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Performance and Exhaust Emissions of a Diesel Engine using Partially Hydrogenated Fatty Acid Methyl Ester (H-FAME)

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Abstract

In the current study, high quality biodiesel called H-FAME has been introduced in order to increase its percentage in the current biodiesel blends which limited at only 7 %. Derived from palm fatty acid methyl ester, H-FAME from partial hydrogenation process is superior oxidation and thermal stability which is the major drawback of the current biodiesel. The specifications of H-FAME meet all biodiesel standards such as EU and US. The potential of H-FAME has been investigated by engine testing. A single cylinder diesel engine was used in the experiment. Engine performance and exhaust emissions of H-FAME and its blends were measured and compared with pure diesel. In addition, combustion characteristic was studied by analyzing in-cylinder pressure data. At high speed, engine torque and power decreased but no effect was observed at other speeds when using biodiesel. Due to lower heating value, increasing percentage of H-FAME in the blends increased the fuel consumption relative to pure diesel. H-FAME blends could decrease exhaust emissions (THC, CO and NO_X) in particular smoke. However, the advantage to reduce the exhaust gases was diminished with the pure biodiesel. With 20% or higher of H-FAME concentration, the pilot combustion happened and premixed combustions were delayed.

***Keywords**:* H-FAME, Biodiesel, Oxidation stability.

1. Introduction

Biodiesel has been used as a fuel in a compression ignition (CI) engine for the last decade due to its domestic resource, renewable energy and environmental friendly [1, 2]. In addition, biodiesel properties are similar or even superior to diesel fuel. For instance, biodiesel yields higher cetane number and better lubricity than diesel thus sometimes using as an additive for lubricity enhancers of petrodiesel [3]. Biodiesel is the viscous and high density fuel. Moreover, thermal and oxidation stability of biodiesel are relatively low which is the major barrier to limit the amount of biodiesel from the acceptance of Original Equipment Manufacturers (OEMs).

The uses of biodiesel and its blends have been studied by many researchers both in CI [4] and gasoline compression ignition (GCI) engines [5]. The studies have found that biodiesel could advance injection timing and shorten injection duration [6]. Spray penetration of biodiesel was longer and cone angle was narrower when compared with diesel [7]. The engine could use biodiesel without any modification and a substantial reduction in performance [1]. However, specific fuel consumption of biodiesel was higher because of its lower heating value. CO, HC and smoke were significantly decreased while NO_X emission was obviously increased with the percentage of biodiesel [8, 9].

Even though there are many researches to prove the use of the high concentration biodiesel, in Thailand only 7 % of biodiesel is accepted to blend with diesel as the commercial fuel. The quality of biodiesel has been questioned by the users and car makers. Therefore, high quality biodiesel is the promising way to increase percentage of biodiesel in the blends.

In the current study, high quality biodiesel called H-FAME has been introduced in order to increase its percentage in the current biodiesel blends Derived from palm Fatty Acid Methyl Ester (FAME), H-FAME has been reduced the number of double bonds/unsaturated fatty acids (methyl linolenate, C18:3) to be monounsaturated FAME (C18:1) by partial hydrogenation process. H-FAME, therefore, is superior oxidation and thermal stability.

The potential of H-FAME has been investigated by engine testing. The effects of H-FAME and its blends on engine performance, fuel consumption and engine-out exhaust emissions have been experimented. Also, combustion characteristics when using H-FAME have been clarified. Pure biodiesel (B100) and its blends (B10, B20, and B50) were compared with neat diesel in the current study.

