CPO.

2. METHODOLOGY

In this study, a Yanmar L60AE-DTM single-cylinder, 4-stroke, direct injection, air-cooled diesel engine with a rated power output of 4.0 kW at 3600 rev/min was used. It was coupled to a swinging field dc dynamometer that provided the brake load. An AVL piezoelectric pressure transducer was installed in the cylinder head to obtain in-cylinder pressure data. Crank angle signals were provided by a shaft encoder fixed to the output shaft. These pressure and crank angle data were fed to a console that conditioned the signals, which in turn passed through an analogue-to-digital converter on their way to a computer for combustion analyses. At various points of the set-up, e.g. the fuel line and fuel tank, thermocouples were used to gather temperature data. A burette and stopwatch were used to measure the time needed for a specific volume of fuel flow. For the emission test, an MSI gas analyser was used, with a maximum inaccuracy of ± 1 ppm. A schematic diagram of the experimental set-up is given in Figure 1.

Figure 1 : Schematic diagram of the experimental set-up.

During the tests, diesel was always used as the fuel for starting up and shutting down the engine, so that CPO did not stay in the fuel lines and injection system and clog them when the temperature dropped to below its solidification point before engine start-up and after engine shut-down. As soon as the engine was warm, the fuel was switched to CPO using the fuel switching circuit.

3. RESULTS AND DISCUSSION

3.1 Effect of heating CPO on engine performance

Brake specific fuel consumption (bsfc) and brake thermal efficiency are used as parameters to gauge engine performance. The graphs are usually plotted against brake mean effective pressure (bmep). In Figure 2, the effect of CPO heating temperature on the bsfc of the engine is shown. It can be seen that the effect of heating is insignificant, which indicates that heating did not result in better fuel economy. This could be due to the fact that during engine operation, the fuel injection pump, high-pressure fuel line and the injector are all at temperatures higher than 100°C, so heating CPO to 100°C had no noticeable effect. This finding is supported by the trend witnessed in Figure 3,

Figure 2 : Effect of heating CPO on brake specific fuel consumption (bsfc).

Figure 3 : Effect of heating CPO on brake thermal efficiency.

which shows the efficiency graphs. As before, the brake thermal efficiency curves for the various heating temperatures are almost identical, indicating that heating had negligible effect.

3.2 Optimum CPO heating temperature

After knowing that heating CPO up to 100°C has no noticeable effect on engine performance, another objective was to determine the minimum temperature to heat CPO so that a smooth flow is achieved in the fuel lines, fuel filter and injection system. For this, the authors used a simple method of visually observing CPO as heating was performed from room temperature (28°C). As the temperature rose beyond 60°C, all solid phase CPO was observed to have dissolved. Thus, 60°C was found to be the minimum temperature to heat CPO so that it can safely flow in the fuel system without causing clogging. This finding is backed up by observations during the previous engine tests - the fuel flow encountered no clogging problem when the fuel inlet temperature was 60°C and above. However, in the previous test, in order to achieve a fuel inlet temperature of 100°C, the heating tank needed to be heated to around 130°C, and the fuel line needed heavy insulation, because severe heat loss occurred between the two points. On the other hand, a fuel inlet temperature of 60°C was obtained by only an 80°C temperature in the heating tank with moderate insulation. So, the optimum heating temperature for CPO is 60°C.

