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Potential Biodiesel Production from Palm Oil for Thailand

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ABSTRACT

The purpose of this study is to review and evaluate aspects on Thailand's energy situation, oil palm plantation, properties of palm oil, conversion process to biodiesel, suitably available lands, biodiesel quality, environmental impacts, engine test performance and benefits of the country from using biodiesel. The results show that if 20% of diesel production from the amount of imported crude oil in 2000, was compensated by this biodiesel production, it would reduce imported crude as estimated value as Bt 13,436 million. To avoid conflict with feedstock for food production, plantation areas of at least 4.4 million rais in 12.9 million rais (1 rai = 0.16 ha) of suitably available lands will be required. Oil Palm is quantitatively the highest commercially potential production among the existing Thailand's major oil crops. Transesterification can provide chemical transformation of crude palm oil (CPO) and crude palm kernel oil (CPK) to biodiesel. The product of this process has been acceptable as diesel fuel substitute. Environmental impacts from biodiesel utilization show positive results compared to diesel fuel No. 2 (DF2). Biodiesel is acceptable as alternative diesel fuel with no significant problems found in both direct and indirect injections. Conclusively, the results of this review and evaluation show high potential biodiesel production from palm oil for Thailand.

Key words: biodiesel, palm oil, conversion, environmental impacts, engine tests

INTRODUCTION

There is no argument that energy is one of the essential things for our everyday living. In fact, most of today utilized energy derived from fossil resources, which are non-renewable energy. Notably, world reserves of oil, natural gas, coal and uranium are being depleted and predicted length of their supply as no longer than 40-50, 55-60, 150 and 80 years, at today world consumption rate, respectively (El Bassam, 1998; Connemann and Fischer, 1999; Crabbe *et al*., 2001). It is then feasible that the prices of petroleum and natural gas are likely to increase or fluctuate regarding the resource reduction.

In Thailand, the consumption of crude and refined oil, in the year 2000, were around 92 Ml/day (50.57% of total commercially energy consumption); whereas, local crude oil production could supply only 9.2 Ml/day (10% of total consumption of crude and refined oil). Nevertheless, imported crude oil was around 102 Ml/day worth Bt 285,862 million per annum as 86% of total commercial primary energy import. Within the final modern energy consumption produced from crude oil, diesel fuel consumption was around 41 Ml/day, which was 49% of total petroleum products (NEPO, 2001).

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Technically, 23.5% of refinery input (crude oil) is basically conversed to DF2 (diesel fuel for transportation) as an output (Sheehan *et al*., 1998). Therefore, to calculate the money saving from reducing imported crude oil procurement for diesel production, the equivalent value of diesel within imported crude (without refinery cost) is around Bt 67,178 million per annum. Supposably, if the country were able to save this part of imported crude oil around 20% (4.79 Ml/day), it would be equivalent to at least Bt 13,436 million per annum. Meanwhile, Thailand, with high capability in agricultural production or biomass, is able to provide the local substitute primary energy for diesel fuel, this amount of money will therefore circulate within the country.

Bioenergy, the sustainable resource

As stated earlier, to prolong or maintain not only as the renewable energy sources and production but also being environmental friendly to the world and local habitats, the term "sustainable" is therefore represented. Many researches confirmed that the bioenergy or biofuel, as a Biomass (as products of plant and animal matters on the earth's surface), is able to address many of the key issues and problems surrounding sustainable development, including combating global climate change, supporting and creating jobs, strengthening rural economics, enhancing the rural environment and recycling resources (Chamber, 2000).

In the work of El Bassam (1998), the comparison among fossil, nuclear and biomass as the energy sources considering on social, economic and environmental aspects of utilization were analyzed. The results have shown that biomass had taken on benefits over the others, especially on renewable, CO_2 reduction, landscape, accident risks, costs of environmental repair, administrative costs, creating new jobs, decentralization of economic structure, improving farmer's incomes, significant time of waste decay, public opinion, genetic deformation, etc. (Table 1)

Biodiesel, the study purpose

The National Energy Policy Committee, NEPC (2001), regulated biodiesel as the fuel for diesel engine produced from vegetable oil, which is transformed into methyl or ethyl ester. The vegetable oil for biodiesel manufactured typically contains up to 14 different types of fatty acids (Tyson, 2001). Popularly, the term "biodiesel" is now usually referring to esters of vegetable oils or animal fats or waste oils and not the corresponding feedstocks. DF2 is the fuel with which biodiesel is usually compared (Knothe and Dunn, 2001). The primary purpose of this study is to review and evaluate on country's energy situation, oil palm plantation, properties of palm oil, conversion processes, suitably available lands, biodisel quality, environmental impacts, engine test performance and country's benefit from using biodiesel.

MATERIALS AND METHODS

In this study, a model of biodiesel production from palm oil is presented as shown in Figure 1, which is fundamentally based on the literature review from Cook (1984); Berger (1984); Kulavanich *et al*. (1988); Gervasio (1996); Van Dyne *et al*. (1996); Muniyappa *et al*. (1996); El Bassam (1998); Noureddini *et al*. (1998); Sheehan *et al*. (1998); Canakci and Van Gerpen (1999); Connemann and Fischer (1999); Ma and Hanna (1999); Demirbas (2000); Crabbe *et al*. (2001); IEM (2001) and Knothe and Dunn (2001).

Oil palm

Oil palm has its scientific name as Elaeis guineensis Jacq. The genus Elaeis is derived from the Greek word "elaion" meaning oil. The specific name guineensis indicates its origin in the Guinea Coast (Salunkhe *et al*., 1992). Oil palm was brought to plant in Thailand before the World War II; consequently, the first commercial plantation started at Krabi and Satun Provinces since 1968. Currently, the popular commercial oil palm species, planted in

Table 1 Social, economic and environmental aspects of utilization of different energy sources (El Bassam, 1998).

