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Effects of Injection Timing on Performance and Emissions of a Direct Injection Diesel Engine Using Neat Palm Biodiesel

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Abstract

With governmental promotion on alternative energy, biodiesel has been focused to reduce the nation dependency an imported crude oil. This study investigated the performance and emissions of a direct injection (DI) diesel engine (4 cylinder, 4 stoke, 3.612 liter), with varied injection timing. The engine, used as a farm truck for agricultural activities, was fueled with conventional diesel and neat biodiesel from palm oil. The engine was performed at full and part load ranging from low to high speed. The results indicated that when tested engine was fueled with palm biodiesel, engine torque was slightly dropped whereas specific fuel consumption was higher than that of diesel. At high load, biodiesel combustion yielded higher thermal efficiency than that of diesel. However, the difference was reduced for medium and low load. Injection timings had no effects on engine torque, BSFC and thermal efficiency when using biodiesel.

At the same injection timing, the reduction of exhaust emissions including carbon monoxide (CO) and total unburned hydrocarbon (THC) was shown when using biodiesel. However, the drawback to increase oxide of nitrogen (NOx) at high load was presented. Injection timing presented insignificant effects on THC whereas oxide of nitrogen obviously increased with the advanced injection timing.

***Keywords**:* Biodiesel, Direct-injection Diesel Engine, Injection Timing, Exhaust Emission.

1. Introduction

Nowadays, the consumption and prices of petroleum in the world have been progressively increased. Moreover, the emission legislations to control harmful exhausts emissions from automobiles such as NO_X, SO_2 and CO_2 have been tightening restricted. Biodiesel is one of the alternative fuels which applied recently to alleviate the prices of fuel and also reduce engine-out emission. Therefore, Thai government has issued the Alternative Energy Development Plan: AEDP (2012-2021) in order to substitute biodiesel 5.97 ML/day [1].

Many researchers have studied on the use of biodiesel in CI engines and compared to the use of regular diesel fuel. The studies were conducted on both indirect (IDI) and direct injection (DI) engines [2-4]. The studies demonstrated the use of biodiesel in a diesel engine without major engine modification due to the similarity between biodiesel properties and those of diesel. In particular, biodiesel has a high cetane number that is comparable to diesel, making it possible to self-ignite in CI engines. Moreover, biodiesel has superior characteristics than diesel in terms of higher lubricity, very low sulfur and aromatic-hydrocarbon content.

When compared with diesel fuel, biodiesel showed slightly reduction in engine torque. Due to its lower heating value, higher specific fuel consumption of biodiesel was necessitated. For exhaust emissions, biodiesel significantly reduced particulate matter and HC [5-7]. Most of the cases decrease CO and increase NO_X emissions [8]. However, different engine operations could cause the opposite results [9, 10].

In the current study, engine performance and regulated exhaust emissions were investigated when using neat palm biodiesel in a direct injection diesel engine. Engine operations were performed in full and part load with varying engine speed. In addition, injection timings were adjusted. Commercial diesel was also applied to be the reference

2. Experimental Setup

A four-cylinder direct-injection diesel engine was used in the experiment. This type of engine is commonly employed in an agricultural farm truck. An in-line pump was used to supply fuel from the tank to the engine. Detailed specifications of the engine are shown in Table I. The engine was mounted on a Tokyo Plant eddy-current dynamometer with a capacity of 150 kW, which was used to control the engine speed and torque. The experiment setup is shown in Figure 1.

Table 1 Engine Specification

Model	YUNNEI 4100QB-2
Type	4-stroke,vertical engine
Bore x Stroke	100 x 115 mm.
Number of Cylinder	4
Cylinder Type	Waterish type
Combustion Type	Direct injection ω type
Displacement	3.612 liters
Idle Speed	750 rpm
Compression Ratio	17.5:1
Firing Order	1-3-4-2
Rated Power	66.2/3200 kW-hr
Max Torque	230/2000-2200 N.m/rpm
Fuel Consumption	≤238 g/kW-hr
Net weight	320 kg
Injection timing/pressure	12°/19.1±0.49MPa

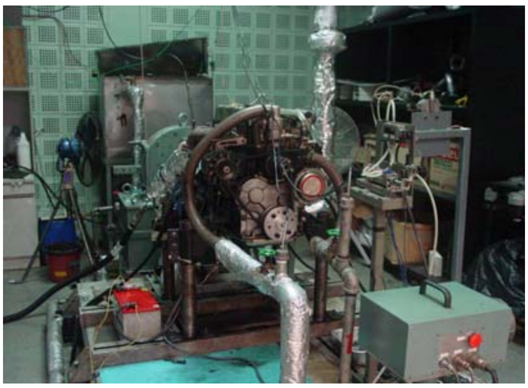


Figure 1 Experimental Setup

A flame ionization detector (FID) analyser was used to measure exhaust UHC emissions.

