Palm Diesel: Green and Renewable Fuel from Palm Oil

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INTRODUCTION

The energy crisis in the mid 1970s coupled with the fast depleting energy reserves, increasing energy consumption and greater environmental awareness have led to an intensified search for viable alternate sources of energy globally. Vegetable oils including palm oil have been used directly as diesel fuel substitutes (Adams *et al.*, 1983; Akor *et al.*, 1983; Pryde, 1983; Strayer *et al.*, 1983; Ziejeswki and Kaufman, 1983). These efforts have shown that all the vegetable oils tested can be used as fuel with some reservations. The most detrimental properties of these oils are their high viscosity, low volatility, poor atomization and auto-oxidation.

One of the most promising alternative fuel is vegetable oils and their derivatives such as biodiesel. Malaysia has been projected to become a net importer of petroleum by 2100, if no new oil is discovered. The golden crop of Malaysia, oil palm, is regarded as the most cost-effective vegetable oil crop with average yields of 3.5-5.0 t of palm oil per hectare per year. Thus, it offers a potential environment-friendly alternative fuel source.

In this respect, the Malaysian Palm Oil Board (MPOB) has embarked on an extensive research and development of palm diesel from palm oil and its products. Since the 1980s, MPOB (then the Palm Oil Research Institute of Malaysia, PORIM) has been in the forefront of research and development in palm diesel and developed several processes to convert crude palm oil (CPO) and its products into methyl esters for use as biodiesel and feedstock for the oleochemicals industry.

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PRODUCTION OF NORMAL AND LOW POUR POINT PALM DIESEL

Commercially, methyl esters of fatty acids can be produced either by esterification of fatty acids or transesterification of fatty triglycerides. The predominant process for production of methyl esters is transesterification of fats and oils with methanol. The ester interchange, *i.e.* replacement of the glycerol component by methanol, takes place quite easily at low temperature, 50°C to 70°C, and under atmospheric pressure with excess methanol and an alkaline catalyst such as sodium hydroxide (Sonntag, 1982; Kreutzer, 1984 and Freedman *et al.*, 1984). These mild reaction conditions, however, require oils neutralized by alkaline refining, steam distillation or pre-esterification of the free fatty acids.

Esterification may be carried out batchwise at 200°C to 250°C under pressure. For high yield, the water produced during the reaction has to be removed continuously. Esterification can also be carried out continuously in a countercurrent reaction column using superheated methanol (Kreutzer, 1984). Esterification is the preferred method for ester preparation from specific oil and fat fractions such as palm stearin and olein.

Vegetable oils such as CPO with varying amounts of free fatty acids can be converted to esters in a continuous process by combining the esterification and transesterification processes. This was successfully demonstrated in a 3000 t per annum pilot plant (Choo *et al.*, 1992). The novel aspect of this patented process is the use of solid acid catalysts for the esterification (Choo and Goh, 1987; Choo and Ong, 1989; Choo *et al.*, 1992). The reaction is carried out below 100°C at atmospheric pressure in a column of solid catalyst. The reaction mixture, which is neutral, is transesterified in the presence of an alkaline catalyst. The conventional washing stage or neutralization step after the

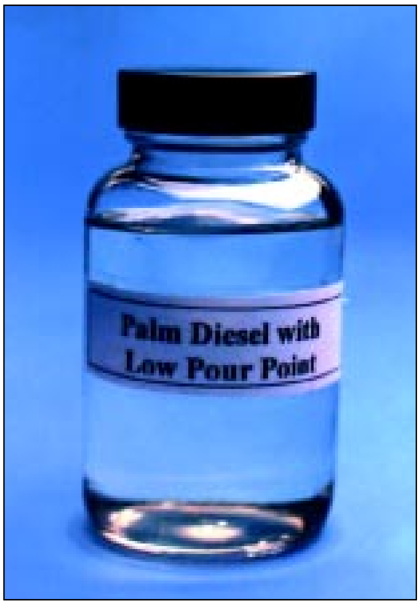

Figure 1. Low pour point palm diesel.

Figure 2. Normal palm diesel (crude/distilled palm oil methyl esters).

esterification process is obviated, an economic advantage. The patented process can also be applied to other raw materials such as crude palm stearin, crude palm olein, crude palm kernel oil and palm kernel products.

Alternatively, the process can also be applied to produce methyl esters of neutralized palm oil, refined, bleached and deodorized (RBD) palm oil and RBD palm olein. In this respect, only transesterification section is sufficient to convert these raw materials into their respective methyl esters.