	Fossil	Energy fuels Nuclear	Biomass
Renewable	no	no	yes
CO_2 reduction	no	yes	yes
Reduction of heat emission	no	no	yes
Landscape	no	no	yes
Avoidance of large accident risks	no	no	yes
Excessive costs of environment repair	yes	yes	no
Reduction of administrative costs	no	no	yes
Innovation	no	yes	yes
Creating new industrial jobs	no	yes	yes
Promoting decentralization of economic structure	no	no	yes
Promoting export	no	yes	yes
Increasing autonomous energy supply (industrialized countries)	no	yes	yes
Increasing autonomous energy supply (developing countries)	no	no	yes
Improving farmers' incomes	no	no	yes
Significant time of waste decay	yes	yes	no
Migration to urban areas	yes	yes	no
Favorable public opinion	no	no	yes
Avoidance of international conflict and wars	no	no	yes
Genetic deformation	no	yes	no

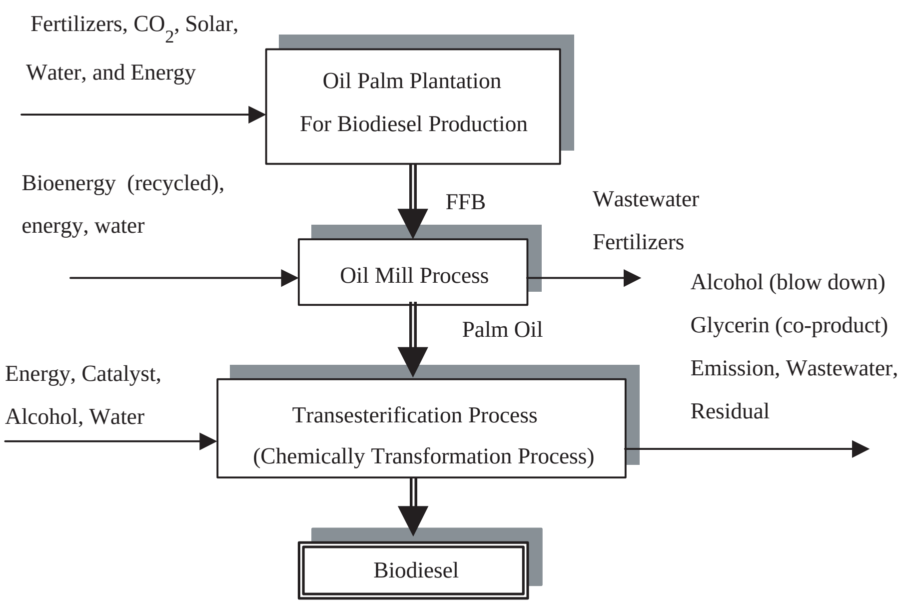

Figure 1 A model overall process model of proposed biodiesel production from palm oil.

Thailand, is Tenera (F1 Hybrid) or DxP, which derived from the hybridization between Dura and Pisifera species (Kulavanich *et al*., 1988; Sarakoon *et al*., 1998).

Among Thailand's major oil crop production, OAE (2000a) reported that, during the past decade, three major oil crops as soybean, coconut and oil palm occupy the most areas of harvested or planted. Harvested areas of soybean, coconut and oil palm in the year 1998/99 are 1.37, 2.066 and 1.129 million rais (1 rai = 0.16 ha), respectively. Nevertheless, areas for oil palm were increasing; whereas, soybean and coconut were reducing and constant, respectively. The average growth of oil palm harvested areas increased at the rate of 8.48% during the past decade (OAE, 2000b).

In term of production yield, oil palm has also shown the highest yield among these major oil crops during the past decade. The production rate was increasing at the average rate of 12.06% (OAE, 2000b). In comparison of oil seed yields and oil contents, Table 2 shows the data of the major oil crops.

Oil yield of oil palm is among the top of these major oil crops. Other researchers also reported about the percent oil content of oil palm as 21.6-24.5% by weight of a fresh fruit bunch (ffb) (Salam, 1985; Kulavanich *et al*., 1988). Conclusively, oil palm is quantitatively high potential for commercial plantation and production for Thailand. Additionally, perennial crops, such as oil palm, generally consume less herbicide and impact on soil erosion than annual crops.

Chemical composition and property suitability

Biodiesel typically contains up to 14 different types of fatty acids that are chemically transformed into fatty acid methyl esters (Tyson, 2001). Palm oil's chemical compositions are within the range of those types of fatty acids (Table 3).

One parameter, which is necessary when defining general standards for biodiesel, is iodine value. Iodine value is the standard to describe and measure the degree or content of unsaturated fatty acid in vegetable oil. Iodine value is only dependent on the origin of the vegetable oil (Mittelbach, 1996; Knothe and Dunn, 2001; Lang *et al*., 2001). Iodine value correlates with cetane number (CN), which is used to measure of fuel ignition characteristics, like octane number for gasoline. Biodiesel from vegetable oils with low iodine value will have a higher CN while the low-temperature properties are poor. Whereas, high iodine value will have low CN while the low temperature properties are better (Knothe and Dunn, 2001). Mittelbach (1996) also stated the necessary of a limitation of unsaturated fatty acids due to the fact that heating higher unsaturated fatty acids results in polymerization of glycerides (esters). This can lead to the formation of deposits or to deterioration of the lubricating oil.

Table 2 Products and oil's yields of various plant species.

Common name	Products' yield (tones/ha)		Oil(tones/ha)
Oil palm	19.1[a]	FFB	4.8[a]
Peanut	5.0[b]	Seed	1.75-2.75[b]
Soybean	2.3[a]/3.1[b]	Seed	0.4[a]/0.403-0.775[b]
Coconut	1.0[a]	Copra	0.625[b]
Castor bean	5.0[b]	Seed	1.75-2.75[b]
Sesame	1.0[a]	Seed	0.45-0.50[b]
Rape seed	3.0[a]	Seed	1.2[a]

Sources: [a] Mattsson et al., 2000; [b] Modified El Bassam, 1998

In German biodiesel standard E DIN 51606 regulated the maximum value of 115 g Iodine/100g (see Table 4). Typically, palm oil was reported its various iodine values of 35-61 (Knothe and Dunn, 2001); 45-60 (TIS, 1978) and 44-58 (Salunkhe *et al*., 1992), respectively. Therefore, palm oil is generally suitable as biodiesel production feedstock (Soybean oil was excluded from this standard).

