Effect of Biodiesel B7 and B10 on Common Rail Diesel Engine Emission Characteristics at Different Engine Speeds

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Abstract. In this study, biodiesel B7 and B10, which contain 7% and 10% biodiesel by volume, respectively, were used as high-speed diesel fuels to study the exhaust gas emissions of carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxide (NOx), oxygen (O2), exhaust gas temperature (EGT), and fuel consumption (FC) with the common rail diesel engine at a ranging engine speed from 1200 to 3000 rpm without engine load. At the maximum engine speed of 3000 rpm, the CO, CO2, and NOx emissions of the biodiesel B10 were 23.79%, 1.94%, and 4.51% lower than the biodiesel B7. Concerning fuel consumption, biodiesel B10 consumed higher fuel than B7 at a maximum engine speed of 3000 rpm. The FC of the biodiesel B10 was 3.09 kg/h, which was 2.86% higher than that of the biodiesel B7 at the maximum engine speed. From the environmental impacts point of view, reducing air pollutants from exhaust gas emissions of the biodiesel B10 was better than B7 fuel. However, the fuel consumption of B10 was a little bit higher than B7.

1. Introduction
In Thailand, most raw materials for biodiesel are produced from crude palm oil (CPO) [1]. A study conducted in 2020 by Krungsri Research found that biodiesel production and palm oil plants produced 1.4 million tonnes of biodiesel and 2.9 million tonnes of crude palm oil, respectively. To support oil palm producers in achieving a more balanced oil palm system in Thailand, the Thai government has mandated that the content of biodiesel blended into the petroleum diesel be increased from 7 vol.% (B7) to 10 vol.% (B10) by 2020 [2]. Therefore, the country also set a target of using biodiesel (B100) at around 7 million liters per day [3]. Moreover, the Department of Land Transport of the Ministry of Transport of Thailand reported a cumulative total of 41.73 million registered vehicles across the country, including 11.76 million diesel vehicles, accounting for 28.2% of the total number of registered vehicles [4]. As a result, more diesel fuel is used each year because there are more diesel cars on the road. In 2021, Indonesia will switch from B20 biodiesel to B30 biodiesel fuel. Biodiesel's feedstock, palm oil, is overstocked. Because European markets are concerned about the environmental impacts of the crude palm oil production process. Moreover, the Indonesian government has stepped up its efforts to get more palm oil used at home [5,6]. Furthermore, the Malaysian government has confirmed its intention to progressively extend the B20 biodiesel project throughout the country. Moving on to biodiesel B30, which will be implemented in Southeast Asia by 2025 [7]. In this study, a common rail direct fuel injection (CRDI) was used to study the effect of biodiesel B7 and B10 on the gas emissions, which were controlled by electronic control fuel systems [8]. However, the high
injection pressures and small hole injector tips employed in this fuel injection system require high-grade diesel fuel [9]. In addition, the CRDI emitted low exhaust gas emissions with biodiesel because, EGR, the final step of the injection system can reduce the NOx, and PM because the fuel is injected in the final stage of the common rail diesel engine to burn the soot again [10, 11]. The objective of this research was to investigate the exhaust emissions (CO, CO2, NOx, O2), EGT, and FC of biodiesel B7 and B10, which are comprised of 7 vol.% and 10 vol.% biodiesel in diesel fuel, in a common rail diesel engine at the range of engine speed between 1200 and 3000 rpm without engine load.

2. Material and method

2.1. Material
The biodiesel B7 and B10 available at petrol stations contain 7 vol.% and 10 vol.% biodiesel in diesel, which were used for testing in a common rail diesel engine. The viscosity of biodiesel B7 and B10 at 40°C ranges from 1.8 to 4.1 cSt [12], with lower heating values (LHV) of 43.7 and 42.9 MJ/kg for B7 and B10, respectively.

2.2. Diesel engine experimental setup
The biodiesel B7 and B10 were performed to study CO, CO2, NOx, and EGT with a gas analyzer (model: Testo 350 XL), and the FC of B7 and B10 fuels were also compared. A common rail diesel engine (model: 2KD-FTV) was used to test the effect of biodiesel on emissions and FC. The engine is a water-cooled, four-stroke diesel with a compression ratio of 15.6:1, a maximum torque of 343 Nm at 2800 rpm, maximum power of 106 kW at 3400 rpm, and a power adder with the turbocharger.