2. Materials and Method

2.1 Engine

A single cylinder diesel engine with a direct injection system by a mechanical pump was used throughout the experiment. Engine bore and stroke is 97 x 96 mm, respectively. The detailed specifications of the engine are listed in Table 1. The engine was connected to the generator set in which the electrical load (halogen lamp) was used to control engine speed

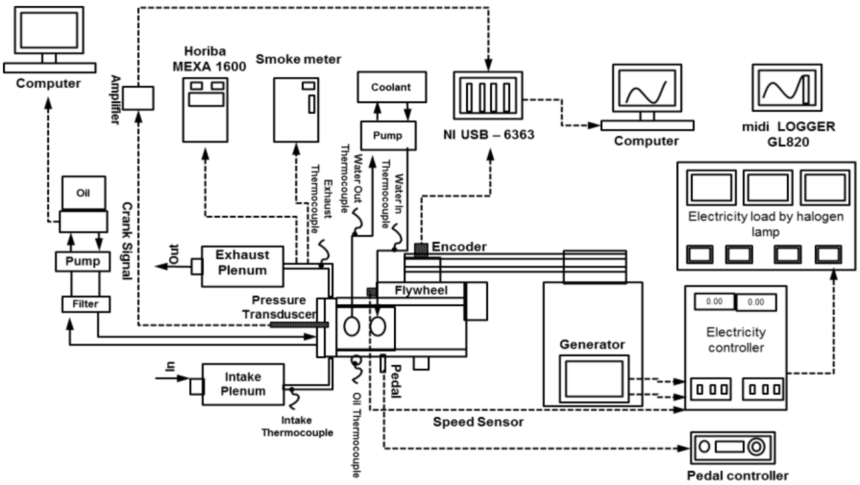


Fig. 1 The schematic diagram of the engine connected with the experimental apparatus.

and load. Fuel consumption was measured by gravimetric fuel consumption meter, FCL-100 R. Fig. 1 presents the schematic diagram of the engine connected with the experimental apparatus.

Table. 1 The specifications of the engine

Model	**KUBOTA RT140 DI-ES**
Number of Cylinders	1
Bore x Stroke (mm)	97x96
Displacement (cc)	709
Max Output (HP(kw)/rpm)	14/2400(10.3kw/2400)
Compression Ratio	18.1
Cooling system	water

2.2 Test fuels

Derived from palm Fatty Acid Methyl Ester (FAME), high quality biodiesel named as H-FAME was used in the experiment. Because of monoenen-rich FAME, H-FAME is superior oxidation and thermal stability. As shown in Fig. 2, ordinary FAME is reduced the number of double bonds/unsaturated fatty acids to monounsaturated FAME by partial hydrogenation process with hydrogen and catalyst at low temperature and pressure. In addition, hydrogenation process can convert Monoglyceride (MG) to Saturated Monoglyceride (SMG) for ease of removal. Therefore the percentage of monoglyceride, which could precipitate even at higher temperature than cloud point and result to a plugged fuel filter, remaining in H-FAME is reduced. Five fuels including diesel, B10, B20, B50, and B100 were employed throughout the experiments, where B stands for biodiesel the numeric value refers to the percentage by volume mixed with diesel. The properties of H-FAME (B100) and pure diesel (B0) are presents in Table 2.

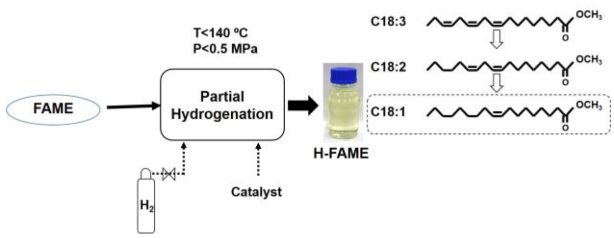


Fig. 2 H-FAME production from partial hydrogenation process

Table. 2 The properties of test fuels

Properties	**Diesel (B0)**	**Palm (B100)**
Heating Value (MJ/kg)	45.2	39.9
Density(g/cm^3)	0.838	0.861
Cloud point	17.5	20.1
Pour point	6	15
Oxidation stability	-	86.3
Cetane number	~50	> 64
Viscosity	3.32	4.50

2.3 Experimental apparatus

A piezoelectric pressure transducer (Kistler type 6052C) connected to a charge amplifier Kistler type model 5108 was used to measure the in-cylinder pressure. Triggered by the encoder signal connected to the crank shaft, the in-cylinder pressure was recorded for 100 consecutive cycles at 0.1 crank angle (CA) resolution and the averaged values were used in the subsequent heat release analysis. The net heat release rate was calculated from the one zone thermodynamic model prescribed by Heywood [10], shown in equation 1.