It was believed that some general parameters, like density, cetane number (CN) and content of sulfur, mainly depend on the choice of vegetable oil and cannot be influenced by different production methods or purification steps (Mittelbach, 1996). Nevertheless, Lang *et al*. (2001) found that the density of the biodiesel is influenced by the original crude oil and the refining steps to make the product. However, recently, the results of many researches reported on some improvement in CN of original vegetable oils after transesterified to biodiesel (Knothe and Dunn, 2001; IEM, 2001; Altin *et al*., 2001; Crabbe *et al*., 2001).

Suitably available land for oil palm plantation in Thailand

In the Thailand agricultural statistic on production and marketing reported in OAE (2000b), where showed the balance sheet of Thailand's palm oil from 1991-2000, the quantities of product and local consumption almost balanced. As the results, to avoid the conflict with food feed stock demand, it is necessary to evaluate the possibility to enhance the commercially suitable plantation areas apart from existing harvested areas for food.

Sarakoon *et al*. (1998) had done the study on analysis and classification of the suitably available land in 14 provinces within the southern of Thailand (included Prachuap Khirikhan) for oil palm plantation. These areas were excluded forest, existing plantation and communities or residential areas, the summary was shown as the follows;

- Suitable land, means the production capability of 3 tons-ffb/rai/yr; (L1), equals 12,971,928 rais

Table 3 Weight percent of fatty acids in palm oil and kernel oil with typical 14 fatty acids in biodiesel.

14 Fatty acids (Tyson, 2001)	Carbon & double bond (Tyson, 2001)	Palm oil % fatty acid content				Palm kernel oil % fatty acid content		
		(Tyson, 2001)	(Knothe and Dunn, 2001)	Malaysia (Salunkhe *et al*., 1992)	(Kulavanich *et al*., 1988)	(Tyson, 2001)	(Salunkhe *et al*., 1992)	(Kulavanich *et al*., 1988)*
Caprylic	C8					2-4	3-4	2.8
Capric	C10					3-7	3-7	3.0
Lauric	C12					45-52	46-52	48
Myristic	C14	1-6	0.6-2.4	0.5-0.8	2	14-19	15-17	17.7
Palmitic	C16:0	32-47	32-46.3	46-51	43	6-9	6-9	8.2
Palmitoleic	C16:1					0-1		
Stearic	C18:0	1-6	4-6.3	2-4	7	1-3	1-3	1.7
Oleic	C18:1	40-52	37-53	40-42	39	10-18	13-19	16
Linoleic	C18:2	2-11	6-12	6-8	9	1-2	0.5-2.0	1.6
Linolenic	C18:3							
Arachidic	C20:0					1-2		
Eicosenoic	C20:1							
Behenic	C22:0					1-2		
Euricic	C22:1							

Remark: * reported that kernel oil also has another 1% of caproic.

- Moderate suitable land, means the production capability of 2.5-3 tons-ffb/rai/yr; (L2), equals 10,181,494 rais
- Total additionally potential land available equals 22,078,387 rais (1 rai = 0.16 ha)

The results showed that Surathani (~ 4 million rais) and Nakorn Si Thamarat (~ 3.5 million rais) have large available suitable land remaining, respectively. (Figure 2.)

To substitute 20% of today diesel fuel consumption, as stated earlier, it would require at least 2,993 Ml/year of biodiesel. Normally, the yield of methyl esters conversion process is around 95 % (see transesterification process), density of palm oil is around 0.9 kg/l (TIS, 1978; Salunkhe *et al*., 1992) and % oil content in ffb is around 21.6 % (Salam, 1985). Therefore, it would require at least 4.4 million rais of oil palm plantation areas for this purpose.

Conversion Processes

Before starting going into conversion processes to transform ffb and its oil to biodiesel, normally, there are questions on why not using crude oil in stead. Since, Rudolf Diesel's invention of the compression ignition (diesel) engine over 100 years ago, it had been known that the engine could operate on vegetable oils. Although, petroleum became the dominant world energy source, some interested researchers have been developing vegetable oil as diesel fuel source during the past century (Raneses *et al*., 1999). For example, several researches reported the using neat vegetable oils and/or the use of it blends of the oils with both direct or indirect diesel engines could cause severe numerous engine-related problems, while short term tests were almost always positive. Conclusively, long-term use of neat vegetable oils can lead to severe engine problems, emission and storage such

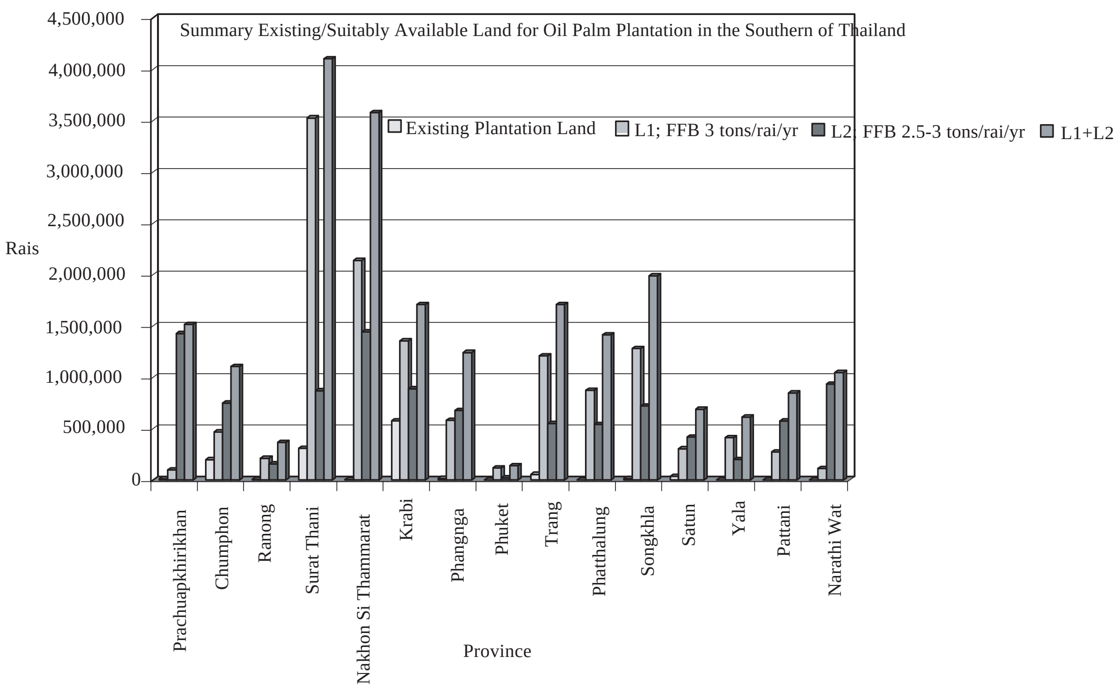

Figure 2 Summary of existing and suitably available lands for oil palm plantation among studied provinces (Modified Sarakoon *et al*., 1998)