Recently, MPOB has designed and is now building a 60 000 t per annum palm diesel plant based on its 3000 t pilot plant. RBD palm oil or RBD palm olein in excess methanol and alkaline catalyst is heated to the reaction temperature and passed through multi stage continuous reactors in series to maximize the reaction conversion. The glycerol is removed after each reactor to push forward the reaction for a higher conversion rate. After the reaction is completed, the excess methanol is recovered by flashing through flash vessels and distilled in a methanol purification column with structured packing. This recovered methanol is recycled in the reaction. The crude palm diesel is washed in hot water and then separated out by centrifugation. It is then dried under vacuum to achieve a low moisture content for the final product to be stored in tanks. The glycerol is flashed to recover more methanol and then sent to storage tanks as crude glycerol. The final quality of the palm diesel meets the European Standard on Biodiesel (EN14214) with a minimum product yield of 96.5%.

In recent years, the research effort has paid off when it became possible to produce palm diesel with low pour points (*Figure 1*) to meet the seasonal requirements, for example in spring (pour point of -10°C), summer (0°C), autumn (-10°C) and winter (-20°C). By overcoming the pour point problem, the MPOB patented technology (Choo *et al.,* 2002a) has turned palm diesel into a more versatile product. With the improved pour point, palm diesel can be used in temperate countries. Besides having good low temperature flow characteristics, low pour point palm diesel also exhibits comparable fuel properties as petroleum diesel.

EVALUATION OF PALM OIL METHYL ESTERS AS DIESEL SUBSTITUTE

Laboratory evaluation of palm oil methyl esters (*Figure 2*) has been carried out, including determination of the cetane number, and the results indicate that palm oil methyl esters can perform better than petroleum diesel (Choo *et al.*, 1995). This has been borne out by results from stationary engine tests and a field trial, which was systematically and exhaustively evaluated from 1983 to 1994. The field trial was run on a large number of vehicles, including taxis, trucks, passenger cars and buses. Exhaustive field trials with 30 Mercedes Benz engines from Germany mounted on to passenger buses have been successfully completed with each bus covering 300 000 km, the expected life of the engines. Some of the results are:

- no modification of the engine was required.
- the performance of the engines was generally as good as on petroleum diesel. The engines were easy to start, with no knocking and smooth running.
- the exhaust emissions of the

engines were much cleaner with less hydrocarbons, NOx, CO_2 and SO_2; therefore, the fuel was more environmentally-friendly.
- the engine oil was still usable at the recommended mileage.
- the palm oil methyl esters did not produce an explosive air/fuel vapour. Instead, they offered enhanced safety with a higher flash point (174°C compared to 96°C of petroleum diesel).
- carbon build-up in the engine nozzles was normal except that the nature of the carbon was different.
- the fuel consumption of palm diesel was comparable to that of petroleum diesel (*e.g.* 3-4 km $litre^{-1}$).
- the palm oil methyl esters attacked low grade plastic and rubber products, such as hoses, seals, *etc*. and also reacted with the binding material in cement floors.

The storage properties of the palm oil methyl esters were very good with little deterioration in the fuel quality parameters except for colour. After storing for more than six months, the colour changed from orange to a light yellow. This was due to breakdown of the carotenes in the methyl esters. The palm oil methyl esters had a high flash point, making their storage and transportation much safer.

PRODUCTION OF PALM PHYTONUTRIENTS FROM PALM DIESEL

The processes developed involve very mild reaction conditions, leaving the endogenous phytonutrients which are originally present in CPO to remain intact in the palm diesel (palm oil methyl esters). This allows them to be recovered as high-value phytonutrients such as carotenes (pro-vitamin A), vitamin E, sterols, squalene, phospholipids (better known as lecithin) and co-enzyme Q_{10}. Several processes which incorporate technologies such as short path distillation, supercritical fluid technology, saponification, crystallation and solvent treatment have been developed in MPOB to recover them (Choo *et al*., 1999; 2002b, c, d; 2003; 2004a, b). Supercritical fluid chromatography and flash chromatography have also been developed for the recovery of their valuable palm carotenes (*e.g*. α-carotene, β-carotene, lycopene, phytoene) tocotrienols isomers and β-sitosterol from crude palm oil methyl esters (Choo *et al.,* 2000; 2002e, f; 2003; Ng *et al.,* 2003) (*Figure 3*). Each of these phytonutrients has been recovered in high purity, and this will make the production of palm diesel more viable as the phytonutrients are of high value.