2.3. Experimental procedure
The exhaust gas emissions from the combustion engine were measured with a gas analyzer (model: Testo 350 XL). It was used to analyze the CO, CO2, NOx emissions, and O2 in the exhaust gas. The techniques for executing the biodiesel B7 and B10 tests in a diesel engine are as follows: (First step) Turn on the circulating water system to cool the engine at the cooling tower using a pump (model: WCH-375S) and after that, the engine was started using biodiesel. Biodiesel fuel in the graduated cylinder will be sucked into the engine by a high-pressure pump that passes through the fuel filter into the common rail and to the injectors with a pressure of 1800 bar in the common rail, which will make the fuel droplet size smaller and burn better. The engine runs at a low speed of 900 rpm for approximately 30 min before running with biodiesel and a fixed engine inlet water temperature of 30°C. The water temperature at the cooling tower reservoir was measured using a thermocouple thermometer (model: FLUKE-5111). All of the engine speeds from the experiment were measured using a tachometer (model: DT2236B). (Second step) When the engine speed was increased to 1200 rpm, a graduated cylinder and a digital scale (model: EK-3000i) were used to measure and estimate the mass flow rate of the biodiesel. Biodiesel fuel in the graduated cylinder will be sucked into the engine by a high-pressure pump that passes through the fuel filter into the common rail and to the injectors with a pressure of 1800 bar in the common rail, which will make the fuel droplet size smaller and burn better. The engine runs at a low speed of 900 rpm for approximately 30 min before running with biodiesel and a fixed engine inlet water temperature of 30°C. The water temperature at the cooling tower reservoir was measured using a thermocouple thermometer (model: FLUKE-5111). All of the engine speeds from the experiment were measured using a tachometer (model: DT2236B). (Second step) When the engine speed was increased to 1200 rpm, a graduated cylinder and a digital scale (model: EK-3000i) were used to measure and estimate the mass flow rate of the biodiesel. A gas analyzer was used to study the CO, CO2, NOx, O2 gases, and EGT generated by combustion in a common rail diesel engine. All data were recorded every 90 seconds while the engine was running. (Third step) After completing the experiment, the engine speed was reduced to 900 rpm for 30 min before switching off. The mass flow rates and exhaust gases generated by the engine's combustion were then investigated.

2.4. Fuel consumption
The FC was measured using a 1000 mL graduated cylinder and a digital scale and was calculated in the unit of kg/h for the common rail diesel engine under different engine speeds. The fuel consumption was expressed in kilograms per hour (kg/h).

3. Results and discussion

3.1. Carbon monoxide emissions
Figure 1a shows the CO emissions at the engine speeds of 1200 to 3000 rpm with biodiesel B7 and B10. At a maximum engine speed of 3000 rpm, CO emissions from biodiesel B10 emitted 683.16 ppm,
which decreased by 19.21% compared with B7 fuel. In terms of CO reduction, increasing the biodiesel content from B7 to B10 could reduce CO emissions at all engine speeds. Because a higher percentage of biodiesel in diesel contains more O\textsubscript{2} components resulting in more completed combustion [13]. Furthermore, the CO emissions of biodiesel B10 were found to be lower than those of biodiesel B7. Similar results are described by Alptekin 	extit{et al.} (2017), who reported that testing of biodiesel and oxygenated fuel in a common rail diesel engine could increase the amount of O\textsubscript{2} and help reduce the amount of CO from exhaust gases. Moreover, CO emissions increased when the engine speed increased due to the recirculating of exhaust gas using the emission control technology or exhaust gas recirculation (EGR) [14].