as (Muniyappa *et al*., 1996; Noureddini *et al*., 1998; Canakci and Van Gerpen, 1999; Ma and Hanna, 1999; Ranesses *et al*., 1999; Monyem *et al*., 2001; Knothe and Dunn, 2001; Altin *et al*., 2001);

- Coking and trumpet formation on the injectors to such an extent that fuel atomization does not occur properly or is even prevented as a result of plugged orifices,
- Carbon deposits,
- Oil ring sticking,
- Thickening and gelling of the lubricating oil as a result of contamination by the vegetable oils,
- Tendency to polymerization within the cylinder,
- Incomplete combustion,
- Triglyceride in vegetable oils can lead to formation of aromatics via acrolein from the glycerol moiety, this is able to cause PAHs known as carcinogens,
- Polymerization and gum formation caused by oxidation during storage
- Increase particulate emissions.

Bari *et al*. (2002) studied on the effects of preheating of crude palm oil (CPO) on injection system, performance and emission using Yammar L60AE-DTM single cylinder, four-stroke, air-cooled diesel engine. The results released that the suitable heating temperature in the CPO tank was 80°C enable to lower the viscosity and smoother flow with no effect to injection systems; otherwise, some effects from surplus higher temperature from heating fuel and combustion chamber during running might damage the injection pump and caused significant changes in friction between the moving parts. Moreover, the study found that CO and NO_x as emissions were higher over the whole range, compared with that of diesel, by an average value of 9.2 and 29.3%, respectively.

In order to reduced or eliminate the problems on using neat vegetable oil, it is very important to be improved, especially, viscosity, volatility and flow properties of relative triglyceride molecule in vegetable oils. Schuchardt *et al*. (1998) concluded alternative ways, which had been considered to reduce the high viscosity of vegetable oils. Among all these alternatives, in which were dilution (25%), microemulsions, thermal decomposition, catalytic cracking and transesterification, transesterification is confirmed as the most appropriate available technology for producing monoesters, as known as biodiesel, from crude vegetable oils. Moreover, biodiesel as diesel fuel substitute, can replace diesel fuel without causing harmful effects to unmodified engines, while simultaneously reducing most of harmful exhaust emissions, especially PAHs (Polycyclic Aromatic Hydrocarbon Compounds) as known as mutagens and carcinogens, except NO_X (Gervasio,1996; Van Dyne *et al*., 1996; Muniyappa *et al*., 1996; Noureddini *et al*., 1998; Sheehan *et al*., 1998; Canakci and Van Gerpen, 1999; Connemann and Fischer, 1999; Ma and Hanna, 1999; Tat *et al*., 2000; Krahl *et al*., 2001; Crabbe *et al*. 2001; IEM, 2001; Knothe and Dunn 2001; Monyem *et al*., 2001).

Oil mill factory in Thailand

Kulavanich *et al*. (1988) reported the information regarding the palm oil mill factory in the southern of Thailand. There are 14 standard factories, which have capacity from 10 to 30 tons of ffb/hr. Ten years later, Sarakoon *et al*. (1998) reported that there are 18 large factories (separated process) with total capacity as 765 tons of ffb/hr. Within these 18 factories, their capacity varies from 25 to 90 tons of ffb/hr; in addition, others 24 factories are considered small, with all together capacity is around 143 tons of ffb/hr. However, in 1997, total oil palm product (ffb) was able to cover only 53 % (year-average) of all oil mill factories' capacity.

Therefore, the total remaining capacity of these oil mill factories is around 2.05 M tons of ffb/y (based on 16 working hrs/day, 300 working days/year), which is equivalent to around 442,465 tons of crude palm oil (CPO) and crude palm kernel oil

(CPK)/y. If this remaining capacity is able to provide crude oil for biodiesel production, it will be equivalent to 1.28 Ml of biodiesel/day. This amount of biodiesel production can compensate only 3.12 % of diesel fuel consumption (41 Ml/day).

Transesterification

Transesterification is the process to transform triglyceride molecules into smaller, straight-chain molecules. These straight-chain molecules are very similar to diesel (Van Dyne *et al.*, 1996; Muniyappa, *et al.*, 1996). (Nevertheless, there are some chemically different in molecular structure and composition between biodiesel (methyl ester) and diesel. Normally, diesel molecule, as a hydrocarbon compound, has no oxygen, its general chemical formula is $C_{16}H_{34}$ or CH_3-$(CH_2)_{14}$-CH_3. On the other hand, vegetable oil molecule contains oxygen, its general chemical formula is $C_{18}H_{22}O_2$. Molecule of vegetable oil is esters of fatty acids combined with glycerol. These molecules are therefore called as aclyglycerol or glyceride, which most of them are triglyceride.). Transesterification reaction comprises of an alcohol and a triglyceride molecule in the presence of a base or acid catalyst (Noureddini *et al.*, 1998). Normally, transesterification is explainable as the displacement of the alcohol from an ester by another alcohol in a process similar to hydrolysis except that an alcohol is used instead of water. This reaction is more specifically called alcoholysis; for instance, if methanol is used, the reaction will be termed methanolysis (Gervasio, 1996).

Moreover, both Noureddni *et al.* (1998) and Knothe and Dunn (2001) stated that transesterification is currently the most common and effective method or process for transformation of the triglyceride molecules into smaller, straight-chain molecules, reducing the high viscosity of fats and oils to a range close to that of conventional DF. The general equation of transesterification shows in Figure 3.