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dp}{d\theta} \qquad (1)$$

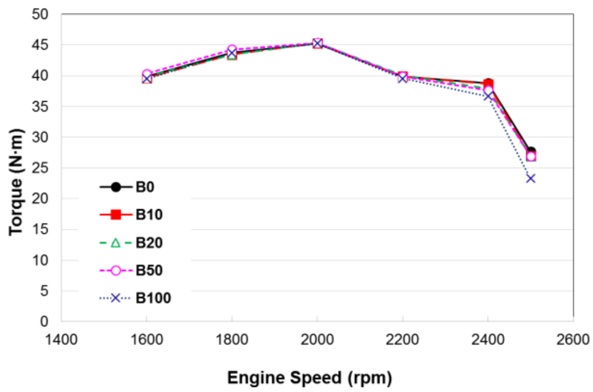
where p is the in-cylinder pressure, γ is the fixed ratio of specific heats, and V is the cylinder volume. The model assumes uniform in pressure, temperature and a fuel/air ratio distribution.

A flame ionization detector (FID) analyser, Horiba model FCA-266 was used to measure exhaust unburned hydrocarbon (HC) emissions. A Horiba model FCA-266 Chemiluminescent analyser was used to measure the oxides of nitrogen (NO_X) in the exhaust gas. CO concentration was measured by the non-dispersive infrared (NDIR) technology, a Horiba Model AIA-260. Smoke level was detected by an AVL smoke meter 145SE.

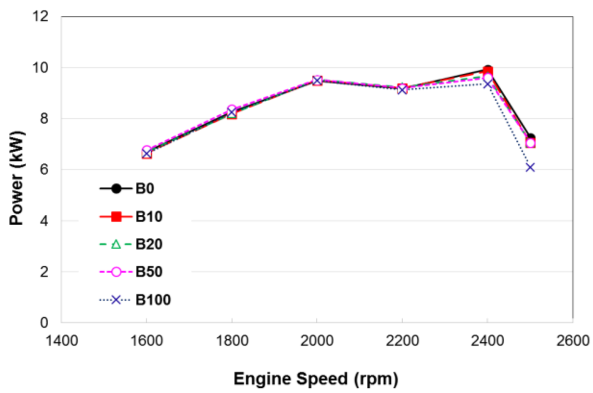
3. Results and discussions

3.1 Performance and fuel consumptions

Torque and power of palm H-FAME and its blends compared with pure diesel are presented in Fig.3. It is surprising that there was no significant change of torque and power when using biodiesel and its blends at 1600 – 2200 rpm of engine speed. Torque and power, however, were decreased when increasing percentage of biodiesel at high speed (more than 2400 rpm). Although biodiesel has the lower heating value but its density is higher than diesel. Hence, more mass of biodiesel injected with the same volume flow rate were combusted and produced the same torque and power. Morover, oxygen content in biodiesel molecules promoted more complete combustion. Due to higher viscosity and density of biodiesel, the rate of biodiesel vaporization and fuel-air mixing process decreased with less avalable time at high speed. This is the cause of torque and power reduction [11, 12].



(a) Torque



(b) Power

Fig. 3 Engine torque and power when using H-FAME and its blends compared with diesel

Fig.4 illustrates break specific fuel consumptions (BSFC) of each test fuel. Due to lower heating value, break specific fuel consumption increased with the percentage of biodiesel H-FAME. The magnitude of the difference was significant at high speed because biodiesel hardly evaporated and mixed with air within the limited time.

