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A Comparison of Combustion and Emissions of a Diesel Engine using Jatropha and Palm H-FAME Fuels

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Abstract

The effects of biodiesel feedstocks including jatropha and palm on engine performance, exhaust emissions and combustion characteristics were investigated in the current study. Derived from palm and jatropha Fatty Acid Methyl Ester (FAME), high quality biodiesel from partial hydrogenation process were analyzed their properties and effects in a single cylinder diesel engine. Ten percent of H-FAME (B10) was mixed with petro diesel and applied in the engine. Also, neat diesel was used for the reference. The specifications of both H-FAME meet all biodiesel standard including EU and US. Both H-FAME showed higher stability than those of corresponding FAME due to the reduction of the number of double bone. Palm H-FAME yielded better oxidation stability than jatropha. Heating values are nearly the same but lower than diesel fuel. There was no significant effects of biodiesel feed stock on engine performance but obviously impact on exhaust emissions. Palm biodiesel could decrease NO_X emissions but jatropha resulted in the opposite trend. Due to lower heating value, specific fuel consumption slightly increased. With only 10 % of H-FAME, combustion characteristics were nearly the same with different biodiesel.

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

1. Introduction

To reduce the demand of imported petroleum fuels, domestic fuels such as ethanol and biodiesel have been introduced in the market. Ethanol has been succeeded to blend with gasoline up to 85 % whereas only 7% of biodiesel has been mixed with diesel for the current engine technology. Therefore, the necessity to increase percentage of biodiesel in the blends is absolutely crucial. The major hindrance to limit the amount of biodiesel is the acceptance from the Original Equipment Manufacturers (OEMs) who question the quality of biodiesel in particular oxidation stability.

Upgraded by partial hydrogenation process, high quality biodiesel can be derived from different biodiesel feed stocks. Many researches have proved that conventional biodiesel from different raw materials yielded different physical and chemical properties, hence, different impacts on engine performance and emissions [1]. Biodiesel which contains high saturated molecules yields higher cetane number than those of unsaturation. However, cloud point and cold filter plugging point (CFPP) are higher for higher fraction of saturated fatty acids [2].

Many researchers have conducted studies on the use of both pure biodiesel and biodiesel blends in compression ignition (CI) engines [3]. The studies included engine performance, fuel consumption, emissions, combustion characteristics and material compatibility, compared to results from using regular diesel fuel [4]. The test demonstrated the use of biodiesel in a diesel engine without a substantial reduction in engine performance or requiring engine modification [5]. Cycle-to-cycle variability with biodiesel was shown to be on the same order as that of petroleum diesel fuel [6]. Higher specific fuel consumption of biodiesel was necessitated, due to its lower heating value, but lower exhaust emissions, such as CO and HC, were emitted [7]. Moreover, particulate matter was significantly reduced [8, 9]. However, increased NO_X emission was measured.

Although there are many researches to compare the effects of biodiesel feedstock on engine performance and emissions [10], there is a lack of information for the effects of high quality biodiesel from different feedstock. Therefore, derived from jatropha and palm, high quality biodiesel from partial hydrogenation process has been investigated. Jatropha biodiesel has been selected due to the potential non-edible resource while palm is the current biodiesel feedstock in Thailand. In order to increase the percentage of biodiesel blended in commercial diesel, the effects of ten percent of high quality biodiesel (B10) on engine performance and emissions have been experimented. Also, combustion characteristics of the blends have been tested and compared with pure diesel (B0).