Regarding the stated general equation, theoretically calculated molecular weight of palm oil triglycerides and palm methyl esters (based on data of various glyceryl structures, methyl esters, and percent acid content from Sawyer and McCarty (1978); Kulavanich *et al.* (1988) and Knothe and Dunn (2001), respectively), are 865.82 and 284.18, respectively. Molecular weight of methanol and glycerine are 96 and 100, respectively. As the results, balance of the equation shows the estimated total weight ratio between triglyceride and methyl ester is almost 1:1.

Methanol usually use as an alcohol in transesterification because of its lower price than other alcohols (Ma and Hanna, 1999; Lang *et al.*, 2001; Knothe and Dunn, 2001). A conversion of 90-99% is usually obtained from this reaction depend on the process conditions. The main process conditions, which influence the conversion rate, are temperature, agitation, excess methanol (molar ratio), wt.-% catalyst, type of catalyst, reaction time, amount of water in oil, and amount of free fatty acid in oil. Practically, molar ratio of alcohol to triglycerides is higher than its stoichiometry; normally, the process has been done on the molar ratio of 6:1 or more. The reaction can be catalyzed by alkalis, acids or enzymes. The alkalis include NaOH, KOH, carbonates and corresponding sodium and potassium alkoxides such as sodium methoxide, sodium propoxide and sodium butoxide. Sulfuric

$$\begin{array}{l} RCOOCH_2 \\ \quad | \\ RCOOCH \\ \quad | \\ RCOOCH_2 \end{array} + 3CH_3OH \underset{\text{Catalyst}}{\rightleftharpoons} 3RCOOCH_3 + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

Fat or oil — Methanol — Methyl ester — Glycerine

Figure 3 General equation of transesterification (Methanolysis), (Gervasio, 1996; Ma and Hanna, 1999).

acid, sulfonic acids and hydrochloric acid are usually used as acid catalysts. Lipases also can be used as biocatalysts. Alkali-catalyzed transesterification is much faster than acid-catalyzed transesterification and is most often used in commercial scales (Muniyappa *et al*., 1996; Noureddini *et al*., 1998; Canakci and Van Gerpen, 1999; Ma and Hanna, 1999; Crabbe *et al*., 2001).

There are several patents on transesterifica tion of biogenic oils and fats during the past 50 years (Connemann and Fischer, 1999). Mainly, these technologies are able to divide into two groups. One is batchwise and the other is continuous process. However, the continuous process is normally well suited for large capacity requirements and using unrefined oils as feedstock. Furthermore, the unit can be designed to operate at various pressure or temperature or at atmospheric pressure and slightly temperature (Gervasio, 1996). Ma and Hanna (1999) concluded some more benefits gain from continuous process as lower the production costs, shorter reaction time, greater production capacity, more recovery of high quality glycerol, less water presented in the system, more concentrated glycerol, and lower energy required.

Currently, there are 85 biodiesel plants around the world. Within this number, there is one in Malaysia using palm oil as feedstock (Demirbas, 2000). The process of this pilot plant is two steps continuous; esterification and transesterification (esterification is the reaction of an acid with an alcohol in the presence of a catalyst to form an ester and water (Gervasio, 1996)). Malaysia's first proposed an annual capacity of 500,000 tons of palmdiesel with carotene and vitamin E recovery facilities is estimated to require an investment of RM 438 million or around Bt 5,313 million (IEM, 2001).

Biodiesel quality

Because of the fact that biodiesel is produced in quite differently scaled plants from vegetable oils of varying origin and quality, it was necessary to install a standardization of fuel quality to guarantee engine performance without any difficulties. Generally, the parameters, which are selected and established to define the quality of biodiesel, can be divided into two groups. One group contains general parameters, which are also used for mineral-oil-based fuels, and the other group especially describes the chemical composition and purity of fatty acid methyl esters. Consequently, several countries in Europe did establish standards for biodiesel such as Austria (Ö-NORM C1190/1191), Czech Republic (CSN656507), France, Germany (DIN E 51606, Table 4), Italy (UNI10635) and Sweden (SS155436); while, in USA, ASTM provides ASTM PS 121 (Table 5) as the standards to ensure good fuel quality for both pure biodiesel (B100) and blended 20% of biodiesel and 80% diesel (B20), (Mittelbach, 1996; Knothe and Dunn, 2001; Tyson, 2001).

Environmental impacts

Several researchers, such as Tat *et al*. (2000); Monyem *et al*. (2001); Krahl *et al*. (2001), Knothe and Dunn (2001) and Tyson (2001), accomplished and reported the experiments on various diesel engines in order to find the significant effects regarding methyl esters from various vegetable oils (e.g. rape seed and soybean, etc.). The results can be summarized as follows;

- Biodiesel can significantly reduce environmental impacts on PAHs as a mutagenicity compared to DF (World Health Organisation, has concluded that mineral diesel fuel is probably carcinogenic (Williamson and Badr, 1998))
- Biodiesel emissions on hydrocarbon, particulate and CO are less than DF2
- With larger hydrocarbon molecules of biodiesel are less compressible than smaller molecules. Less compressible fuels can cause early injection timing, and this can produce higher combustion pressures and temperature, which in turn produce higher NO_X emissions.

Moreover, Tyson (2001) and Altin (2001) reported the tailpipe emission changes with biodiesel fuel produced from soybean. The results of higher blends can provide significant emission reduction benefits for carbon monoxide, particulate, soot, smoke intensity, hydrocarbons, and especially, PAHs. Körbitz (1999) also reported on some significant locally impacting emissions as summarized in Table 6.

In term of the biodegradability of biodiesel in an aquatic environment, El Bassam (1998) concluded that all of the biodiesel fuels were “readily biodegraded” compounds according to Environmental Protection Agency (EPA) standards, and have a relatively high biodegradation rate in an aquatic environment. Biodiesel can promote and speed up the biodegradation of faster the degradation rate. The biodegradation pattern in a blended biodiesel/diesel is that microorganisms metabolize both biodiesel and diesel at the same time and at almost the same rate.