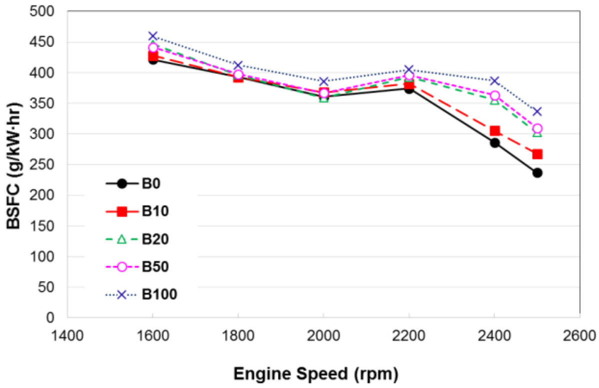


Fig. 4 Break specific fuel consumption when using H-FAME and its blends compared with diesel.

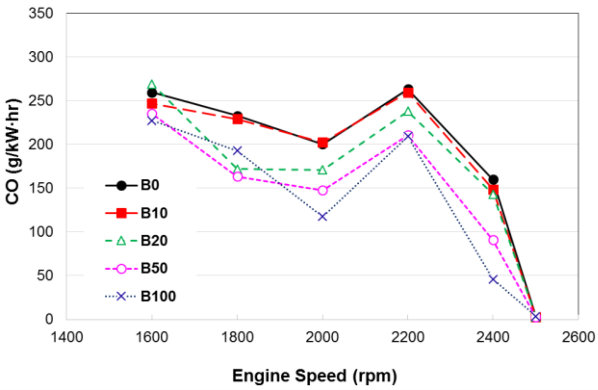
3.2 Engine-out exhaust emissions

Engine-out exhaust emissions including carbonmonoxide (CO), total hydrocarbon (THC), oxide of nitrogen (NO_X) and smoke are presented in Fig. 5. CO emissions decreased when the percentage of biodiesel H-FAME increased in the blends. However, B100 had the similar levels of CO or higher than B50 at some engine speed. Due to oxygen content in biodiesel, injected fuels were oxidized with the sufficient oxygen. But, too lean mixture of pure biodiesel may result in misfire conditions and then increase CO concentration.

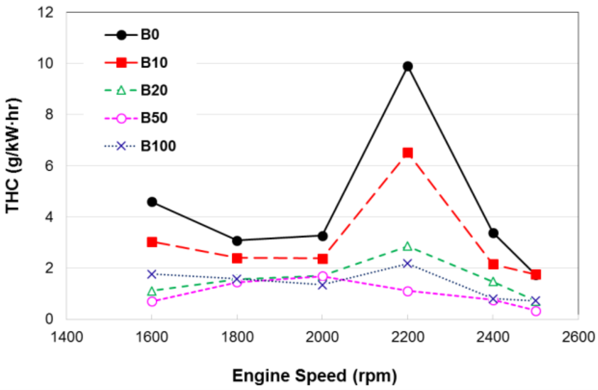
Oxygen molecule in biodiesel also resulted in lower THC emissions as shown in Fig.5 (b) because more complete combustion occurred. Corresponding with the trend of CO emissions, incomplete combustion was observed with pure biodiesel and led to equivalent or higher levels of THC emissions than those of B50.

In the current study, NO_X emissions decreased with the concentration of biodiesel H-FAME except for B100. The results differ from most of the previous studies in which biodiesel from FAME increased the concentration of NO_X due to the advance injection timing [13, 14]. Heat release rates which will be discussed later show that the delay of premixed combustion is the cause of NO_X reduction when using the blends.