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 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

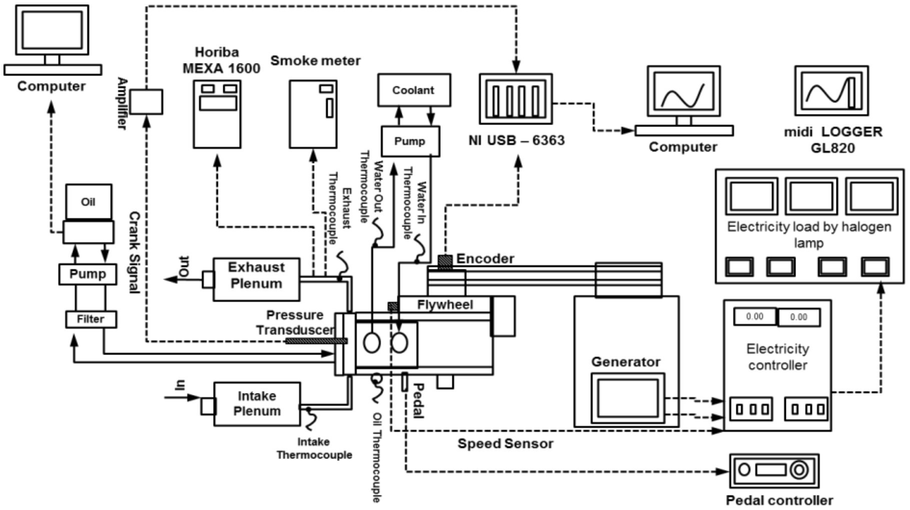


Fig. 1 The schematic diagram of the engine connected with the experimental apparatus.

2.2 Test fuels

Derived from jatropha and palm Fatty Acid Methyl Ester (FAME), ten percent (B10) of high quality biodiesel named as H-FAME blended with diesel 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. The properties of test fuel including pure diesel (B0) are presents in Table 2.

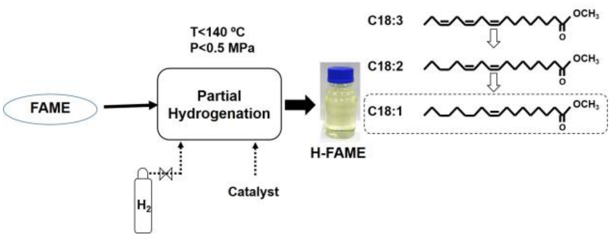


Fig. 2 H-FAME production from partial hydrogenation process

Table. 2 The properties of test fuels

Properties	B0	Palm (B100)	Jat. (B100)
Heating Value (MJ/kg)	45.2	39.9	39.9
Density (g/cm^3)	0.838	0.861	0.876
Cloud point (°C)	17.5	20.1	-
Pour point(°C)	6	15	-
Oxidation stability (hr)	-	86.3	15.1
Cetane number	-	> 64	57
Viscosity (mm^2/s)	3.32	4.50	5.11

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 [11], shown in equation 1.

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

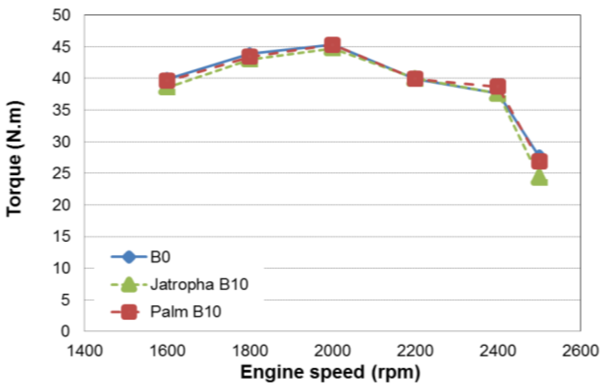
where Q is the heat release, θ is crank angle, p is the in-cylinder pressure, γ is the fixed ratio of specific heats, and V is the cylinder volume. The model assumes uniform in pressure, temperature and a fuel/air ratio distribution.

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.