3.3 Comparison with diesel

3.3.1 Engine performance

In this part of the study, the performance, combustion and emission of the engine fuelled with CPO and diesel were compared. Figure 4 shows the bsfc for CPO at 60°C and diesel at room temperature. It is clear that more CPO was consumed to produce the same power, with the bsfc at 400 kPa bmep for CPO about 13% more than that for diesel. This is due to the lower calorific value of CPO. It is also noticed that the engine reached a lower power when fuelled with CPO, with the maximum bmep lower by 13.5%. Since the volume of fuel injected at the maximum fuel rack position is limited, CPO produced a lower maximum power because of its relatively lower calorific value. A look at Figure 5 confirms that the maximum power of the engine achieved by using CPO was lower. However, CPO combustion produced a higher efficiency than diesel combustion. This could be the effect of the oxygen content of the CPO molecules, which could take part in the combustion process and improve efficiency. CPO consists of about 50% saturated and 50% unsaturated fatty acids¹⁶. Under high temperature and pressure conditions, which is found inside the combustion chamber, the unsaturated double bonds of the CPO molecules crack to produce light volatile compounds that are easily vaporised¹⁷⁻¹⁹. Easier vaporisation also improves mixing¹⁷, producing better combustion, and possibly higher efficiency. An additional explanation for CPO's higher efficiency is given in the next section. Nwafor and Rice²⁰ reported similar findings that neat rapeseed oil gave higher brake thermal efficiency compared with diesel.

Figure 4 : Comparison of bsfc for CPO and diesel.

Figure 5 : Comparison of brake thermal efficiency for CPO and diesel.

3.3.2 Combustion analyses

Figures 6 to 8 are the results of three separate combustion analyses conducted at 70% full load. In Figure 6, it can be seen that CPO combustion produced a higher peak pressure, compared with diesel combustion, by about 7%, which occurred about 1.7 degrees earlier. This combination of higher peak pressure and earlier occurrence of peak pressure contributed to the higher brake thermal efficiency witnessed in Figure 5 previously, because more work was performed. Figure 7 gives the heat release rates, and shows that the ignition delay for CPO was shorter by about 3.3 degrees. However, CPO produced a lower peak heat release rate compared with diesel, by about 26%. The explanation given in the previous section about thermal cracking of the unsaturated fatty acids also applies in this case. As mixing of CPO vapour and air in the cylinder occurs easily, combustion starts earlier (shorter ignition delay). A shorter ignition delay also means that less fuel is injected before combustion starts, resulting in a less intense premixed combustion phase and a lower peak heat release rate. Moving on to Figure

8, it is seen that CPO had a longer combustion period of about 11.6 degrees compared with diesel. This phenomenon could be due to the chemical reaction at the core of the fuel spray of CPO, polymerisation, which produces heavy compounds that are less volatile. These compounds take a longer time to vaporise and mix with air, and burn in the late combustion phase, producing a longer combustion period for CPO. Portions of these heavy compounds do not find the right conditions for combustion, and either leave the combustion chamber as soot or are left on any available surface in the combustion chamber as carbon deposits¹⁷⁻¹⁹.

Figure 6 : Comparison of in-cylinder pressure for CPO and diesel.

Figure 7 : Comparison of heat release rate for CPO and diesel.

Figure 8 : Comparison of net heat release for CPO and diesel.

3.3.3 Emission

The emission for CPO and diesel were compared using averages over the entire load range. Figure 9 shows CO and NO emissions for both the fuels. It is observed that CPO combustion produced about 2.8% more CO emissions than diesel combustion. Meanwhile, the NO emissions for CPO were higher than that for diesel by 25.7%. Using the same explanation as above, the high pressures and temperatures inside the combustion chamber cause CPO to undergo thermal cracking and polymerisation chemical reactions. Polymerisation at the spray core produces heavy low-volatility compounds that are difficult to atomise. The presence of these heavy compounds results in locally rich mixtures that cause more CO to be produced. The higher pressure experienced in the cylinder during CPO combustion (Figure 6) gives rise to higher temperatures, which favour the formation of more NO.

Figure 9 : Comparison of CO and NO emissions for CPO and diesel.

3.4 Inspection of various engine parts

As the operating time with CPO neared a cumulative 500 hours, it was noticed that engine power had deteriorated even when using diesel, and the engine was not running as smoothly as it had initially. Therefore, the authors decided to dismantle the engine for inspection and overhaul at the 500-hour mark. The extent of power loss was easily ascertained by comparing the bsfc vs. bmep curves of the engine fuelled with diesel before CPO was used and after the 500 hours of CPO use. The results of this comparison are shown in Figure 10. The engine's fuel consumption while running with diesel increased by 26%, and the maximum bmep decreased by 17% after using CPO for the said period.