Engine test performance

Although, as stated earlier, many researchers

Table 4 German biodiesel standard E DIN 51606 (Knothe and Dunn, 2001).

Fuel Property	Unit	Test method	Limit (min)	Limit (max)
Density at 15°C	g/ml	DIN EN ISO 3675	0.875	0.900
Kinematic viscosity at 15°C	mm^2/s	DIN EN ISO 3104	3.5	5.0
Flash point closed cup, Pensky-Martens	°C	DIN EN ISO 22719	110	
CFPP (cold-filter plugging point)				
-April 15-September 30	°C	DIN EN 116		0
-October 1-November 15				-10
-November 16-February 28				-20
(leap year including February 29)				
-March 1-April 14				-10
Sulfur content	wt.-%	DIN EN ISO 24260 or DIN EN ISO 14596		0.01
Carbon residue	wt.-%	DIN EN ISO 10370		0.05
Cetane number		ISO/DIS 5165 : 1996 or DIN 51773	49	
Ash	wt.-%	DIN 51575		0.03
Water	mg/kg	ISO/DIS 12937: 1996 or		300
Total contamination		DIN 51777-1		
Copper strip corrosion	mg/kg	DIN EN ISO 51419		20
(3h at 50°C)		DIN EN ISO 2160		1
Oxidative stability, induction time	h	IP 306***		tobe defined
Acid number	mg KOH/g	DIN 51558-1		0.5
Methanol	wt.-%	E DIN 51608		0.3
Monoacylglycerols	wt.-%			0.8
Diacylglycerols	wt.-%	E DIN 51609		0.4
Triacylglycerols	wt.-%			0.4
Free glycerols	wt.-%	To be defined		0.02
Total glycerols	wt.-%	To be defined		0.25
Iodine value	g Iodine/100g	DIN 53241-1		115
Phosphorus	mg/kg	DIN 51440-1		10
Alkali content (Na+K)	mg/kg	To be develop from DIN 51797-3, complemented by potassium		5

Table 5 Selected fuel properties for diesel and biodiesel fuels (Tyson, 2001).

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM PS 121
Fuel composition	C10-C21 HC	C12-C22 FAME
Lower heating value, Btu/gal	131,295	117,093
Kin. viscosity,@40°C	1.3-1.4	1.9-6.0
Specific gravity kg/l @ 60°F	0.85	0.88
Density, lb/gal @ 15°C	7.079	7.328
Water, ppm by wt	161	0.05% max
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen, by dif. wt%	0	11
Sulfur, wt%	0.05 max.	0.0-0.0024
Boiling point, °C	188-343	182-338
Flash point, °C	60-80	100-170
Cloud point, °C	-15 to 5	-3 to 12
Pour point, °C	-35 to –15	-15 to 10
Cetane number	40-55	48-65
Stoichimometric air/fuel ratio wt./wt.	15	13.8
BOCLE Scuff, grams	3,600	>7,000
HFRR, microns	685	314

Table 6 Emission changes with biodiesel fuels.

Emission	Tailpipe emission changes (Tyson, 2001)		Locally impacting emission
	B100[a] (%)	B20[b] (%)	(Körbitz, 1999) (%)
CO	-43.2	-12.6	-20
HC	-56.3	-11.0	-32
Particulates	-55.4	-18.0	-39
NO_x	+5.8	+1.2	Slight increase[d]
Air toxics	-60 to –90	-12 to –20	ND
Mutagenicity	-80 to –90	-20	ND
CO_2	-78.3[c]	-15.7[c]	-3.2 kg/1 kg of biodiesel[e]
SO_x	ND	ND	-99
Soot	ND	ND	-59

a average of data from 14 EPA FTP Heavy Duty Test Cycle tests, variety of stock engines
b average of data from 14 EPA FTP Heavy Duty Cycle tests, variety of stock engines
c life cycle emissions
d with delay of injection timing however a decrease of 23% can be obtained
e the reduction of greenhouse gaes by at least 3.2 kg CO_2-equivalent per 1 kg biodiesel

confirmed that biodiesel could substitute diesel fuel in unmodified diesel engines both direct and indirect injections with no significant effects. There are some reports, which was reviewed by Knothe and Dunn (2001) summarized as the follows;

- In numerous on-the-road tests, primarily with urban bus fleets, vehicles running on blends of biodiesel with conventional DF (80% of DF with 20% of biodiesel) required only about 2-5% more of the blended fuel than of conventional fuel. No significant engine problems were reported
- Methyl and ethyl esters of soybean oil were evaluated by 200h EMA (Engine Manufacturers Association) engines tests and compared to DF2
- Even at low blend level (≤ 2 wt%), biodiesel could serve not only as a fuel component but as a lubricity-improving additive. (Conventional DF serves as its own lubricant within the fuel system; otherwise, at low sulfur levels, this ability is lost).

In Malaysia, Schäfer (1998) and IEM (2001), reported the biodiesel quality produced from crude palm oil and palm kernel using two stage-continuous esterification and transesterification processes. The results did show that the products' quality is comparable with Malaysian diesel, especially viscosity (0.04 @40°C (ASTM D445, cST)) and pour point (16.0°C (ASTM D97)); otherwise, it didn't completely meet the DIN 51606. Its cetane number (CN) was 62.4 for pure palm oil methyl esters (POME), which is higher than European DF2; nevertheless, most engine manufacturers designate a range of required CN, usually from 40 to 50, for their engine (Knothe and Dunn, 2001). Moreover, the results of a long-term operation, both bench test and field trials (OM 352 engines), which had been done on 30 buses, 10 on 100% of this POME, 10 on 50% blended and 10 on DF2, for more than 300,000 km-each was successfully done without any major problems from this alternative fuels. Consequently, the some analysis results are,

- Modification of conventional diesel engine is not required
- The engines run smooth and are easy to start with no knocking
- Exhaust gas emission is cleaner with reduction of HC, CO, CO_2, and SO_2
- Fuel consumption is comparable to petroleum diesel e.g. 3-4 km/l for buses tested.