Chemiluminescent analyser was used to measure the oxides of nitrogen in the exhaust gas. CO and CO2 concentration was measured by the non-dispersive infrared (NDIR) technology. Fuel consumption was weighed by Load cell Tokyo Plant DY -1000T.

Pure palm-olein biodiesel (B100), purchased from a commercial source, was used throughout the experiment. The biodiesel properties, which comply with Thailand's commercial biodiesel standard, are shown in Table 2. Commercial diesel (B2) from the retail station was tested to be the reference at standard injection timing.

Before the test started, the engine was warmed up until engine oil temperature reached 60 ^{O}C. The experiments were conducted in full and part load (fixed torque at 100 N.m) with varying engine speed. Injection timings were set at 10 – 14 ^{O}BTDC with 1 degree increment.

Table. 2 Fuel Properties

Properties	Methods	Results	Units
WaterContent	ASTM D6304	335.5	ppm
Acid Value	ASTM D 664	0.27	mgKOH/g
Oxidation Stability	EN14112	11.01	Hour
CarbonResidue	ASTM D 4530	0.01	%wt
Gross Heat	ASTM D 240	38.20	MJ/kg
Density	ASTM D 4052	0.85	g/cm^3
ASTM Color	ASTM D1500/156	0.8	-
Pour Point	ASTM D 97	18	ºC
Flash Point	ASTM D 93	165	ºC
Kinematic viscosity at 40 ºC	ASTM D 445	4.5	mm^2/sec

3. Results and Discussion

3.1 Full load (Wide open throttle)

Figure 2 in which BDF stands for biodiesel illustrates engine torque at full load when injection timings are adjusted. Biodiesel was used as a fuel and also diesel was applied for the reference at 12^{O} BTDC of injection timing. The results show that adjusted injection timing has no significant effect on engine torque when using biodiesel. Due to lower heating value, biodiesel slightly decreases engine torque when compared with diesel fuel.

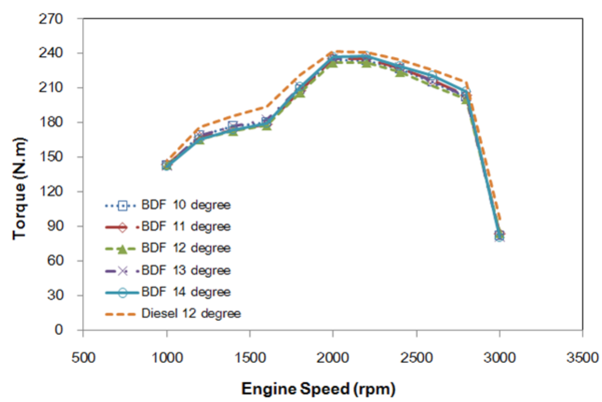


Figure 2 Engine Torque at full load with adjusted injection timings

As the same engine torque, adjusting injection timing has no effects on break specific fuel consumption and thermal efficiency when using biodiesel as shown in Figure 3 and 4. The results show the different trend from the study of Ganapathy et.al [11] in which varying injection timing show significant effect on fuel consumption and thermal efficiency of jatropha biodiesel. The effect of injection timing can be observed due to 5 degree increment of varying injection timing whereas less increment (1 degree) was set up in the current study.

Diesel fuel present lower BSFC due to its higher heating value. However, thermal efficiency of diesel is lower than that of biodiesel for all injection timings. This means that although biodiesel has lower energy input, its combustion more efficiently releases heat. Due to oxygen available in biodiesel molecule, it could enhance readily and complete combustion more than diesel fuel.