Figure 10 : Performance of the engine using diesel, initially and after 500 hours of cumulative running with CPO.

Upon inspection after the engine was dismantled, heavy carbon deposits were found on the cylinder head, on the piston crown and around the injector nozzles. The upper layer of the deposits were soft. However, the lower layer, which were in contact with metal surfaces were hard, and were difficult to remove. Deposits were also detected on both the valve stems. These deposits prevented the valves from returning to their seats properly, which probably caused a certain amount of compression loss. Meanwhile, traces of wear were discovered on the injection pump plunger, the piston land and the piston rings, but these were normal after 500 hours of operation. Figures 11 and 12 show two parts covered with carbon deposits.

After inspection, the engine was overhauled. Immediately after reassembly, the engine was operated on diesel to gauge the performance, and the results show that power and fuel consumption were restored to almost their original values.

Figure 11 : Carbon deposits on the cylinder head, valves, and around the injector tip.

Figure 12 : Carbon deposits on the cylinder head, valves, and around the injector tip.

4. CONCLUSIONS

This study showed that the performance of the engine was not affected by heating crude palm oil (CPO) fuel to 100°C. This was because the engine itself was already at a higher temperature. It was found that a temperature of 60°C was enough to liquefy CPO and maintain a smooth flow in the fuel system. At 60°C, CPO produced distinguishable results from diesel in terms of performance, combustion characteristics

and emission. The brake specific fuel consumption (bsfc) for CPO was roughly 13% higher than that for diesel at 400 kPa bmep. The maximum brake mean effective pressure (bmep) achieved by using CPO was approximately 13.5% lower than that achieved by using diesel, caused by the lower calorific value of CPO. In a reversal of trends, it was discovered that the engine running on CPO had a higher brake thermal efficiency than when running on diesel, due to the chemical reactions that took place in CPO under high pressure and temperature conditions.

At 70% full load, the combustion of CPO, when compared with that of diesel, yielded a 7% higher peak pressure that occurred 1.7 degrees earlier. CPO also had a 3.3-degree shorter ignition delay and an 11.6-degree longer combustion period, but peak heat release rate was 26% lower. Emissions-wise, the chemical reactions that CPO underwent resulted in a 2.8% increase in CO emissions and 25.7% higher NO emissions, compared with diesel operation

At the end of a period of 500 accumulated hours of running with CPO, the engine, running on diesel, consumed 26% more fuel but produced 20% less power compared with initial conditions. Part by part inspection revealed a lot of carbon deposits on the cylinder head, the piston crown, the injector tip and the valve stems. Wear was detected on the injection pump plunger, piston land and piston rings. After overhaul, the engine performed almost as before, with the power and fuel consumption restored.

In summary, for use as a fuel in diesel engines, CPO performed as expected of a vegetable oil. However, overhaul was required at a much earlier time compared with that required for diesel fuel operation.

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REFERENCES

1. Ekasari M. and Sutardjo M. Synthesis of methyl ester from palm fatty acid distillate. Proc. 1998 PORIM Int. Biofuel and Lub. Conf., Bangi, 4-5 May 1998. p. 69-70.
2. Ahmad H. and Salmah J. Preliminary observations of using palm oil as fuel for cars fitted with Elbett engine. Elaeis - Spec. Issue: Proc. 1995 PORIM Int. Biofuel Conf. Langkawi, 16-17 January 1995. p. 92-96.
3. Ahmad H. and Salmah J. Palm oil as diesel fuel: Field trial on cars with Elsbett engine. Proc. 1998 PORIM Int. Biofuel and Lub. Conf., Bangi, 4-5 May 1998. p. 165-181.
4. Marshall W., Schumacher L.G. and Howell S. Engine exhaust emissions evaluation of a Cummins L10E when fueled with a biodiesel blend. SAE Paper 952363, 1995.