In the work of Körbitz (1999) mentioned on a large fleet tests done in 1990, using biodiesel from farmers' cooperative commercial production, led to engine guarantees by most of tractor producers as e.g. John Deere, Ford, Massey-Ferguson, Mercedes, Same. Later on, the year 1996, biodiesel produced from large industrial scale plants in France and Germany with the latest biodiesel standard DIN E 51606 was the basis for warranties given by major diesel engine producers such as Volkswagen, Audi, Ford, IVECO, John Deere, Kubota, MAN, Mercedes-Benz, Seat, Skoda, and Volvo.

RESULTS AND DISCUSSSION

Based on the above information, the following results and discussion can be drawn;

1. Thailand's imported crude oil reached 102 Ml/day worth Bt 285,862 million per annum in 2000. If the country were able to substitute the amount of imported crude oil for 20% of diesel consumption, it would be equivalent to at least Bt 13,436 million per annum. This amount of money will therefore circulate within the country.

2. Biodiesel is not only the renewable energy sources but also does less harmful emissions than diesel fuel, specially, on CO_2, SO_2 and PAHs. Moreover, its biodegradability can conduct the benefits on aquatic environment.

3. In term of social, economic and environmental aspects in comparison among fossil, nuclear and biomass, biomass has taken the advantages over the others.

4. Thailand's benefits form biodiesel production system can provide more incomes, jobs, products' price stability for both agricultural sectors

and rural communities, reduce risk on health, currency exchange, reliance on foreign oil and environment impacts. Biodiesel can also increase country's energy security and enhance and emphasize the country's research and development for renewable energy resources in order to prepare for the fossil energy depletion in the future.

5. Oil Palm is quantitatively the highest production yield and increasing on harvested/ plantation areas' rate over other major oil crops in Thailand. Chemical compositions and properties of both CPO and CPK are suitable as biodiesel's feedstock.

6. In case of 20% diesel substitute, biodiesel production would require at least 4.4 million rais for oil palm plantation. There are suitably available lands for oil palm plantation (excluded existing plantation, residential, community and forest areas) as 12,971,928 rais remains in 14 southern provinces (including Prachuap Khirikhan) of Thailand.

7. Using either neat vegetable oils or blended with diesel in both direct or indirect injections, although, short term tests are almost always positive, for long term uses can lead to severe engine problems, emissions and storage.

8. Although, oil mill industry's capacity in Thailand remains almost 47% by year-average, this is able to provide biodiesel only 3.12% of diesel consumption per day.

9. Transesterification is the most commercially appropriated available technology to transform crude vegetable oil to biodiesel. Oils and fats as feedstocks for advanced continuous transesterification would be limited only on water and fatty acid contents.

10. Biodiesel (from transesterification process) is acceptable to substitute diesel fuel in unmodified diesel engines without any significant effects.

11. Many industrialized countries have developed standards for biodiesel in order to guarantee engine performance without any difficulties. Notably, some parameters in these standards are significantly different depend on the environmentally utilization conditions and raw materials in each country.

12. Malaysian crude palm methyl esters had satisfied the field tests either unmodified bus diesel engine or its emissions. The first commercial biodiesel production in Malaysia was proposed an investment of RM 438 million or equivalent to around Bt 5,313 million for 500,000 tons/year.

CONCLUSION

As the results, potential biodiesel production from palm oil for Thailand is highly positive; however, the price of extracted oil palm is higher than the final competing product, petroleum diesel. Therefore, the ways to minimized cost of biodiesel is to review taxation system, develop the market of its high value co-product (glycerin) and improve the industrial crop yield and management. Currently, in UK, the market price of glycerin is £ 1300 tonne^{-1} for purified product, and is predicted to be between £ 1000 and 1300 tonne^{-1} in the year 2004 (William son and Badr, 1998). Nevertheless, within this initial stage, another market for biodiesel would be a fuel additive because of more stringent regulation on sulfur content in diesel fuel. Biodiesel's high lubricity and CN properties are comparable with today's diesel-fuel additives, which their prices are normally substantially higher than petroleum diesel itself.

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LITERATURE CITED

Altin, R., S. Çetinkaya, and H.S. Yücesu. 2001. The potential of using vegetable oil fuels as fuel for diesel engines. Energy Conversion and Management. 42 : 529-538.

Bari, S., T.H. Lim, and C.W. Yu. 2002. Effects of preheating of crude palm oil (CPO) on injection system, performance and emission of a diesel engine. Renewable Energy 27 : 339-351.

Berger, K.G. 1984. Diversification of palm oil applications, pp. 199-221. *In* Proceedings of the International Seminar on Market Development for Palm Oil Products. 23-27 January 1984. Palm Oil Research Institute of Malaysia.

Canakci, M. and J Van Gerpen. 1999. Biodiesel Production via Acid Catalysis. Transaction of ASAE 42(5) : 1203-1210.

Chambers, K. 2000. Bioenergy: 21st Century fuel, pp.11-16. *In* Guide to UK Renewable Energy Companies 2000. dti, Jame x Jame, UK.

Connemann, J. and J. Fischer. 1999. Biodiesel processing technologies and future market development, pp.1-12. *In* Paper presented at the symposion "Biodiesel-Fuel from Vegetable Oils for Compression-ignition Engines" at the TAE. May 17, 1999. Ostfildern/Stuttgart.

Cook, E.W. 1984. Diversification of palm oil applications, pp. 215-221.*In* Proceedings of the International Seminar on Market Development for Palm Oil Products. 23-27 January 1984. Palm Oil Research Institute of Malaysia.

Crabbe, E., C. Nolasco-Hipolito, G. Kabayashi, K. Sonomoto, and A. Ishizaki. 2001. Biodiesel production from crude palm oil and evaluation of butanol extraction and fuel properties. Process Biochemistry 37: 65-71.

Demirbas, A. 2000. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Conversion and Management 42 : 1357-1378.

El Bassam, N. 1998. Energy Plant Species, Their Use and Impact on Environment and Development. James and James (Scienece Publishers) Ltd. UK. 321 p.

Gervasio, G.C. 1996. Fatty acids and derivatives from coconut, pp. 33-56. *In* Y.H Hui (ed.). Bailey's Industrial Oil and Fat Product. Vol. 5. Industrial and Consumer Nonedible Products from Oils and Fats. John Wiley and Son, Inc. NY.