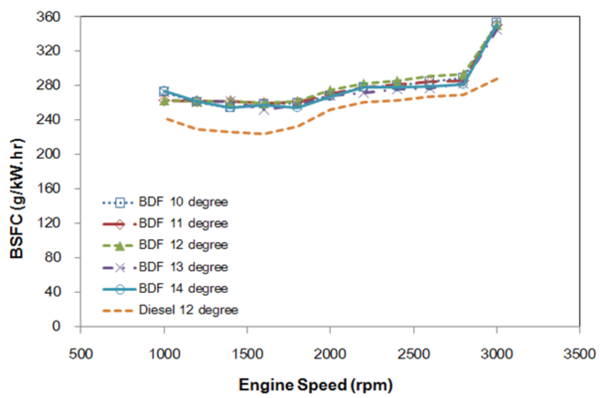


Figure 3 Break specific fuel consumption at full load with adjusted injection timings

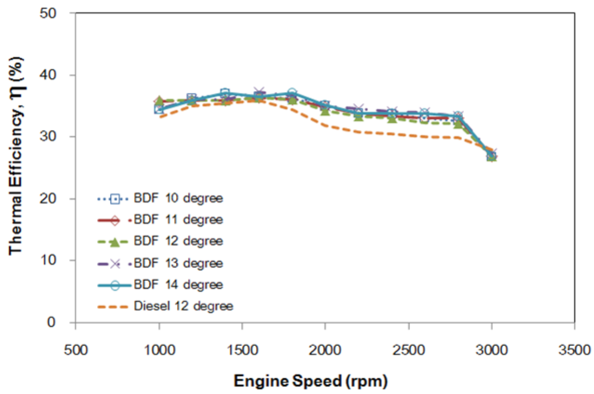


Figure 4 Thermal efficiency at full load with adjusted injection timings

As similar to the study of Bhusnoor et.al [12], injection timings have obviously effects on engine out exhaust emissions in particular carbon monoxide (CO) and oxide of nitrogen (NO_X) as exhibited in Figure 5 and 6. Of advanced at 11° - 13° BTDC, injection timings show marginal effects on CO but significant increase with much more advanced timing at 14° BTDC. This can conclude that advanced injection timings can increase CO emissions. With advanced injection timings, combustion should occur early. On the other word, combustion could be terminated earlier than that of retard injection timings. There is much more time for heat transfer from the gas to the chamber wall resulting in reduced gas temperature. Therefore, CO is oxidized to CO_2 at a slower rate due to lower temperature during the exhaust stroke.

Corresponding well with the previous study [2, 5] when compared with diesel fuel, CO emission reduces when using biodiesel. CO emissions primarily depend on air/fuel ratios. From stoichiometric to lean mixtures, combustion produces low carbon monoxide because the fuel is oxidized with sufficient oxygen. As the results, oxygenated molecule in biodiesel is the key factor to decrease CO.

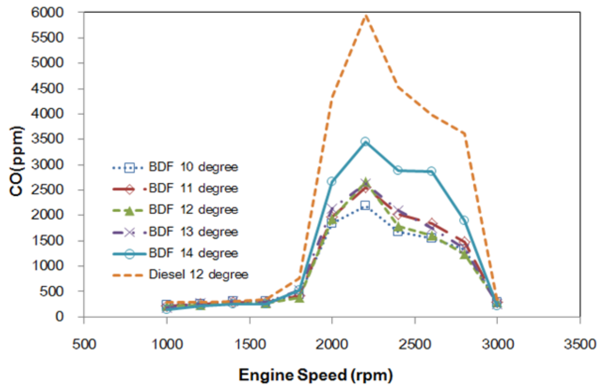


Figure 5 CO emissions at full load with adjusted injection timings

The chemical kinetic mechanism of NO_X formation intimately depends upon gas temperature during the combustion and early part of the expansion stroke. Due to the advanced injection timing, there is much more time for ignition delay period before the combustion occurs. The longer ignition delay time results in increased combustion temperature. As the results, oxide of nitrogen increases with the advanced injection timing.

When compared with diesel at the same injection timing, biodiesel shows its drawback to increase NO_X emissions as the same the study of [8]. The complete combustion of oxygenated fuel enhances the combustion temperature, which strongly influences to NO_X emissions.