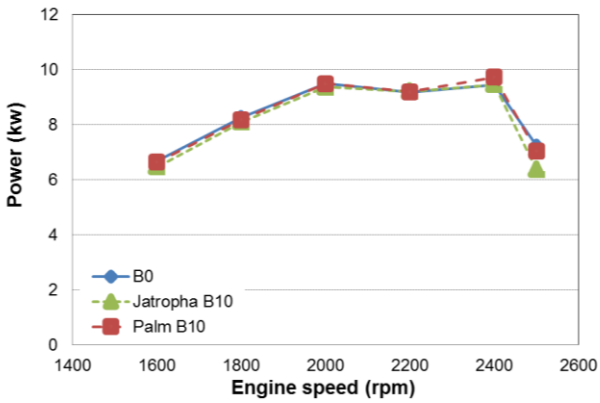
3. Results and discussions

3.1 Performance and fuel consumptions

Torque and power when using B10 from jatropha and palm H-FAME compared with pure diesel are presented in Fig. 3. There was no significant change of torgue and power when using biodiesel. Jatropha, however, slightly decreased the torque and power at high speed. Due to less avalable time of mixing process, higher viscosity and density of jatropha which decrease the atomization rate are the major cause for torque reduction [12,13].



(a) Torque



(b) Power

Fig. 3 Engine torque and power when using B10 (jatropha and palm H-FAME) compared with B0

Brake specific fuel consumptions (BSFC) of each test fuels are illustrated in Fig. 4. Based on lower heating value of biodiesel, H-FAME from jatropha and palm slightly increased BSFC when compared with B0.

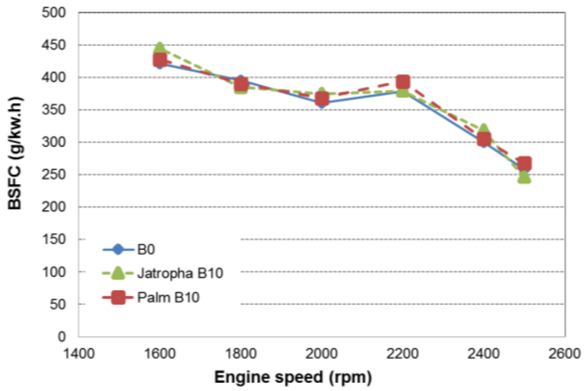


Fig. 4 Brake specific fuel consumption when using B10 (jatropha and palm H-FAME) compared with B0

3.2 Engine-out exhaust emissions

Fig. 5 shows the effects of biodiesel on engine-out exhaust emissions including THC, CO, NO_X and soot. Except for jatropha at 1600 and 1800 rpm of engine speed, H-FAME biodiesel significantly decreased THC in the exhaust gas when compared with neat diesel. Due to more oxygen content available in the blends, more complete combustion is the cause to lower THC. At low speed, however, too lean mixture of high density jatopha resulted to incomplete combustion thus increasing THC concentration. When considering the type of biodiesel, palm H-FAME seemed to decrease THC more than jatropha. Higher cetane number of palm shortens the ignition delay. Therefore, the amounts of THC were reduced [14].

Relative to B0, the blends from H-FAME slightly decreased CO concentration in Fig. 5(b) except for jatropha at low speed. Carbon monoxide levels from internal combustion engines is primarily controlled by air/fuel ratios [11]. From stoichiometric to lean mixture, the level of CO is relatively low because there is sufficient oxygen for fuels to oxidize. However, too lean mixture at low speed is the cause of higher CO for jatropha combustion.

Different H-FAME feedstock resulted in different trend of NO_X when compared with pure diesel as seen in Fig. 5 (c). B10 from jatropha obviously increased but palm considerably decreased NO_X in the exhaust gas. The results correspond well with the previous study [14]. Due to higher bulk modulus of jatropha which has higher viscosity, injection timings were advanced and resulted in increased NO_X emission [15]. In addition, the higher unsaturated molecule/ double bonds of jatropha (oleic and linoleic fatty acids) results in higher NO_X emission [16, 17]. Palm H-FAME has lower viscosity and density than jatropha. Therefore, the effects of bulk modulus resulted in less advanced injection timing. Also, saturation of palmitic fatty acid molecules in conjunction with the reduction of double bonds by partial hydrogenation process produces lower NO_X concentration [18]. Due to higher cetane number, palm H-FAME could decrease NO_X level lower than pure diesel [14, 19].