ECONOMIC VIABILITY OF A PALM DIESEL PRODUCTION PLANT

The economics for a 60 000 t yr^{-1} palm oil methyl esters (palm diesel) production plant are as follow:

CPO	+	Methanol	Esterification → Transesterification	Methyl Esters	+	Glycerol
1 t		0.1 t		0.96 t		0.1

Assumptions:

(1) Capital expenditure (CAPEX): RM 40 million (includes 7 ac land for the factory with main process building, storage tanks, office, *etc*., in Malaysia)

(2) Operational expenditure (OPEX): RM 18 million (includes operating expenses, *e.g*. labour, utilities, catalyst, *etc*.)

(3) Prices of raw materials and products:

Crude palm oil	: RM 1340 t^{-1} (as at 30 August 2005)
Methanol	: RM 756 t^{-1} (as at 30 August 2005)
Glycerol	: RM 1134 t^{-1} (as at 30 August 2005)
Diesel (Industrial grade in Malaysia)	: RM 1.85 $litre^{-1}$ = RM 2125.65 t^{-1} (as at 30 August 2005)

(i) Base case

An economic analysis was performed at current market prices (as at 30 August 2005):

IRR	31.7%
NPV	RM 96.23 million
Payback period	2 years
Break even CPO price	RM 1548.45 t^{-1}

(ii) Break even diesel price

The break even points (*i.e*., when NPV = 0) for palm diesel prices were evaluated with CPO price at RM 1000 t^{-1}, RM 1400 t^{-1} and RM 1800 t^{-1} (*Table 1*).

CONCLUSION

Palm diesel, a renewable fuel derived from palm oil, has been established as diesel substitute since 1996. With the current global trend towards renewable fuels, Malaysia has the edge over other nations as the production technology for palm diesel is already in place and the raw material, palm oil, plentiful in our country.

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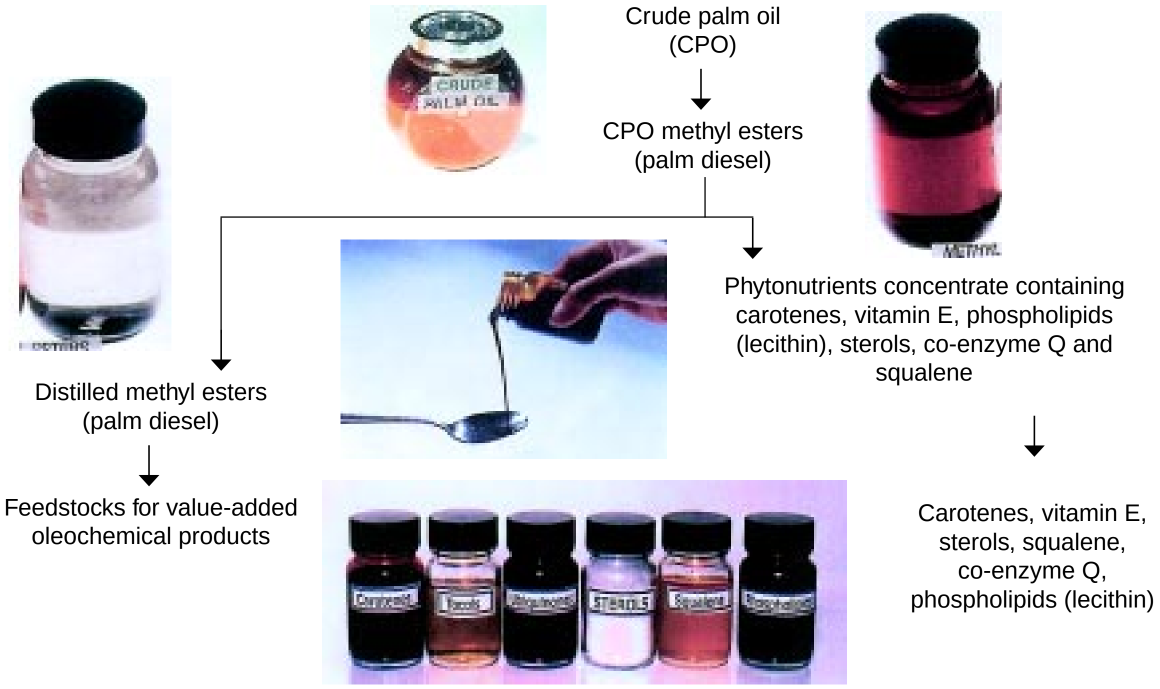

Figure 3. Integrated process for production of palm diesel and palm phytonutrients.

TABLE 1.

CPO price (RM t^{-1})	**Palm diesel price (RM t^{-1})**	**Palm diesel price (RM $litre^{-1}$)**
1 000	1 558.3	1.36
1 400	1 972.1	1.72
1 800	2 385.7	2.08

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