Institution of Engineers Malaysia (IEM). 2001. Palm Diesel Time to Trap a Unique Biofuel. (cover story). JURUTERA Bulletin 8-10.

Knothe, G and R. O. Dunn. 2001. Biofuel derived from vegetable oils and fats, pp. 106-150. *In* F. D. Gunstone, and R. J Hamilton (eds.). Oleochemical Manufacture and Applications. Sheffield Academic Press. CRC.

Körbitz, W. 1999. Biodiesel production in Europe and North America, An Encouraging Prospect. Renewable Energy, 16 : 1078-1083.

Krahl, J., K Baum, U. Hackbarth, H.-E. Jeberien, A. Munack, C. Schutt, O. Schroder,N. Walter, J. Bunger, M.M. Muller, and A. Weigel. 2001. Gaseous compounds, ozone precursors, particle number and particle size distributions, and mutagenic effects due to biodiesel. Trans ASEA 44(2) : 179-191.

Kulavanich, P., S. Klinpikul, S. Kulavanich, and S. Chiramanee. 1988. Transformed Products and Marketing Development Project of Small Palm Oil Milling Regarding HM The King's Patronage. Prince of Songklanakarin University, Songkla. 127 p. (in Thai).

Lang, X., A.K. Dalai, N.N. Bakhshi, M.J. Reaney, and P.B. Hertz. 2001. Preparation and characterization of bio-diesel from various bio-oils. Bioresource Technology 80 : 53-62.

Ma, F. and A. M. Hanna. 1999. Biodiesel production: a review. Bioresource Technology 70 : 1-15.

Mattsson, B., C. Cederberg, and L. Blix. 2000. Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops. Journal of Cleaner Production 8 : 283-292.

Mittelbach, M. 1996. Diesel fuel derived from vegetable oils, VI: Specifications and quality control of biodiesel. Bioresource Technology 56 : 7-11.

Monyem, A., J.H. Van Gerpen, and M. Canakci. 2001. The effect of timing and oxidation on emissions from biodiesel-fueled engines.

Transaction of ASAE 44(1) : 35-42.

Muniyappa, P.R., S.C. Brammer, and H. Noureddini. 1996. Improved Conversion of Plant Oils and Animal Fats into Biodiesel and Co-product. Bioresource Technology 56 : 19-24.

Noureddini, H., D. Harkey, and V. Medikonduru. 1998. A Continuous Process for the Conversion of Vegetable Oils into Methyl Esters of Fatty Acids. JAOCS. 75(12) : 1775-1783

Raneses, A.R., L.K. Glaser., J.M. Price, and J.A. Duffield .1999. Potential biodiesel markets and their economic effects on the aricultural sector of the United States. Industrial Crops and Products 9 : 151-162.

Salam, B. A. 1985. The contribution of the oil palm by-products towards the Nationnal Energy Policy-an economist point of view, pp. 133-145. *In* Proceedings of the National Symposium on Oil Palm By-Products for Agro-Based Industries. 5-6 November 1985. Palm Oil Research Institute of Malaysia, Kuala Lumpur.

Salunkhe, D.K; J.K Chavan.; R.N. Adsule and S.S. Kadam. 1992. World Oilseeds, Chemistry, Technology and Utilization. AVI Book. New York. 545 p.

Sarakoon, N., S. Sinthurahat, and S. Dansakulphon. 1998. Agro-ecological Zoning Analysis for Oil Palm in the South of Thailand. Department of Agriculture. The Ministry of Agriculture and Cooperatives. Bangkok. 266 p. (in Thai.)

Sawyer, C.N. and P.L. McCarty. 1978. Chemistry for Environmental Engineering. 3rd ed, McGraw-Hill. New York. 532 p.

Schäfer, A. 1998. palm oil fatty acid methyl ester (POME) as diesel fuel in Malaysia, pp. 23-43. *In* Proceedings of the 1998 PORIM International Biofuel and Lubricant Conference, 4-5 May 1998, Malaysia.

Schuchardt, U., R. Sercheli, and R.M. Vargas. 1998. Transesterification of vegetable oils : a Review, *J. Braz. Chem. Soc*. 9(1) : 199-210.

Sheehan, J., V. Comobreco, J. Buffield, M. Graboski, and H. Shapouri. 1998. Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in Urban Bus. Final Report. prepared for USDOE and USDOA. National Renewable Laboratory. USA. 285 p.

Tat, M.E., J.H. Van Gerpen, S. Soylu, M. Canakci, A. Monyem, and S. Wormley. 2000. The speed of sound and Isentropic bulk modulus of biodiesel at 21°C from atmospheric pressure to 35 Mpa. JAOCS, 77(3) : 285-289.

The National Energy Policy Committee (NEPC). 2001. NEPC's Minute of Meeting 3/2544. NEPO. Thailand. 8p.

The National Energy Policy Office (NEPO). 2001.Thailand's Energy Situation 2001. NEPO Journal 53 : 53-113.

The Office of Agricultural Economics (OAE). 2000a, Agricultural Statistics of Thailand Crop Year 1998/99. Thailand. 161 p. (in Thai)

The Office of Agricultural Economics (OAE). 2000b. Information on the Important Agricultural Productions and Marketing. Statistical document no. 7/2543. Thailand. 167 p. (in Thai)

TIS 288-2521. 1978. Standard for Palm Oil. Thailand Industrial Standard Institute. 11p. (in Thai)

Tyson, S.K. 2001. Biodiesel Handling and Use Guidelines. National Renewable Laboratory. U.S. Department of Energy. NREL/TP-580-30004. CO. USA. 17p.

Van Dyne, D.L., J.A. Weber, and C.H. Braschler. 1996. Macroeconomic effects of a community-based biodiesel production system. Bioresource Technology 56 : 1-6.

Williamson, A-M. and O Badr . 1998. Assessing the viability of using Rape Methyl Ester (RME) as an alternative to mineral diesel Fuel for Powering Road Vehicles in the UK. Applied Energy. 59(2-3) : 187-214.

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