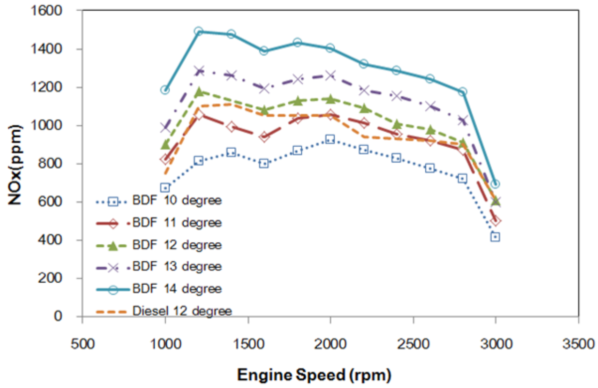


Figure 6 Oxide of nitrogen emission at full load with adjusted injection timings

Although injection timings show the outstanding effects on NO_X emissions, total hydrocarbon (THC) are emitted nearly the same level. However, the advantage of biodiesel in reducing THC can be observed.

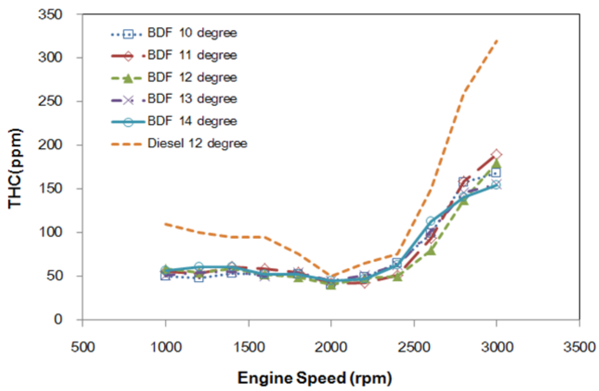


Figure 7 Total hydrocarbon emissions at full load with adjusted injection timings

3.2 Part Load (Fixed torque at 100 N.m)

For part load condition, the throttle was adjusted in order to keep the constant torque at 100 N.m with varying speed at 1000 – 3000 with the increment of 500 rpm. As the same full load, Injection timing has no effects on BSFC and thermal efficiency as in Figure 8 and 9. However, thermal efficiency of diesel shows less difference with biodiesel than that of full load condition. In addition, when decreased the engine torque at 50 N.m, thermal efficiency of diesel is nearly the same as biodiesel (not shown here).

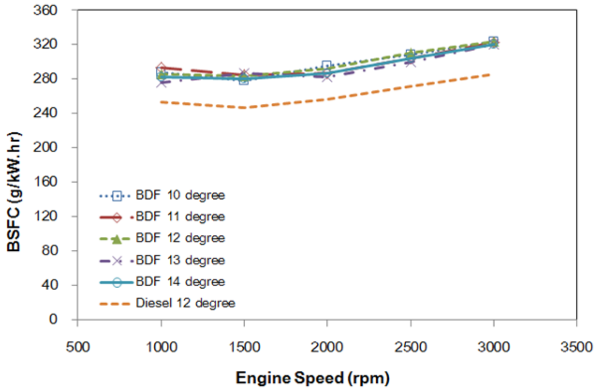


Figure 8 Break specific fuel consumption at part load with adjusted injection timings

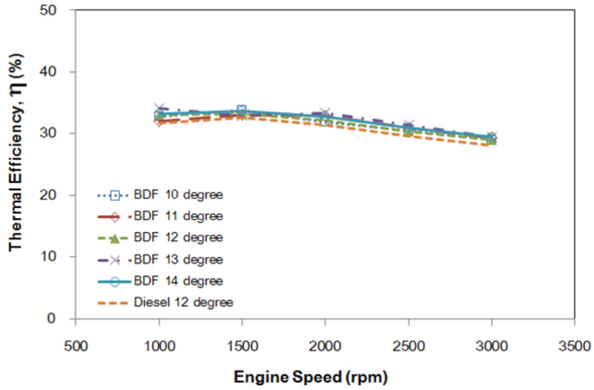
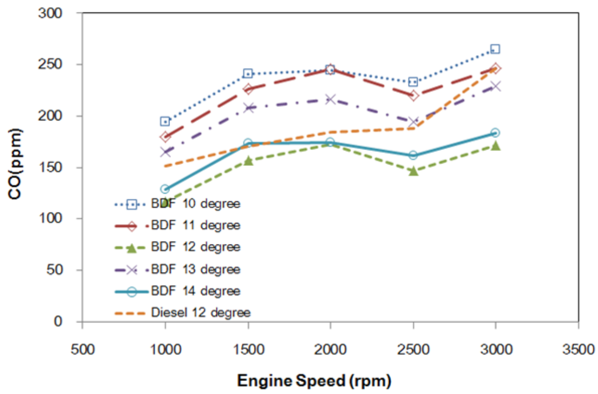