The amount of smoke indicated as Filter Smoke Number (FSN) in Fig. 5 (d) slightly decreased when

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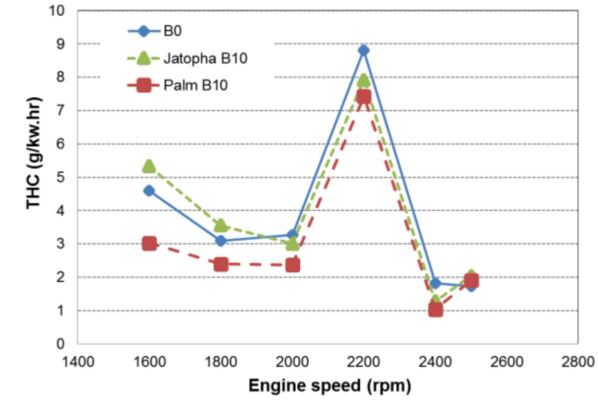
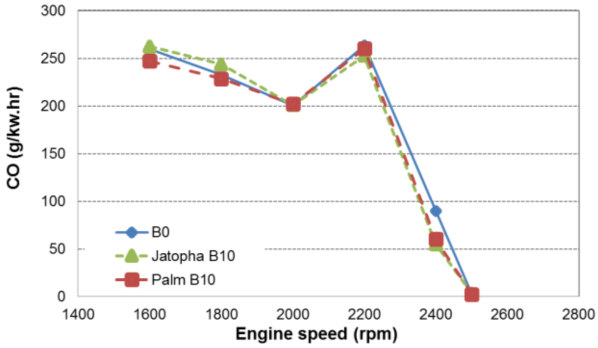
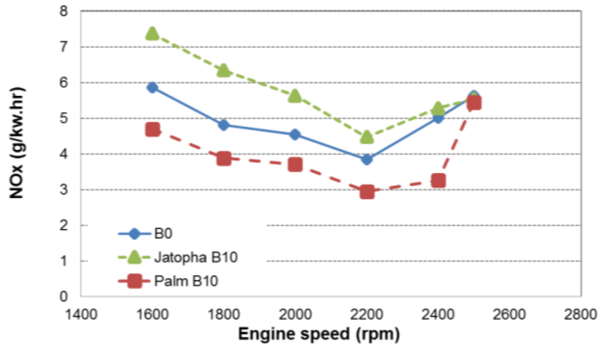
using 10% of biodiesel H-FAME as a fuel. Rich region of the mixture is the major cause of smoke formation. Due to available oxygen in biodiesel molecule, the extent of rich zone is reduced thus decreasing smoke.



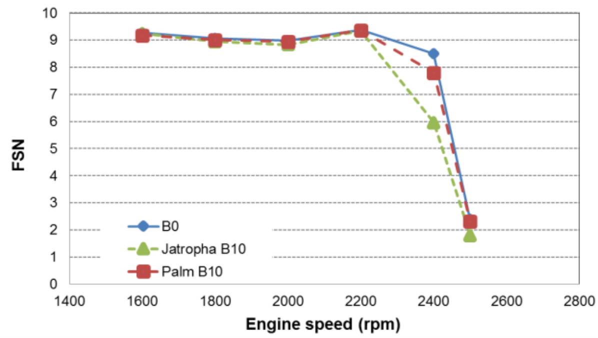
(a) THC



(b) CO



(c) NO_X



(d) Smoke (FSN)

Fig. 5 Engine out exhaust emission when using B10 (jatropha and palm H-FAME) compared with B0 (a) THC (b) CO (c) NO_X and (d) Smoke.

3.3 Combustion characteristics

Fig. 6 presents in-cylinder pressure while Figure 7 shows the heat release rate of B10 from jatropha and palm H-FAME compared with pure diesel (B0) at 1600 rpm of engine speed and 35 Nm of torque. Diesel yielded slightly lower in-cylinder pressure than that of the blends in which palm H-FAME was marginally higher than jatropha. Due to higher cetane number, earlier of start of injection, the combustion started earlier as shown in Fig. 8 and the peak pressure occurred near top dead center (TDC). As the results, the maximum pressures were higher than diesel in which the peak pressure happened further away from TDC in the expansion stroke. The maximum pressure of palm - , jatropha - B10 and diesel are 85.14, 84.08 and 82.43 bar respectively.