5. Prasad C.M.V., Krishna M.V.S.M., Reddy C.P. and Mohan K.R. Performance evaluation of non-edible vegetable oils as substitute fuels in low heat rejection diesel engines. *Proc Instn Mech Engrs, Part D, Journal of Automobile Engineering*, 2000, 214, 181-187.
6. Alfuso S., Auriemma M., Police G. and Prati M.V. The effect of methyl-ester of rapeseed oil on combustion and emissions of DI diesel engines. *SAE Transactions* 932801, 1993.
7. Dunn P.D. and Jompakdee W. Measurement of the rate of carbon build-up in diesel engines employing vegetable oil fuels. *Proc. 3rd Int. Conf. on Small Engines and their Fuels for Use in Rural Areas*. University of Reading, UK, 17-19 July 1990. p. 9-15.
8. Lim T.H. Performance and emission analyses of diesel engine using heated blends of crude palm oil (CPO) with lighter fuel. MSc Thesis, Universiti Sains Malaysia, 2001.
9. Wang Z., Mei D. and Wang X. Study of application of vegetable oil on direct injection diesel engines. *Proc. Sixth Int. Conf. Small Engines, their Fuels and the Environment*. Johor Bahru, 22-24 April 1999. p. 20-25.
10. Cheah K.Y., Choo Y.M., Ma A.N. and Yusof B. Production technology of palm diesel. *Proc. 1998 PORIM Int. Biofuel and Lub. Conf.*, Bangi, 4-5 May 1998. p. 207-226.
11. Schumacher L., Borgelt S.C., Hires W.G., Wetherell W. and Nevils A. 100,000 miles of fueling 5.9L Cummins engines with 100% biodiesel. *SAE Transaction* 962233, 1996.
12. Elsbett G. and Elsbett K. Future trends of biofuel engines with Elsbett-technology. *Elaeis - Spec. Issue: Proc. 1995 PORIM Int. Biofuel Conf.* Langkawi, 16-17 January 1995. p. 35-41.
13. Razali A., Zamsari S., Ahmad H. and Salmah J. Bench test of single-cylinder Elsbett engine in using CPO as fuel. *Proc. 1998 PORIM Int. Biofuel and Lub. Conf.*, Bangi, 4-5 May 1998. p. 182-199.
14. Gafar A., Widodo J.S., Sidjabat O., Legowo E.H., Rahman M., Harimurti K., Sutardjo and Iskandar N.R. Preparation of palm oil esters-diesel fuel mix and its performance test on stationary engine. *Elaeis - Spec. Issue: Proc. 1995 PORIM Int. Biofuel Conf.* Langkawi, 16-17 January 1995. p. 52-57.
15. Lim T.H. and Bari S. Performance study of a diesel engine using heated blend of crude palm oil and diesel. *Proc. Sixth Int. Conf. Small Engines, their Fuels and the Environment*. Johor Bahru, 22-24 April 1999. p. 1-6.
16. Pantzaris T.P. *Pocketbook of Palm Oil Uses*. Malaysian Palm Oil Board, Kuala Lumpur, 2000. p. 35.
17. Ryan T.W., Bagby M.O. Identification of chemical changes occurring during the transient injection of selected vegetable oils. *SAE Transactions* 930933, 1993.
18. Ziejewski M., Goettler H., Haines H., Huang C. Comparative analysis of plant oil based fuels. *SAE Transactions* 952061, 1995.

19. Ziejewski M., Goettler H.J., Haines H., Huang C. EMA durability test on high oleic sunflower and safflower oils in diesel engines. *SAE Transactions* 961846, 1996.
20. Nwafor O.M.I. and Rice G. The use of neat rapeseed oil in diesel engine. Proc. Fifth Int. Conf. on Small Engines, their Fuels and the Environment. University of Reading, UK, 5-7 April 1995. p. 26-30.