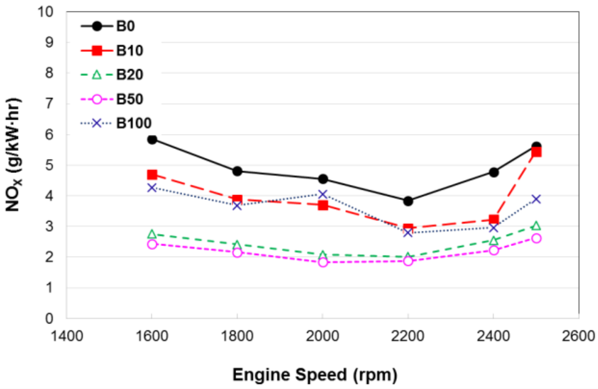
The amount of smoke indicated as Filter Smoke Number (FSN) in Fig. 5 (d) significantly decreased when using biodiesel H-FAME and the blends. Due to available oxygen in biodiesel molecule, the rich regions of the mixture which is the major cause of smoke are decreased.



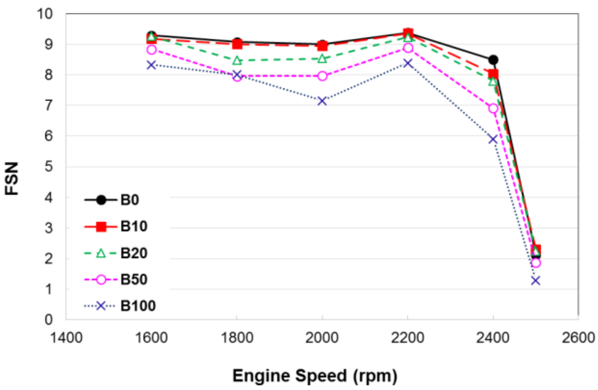
(a) CO



(b) THC



(c) NO_X



(d) Smoke (FSN)

Fig. 5 Engine out exhaust emission when using H-FAME and its blends compared with diesel (a) CO (b) THC (c) NO_X and (d) Smoke

3.3 Combustion characteristics

Fig. 6 presents in-cylinder pressure of the blends compared with neat diesel at 2000 rpm of engine speed and 35 Nm of torque. B10 yielded the highest peak pressure of 80.42 bar at 369.1 CA, equivalent to B50 (80.37 bar at 370.6 CA) and B20 (79.89 bar at 370.9 CA), followed with B0 (79.35 bar at 369.0 CA) while B100 had the lowest peak pressure of 78.73 at 370.7 CA. The crank angle of the maximum pressure of the low blends (B0 and B10) occurred near the top dead center but moved far away for the high blends (B20 – B100). The complexity of different fuel properties are the cause and will be further explained in terms of heat release rate.

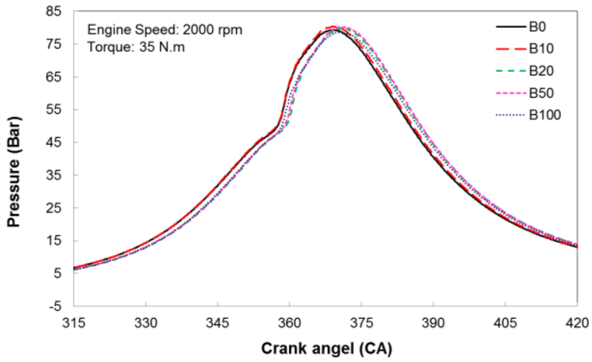


Fig.6 In-cylinder pressure of H-FAME blended fuels compared with pure diesel

Fig. 7 shows the heat release rate of each test fuel at 2000 rpm of engine speed and 35 Nm of torque. Heat release rate indicated the pilot combustion when test fuels were blended with 20 % or higher of palm H-FAME. There was no pilot combustion observed for neat diesel and B10. Relative to diesel fuel, the lower bulk modulus (compressibility) of biodiesel results in advanced injection timings when the engines use an in-line mechanical pump type injection system [15]. The biodiesel blended fuels (B20, B50 and B100) evaporated and mixed with air earlier. Therefore, the oxidation of ready mixture was occurred. Pure biodiesel showed the later pilot combustion than B20 and B50. This is due to the fact that higher viscosity and lower volatility of biodiesel overcome the effect of advanced injection timing.