Except for the different maximum values, the trends of heat release rate of all tested fuels were identical. Although the blends started to combust earlier, their burning rate were slower than diesel after five percent of mass burned due to lower air/fuel mixing rate. In addition, more amount of blends was required to produce the same load with diesel. Therefore, more blended fuels remained to combust and resulted to higher heat release rate.

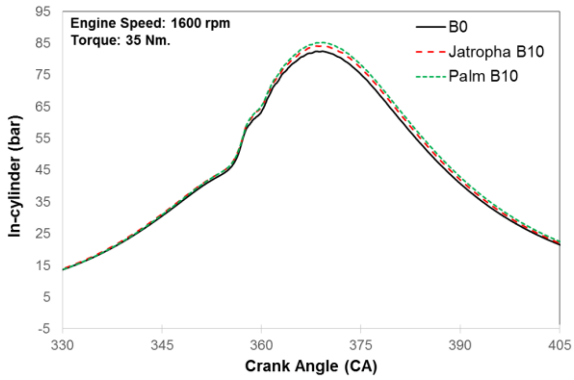


Fig. 6 In-cylinder pressure of B10 from jatropha and palm H-FAME compared with pure diesel

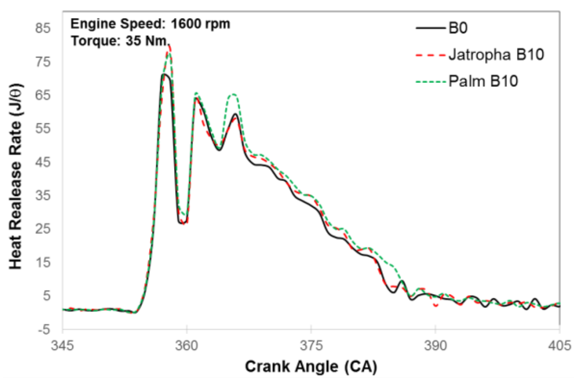


Fig. 7 Heat release rate of B10 from jatropha and palm H-FAME compared with pure diesel

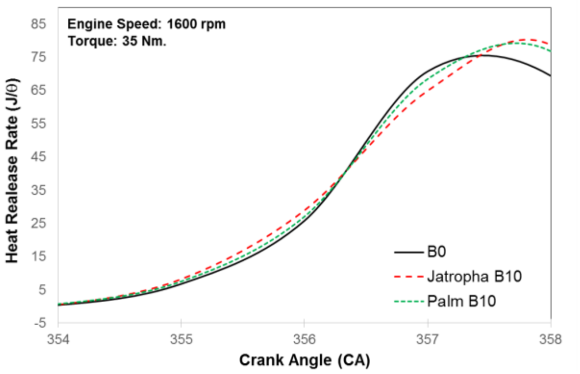


Fig. 8 The magnification of heat release rate of B10 from jatropha and palm H-FAME compared with pure diesel

4. Conclusions

In the current study, the effects of H-FAME from different feedstocks on engine performance, exhaust emissions and combustion characteristics were investigated. Ten percent of jatropha and palm H-FAME was blended with diesel and used as the test fuels (B10). The main conclusions can be summarized as follows:

- High density and viscosity of jatropha resulted in torque and power reduction at high engine speed when using B10. However, no effect of 10 % of palm H-FAME on engine performance was shown.
- Both H-FAMEs from jatropha and palm could reduce the amount of THC, CO, and smoke.
- Different feed stock of biodiesel had the different effects on exhaust emissions. Palm feed stock showed more advantage over jatropha H-FAME in terms of the exhaust gas reduction. In particular, palm biodiesel could decrease NO_X while the levels of NO_X increased with jatropha combustion.
- With only 10 % of H-FAME, there was no significant change in in-cylinder pressure and heat release rate relative to pure diesel.

5. Acknowledgement

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