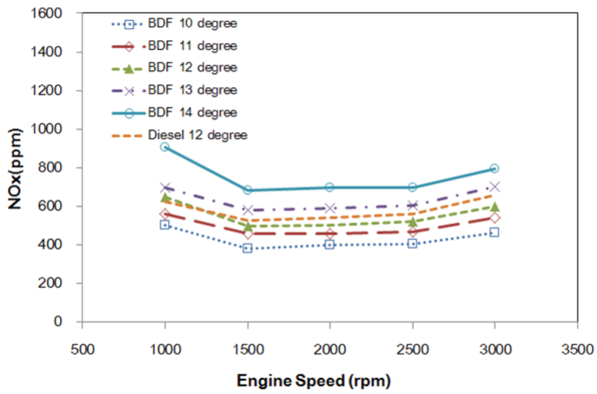
Figure 9 Thermal efficiency at part load with adjusted injection timings

Figure 10 presents exhaust emissions (CO, NO_X and THC) at part load condition. Injection timings present the effects on carbon monoxide but no relationship can be observed. At first, when injection timings are advanced the decreased CO emissions are noticed which is opposite to the full load condition. After the minimum amount at 12° BTDC of injection timing (following engine specification), CO increased with the advanced injection timing (13° BTDC) and then decrease again at 14° BTDC. Fundamentally, air/fuel ratio strongly dominates CO emission. In the current study, air/fuel ratio has not been controlled. Therefore, it is possible that different equivalence ratio occurs with altered injection timing. However, the measurement should be conducted to confirm.

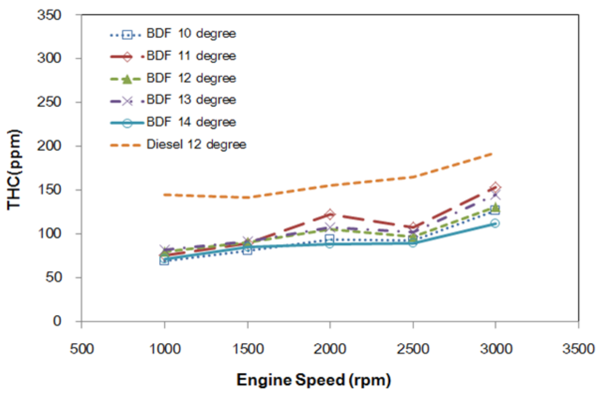
For oxide of nitrogen, injection timing shows the same trend as full load condition in which advanced timing increases the amount of NO_X. THC is emitted nearly the same at low speed and slightly different at medium and high load without relationship with injection timing. Total hydrocarbons are the unburned fuel which escapes from the combustion. Then, they are absorbed and desorbed from oil film, crevices and deposits during the compression and expansion stroke consequently.



(a) CO



(b) NO_X



(c) THC

Figure 10 Exhaust emissions at part load with adjusted injection timings (a) CO, (b) NO_X, (c) THC

4 Conclusions

In the current study, the effects of injection timing on engine performance and engine out exhaust emissions when using biodiesel in a direct injection diesel engine were investigated. The main conclusions can be summarized as follows:

- Injection timings has no significant effects on engine performance , BSFC and thermal efficiency of biodiesel combustion for all test condition
- NO_X strongly depends on injection timing of biodiesel in which advanced injection timing increases its amount.
- Amount of CO emissions are based on injection timing. However, different trend is observed with different engine operating condition.
- There is no effect of injection timing on THC emissions for all test condition.
- When compared with diesel fuel, biodiesel shows the drawbacks in which BSFC is higher whereas engine torque is lower. However, its advantage can increase thermal efficiency at high load and decrease THC and CO.

7. References

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