Although higher biodiesel blended fuels yielded the pilot combustion, the main combustions (premixed combustion phase) of higher blends were delayed more than B0 and B10 as presented in Fig. 8. Pure diesel had the earliest combustion which equivalent to B10, followed by neat biodiesel, B50 and B20, respectively. The difficulty of evaporation and air-mixing process hindered auto-ignition of biodiesel thus retarding the main combustions of high biodiesel blends. However, higher cetane number of biodiesel decreased ignition delay. Consequently, pure diesel showed the earlier premixed combustion than B50 and B20, respectively.

Pure biodiesel had the lowest heat release rate because the less mass were left to oxidize due to the occurrence of pilot combustion in conjunction with the earlier of premixed combustion. Although some mass of B20 and B50 were burned during the pilot combustion, the delay of the main combustion resulted in more remaining mass for oxidation. As the results, their heat release rate were higher than those of B0 and B20. Due to lower heating value, more mass of the high blends were required to produce the same torque with the low biodiesel blends. Therefore, the combustion periods of the high blends were lengthened than B0 and B10.

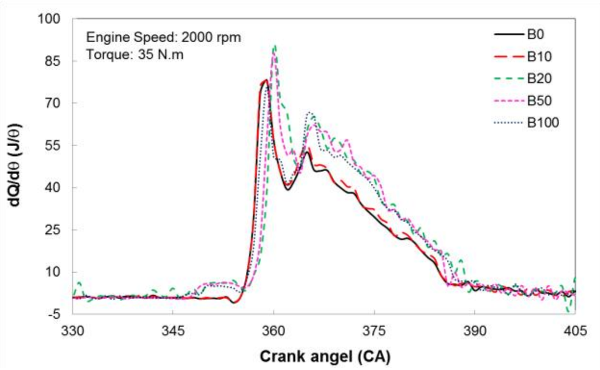


Fig. 7 Heat release rate of of H-FAME blended fuels compared with pure diesel.

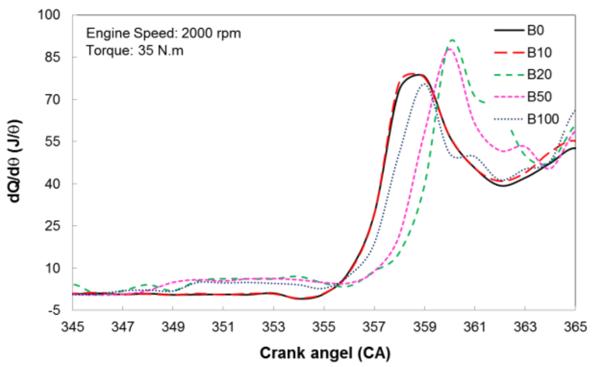


Fig. 8 The magnification of heat release rate to exhibit the start of the premixed combustion of each test fuel.

4. Conclusions

According to its higher thermal and oxidation stability, high quality biodiesel from partial hydrogenation process was introduced in the current study. The effects of H-FAME on engine performance, exhaust emissions and combustion characteristics were clarified. The main conclusions can be summarized as follows:

- Except for high speed, engine torque and power were similar between H-FAME blended fuels and neat diesel. However, specific fuel consumption showed significant increase with the percentage of biodiesel for all speeds.
- All engine-out exhaust emissions (CO, THC, NO_X and smoke) decreased with the increased H-FAME concentration. However, with the difficulty of evaporation and atomization pure biodiesel showed the less advantage of the exhaust gas reduction than B50.
- Pilot combustion followed with the delayed premixed combustion was occurred when using 20 % or higher of H-FAME blended fuels. These combustion phenomena are the cause of NO_X reduction.
- The effects of H-FAME on the modern diesel engine with the common rail injection system have been investigated and will be published in the future.

5. Acknowledgement

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