### 3.2. Carbon dioxide emissions

The carbon dioxide (CO\textsubscript{2}) emission from the exhaust gas indicates that the fuel in the combustion chamber has completely combusted [15]. The CO\textsubscript{2} emission of B7 and B10 in a common rail engine at different engine speeds was shown in figure 1b. At a maximum engine speed of 3000 rpm, CO\textsubscript{2} emissions from biodiesel B10 were emitted at 5.33%, which decreased by 1.9% compared with B7 fuel. In terms of CO\textsubscript{2} emissions, biodiesel B10 emitted significantly less than B7 fuel at over engine speeds of 1600 rpm, as shown in figure 1b. Because the amount of oxygen in B10 is more than B7 in diesel fuel, which can help more completed combustion in the combustion chamber. A similar result was described by How 	extit{et al.} (2018), who reported that testing different types of biodiesel fuel compared to diesel fuel with common rail diesel engines found that the use of biodiesel B10, B20, B30, and B50 at all engine speeds has fewer CO\textsubscript{2} emissions than diesel fuel [16].

### 3.3. Nitrogen oxides emissions

NO\textsubscript{x} emission results with biodiesel B7 and B10 are shown in figure 1c. At an engine speed of 2600 rpm, biodiesel B7 emitted the most NO\textsubscript{x} (69.83 ppm), which increased by 5.73% compared to B10 fuel. Moreover, the results showed that the NO\textsubscript{x} emissions of B10 were significantly lower than those of biodiesel B7 at all engine speeds. Because the O\textsubscript{2} in the biodiesel increased the temperature in the combustion chamber, which resulted in more efficient combustion. However, EGR recirculates exhaust gases from the engine to be burned again. As a similar result, Kumar 	extit{et al.} (2021) tested biodiesel blends compared with petroleum diesel with the EGR of a common rail diesel engine and found that the NO\textsubscript{x} decreased on applying EGR [17].

### 3.4. Oxygen gas

The amount of O\textsubscript{2} in the exhaust gas is correlated to the combustion in the cylinder, particularly the air-to-fuel ratio in the cylinder. Incomplete combustion indicates the high concentration of oxygen in the exhaust gas. Figure 1d shows the percentage of O\textsubscript{2} gas for biodiesel B7 and B10 at different engine speeds. The amount of oxygen gas emissions of B10 is higher in the diesel common rail engine than that of B7.

### 3.5. Exhaust gas temperature

For EGT from the combustion of biodiesel B7 and B10, EGT from biodiesel B7 and B10 combustion increased as engine speeds increased, as shown in figure 1e. When the engine was run at engine speeds ranging from 1200 to 3000 rpm, the EGT ranged from 85 to 183°C. At a maximum engine speed of 3000 rpm, the EGT of biodiesel B7 and B10 had a similar temperature of approximately 182°C. Similar results are described by Jarernporn 	extit{et al.} (2020), who reported that the EGT increased with the increase in engine speeds because the temperature in the combustion chamber increased because more fuel was needed to burn with increasing engine speed [18].

### 3.6. Fuel consumption

The fuel consumption rates of biodiesel B7 and B10 in the common rail diesel engine at various engine speeds are shown in figure 1f. When the engine speed was increased from 2400 to 3000 rpm, the biodiesel B10 consumed more fuel than the B7 fuel. Because the fuel consumption of various biodiesel concentrations in diesel was influenced by LHV. The LHV of B7 was 43.7 MJ/kg, and B10
was 42.9 MJ/kg. Therefore, the LHV value of B10 was lower than that of B7. That is the reason for increased fuel consumption in a comm rail engine using biodiesel B10.

**Figure 1.** Effect of biodiesel B7 and B10 on emissions and fuel consumption at different engine speeds (a) CO, (b) CO₂, (c) NOₓ, (d) O₂, (e) EGT, and (f) fuel consumption.

### 4. Conclusion

In this study, the B7 biodiesel and B10 were tested with a common rail diesel engine at different engine speeds. According to the experimental results, biodiesel B10 could reduce CO, CO₂, and NOₓ by 19.21%, 1.9%, and 4.31% compared to biodiesel B7 at maximum engine speed. Because adding biodiesel to the diesel fuel increases the proportion of O₂ gas in the combustion chamber causing more complete combustion. Furthermore, the EGR system of the common rail diesel engine assists in the reduction of NOₓ through the recirculation of exhaust gases due to a lower proportion of O₂ in return exhaust gases into the combustion chamber. However, as compared to B7 biodiesel, B10 biodiesel fuel has a higher fuel consumption because it has a lower LHV than B7 biodiesel.
5. References

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Acknowledgments
This research is supported by the National Research Council of Thailand (NRCT), grant no. NRCT5-RSA63022-04.