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Article

Effects of Pilot Injection Timing and EGR on Combustion, Performance and Exhaust Emissions in a Common Rail Diesel Engine Fueled with a Canola Oil Biodiesel-Diesel Blend

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Abstract: Biodiesel as a clean energy source could reduce environmental pollution compared to fossil fuel, so it is becoming increasingly important. In this study, we investigated the effects of different pilot injection timings from before top dead center (BTDC) and exhaust gas recirculation (EGR) on combustion, engine performance, and exhaust emission characteristics in a common rail diesel engine fueled with canola oil biodiesel-diesel (BD) blend. The pilot injection timing and EGR rate were changed at an engine speed of 2000 rpm fueled with BD20 (20 vol % canola oil and 80 vol % diesel fuel blend). As the injection timing advanced, the combustion pressure, brake specific fuel consumption (BSFC), and peak combustion pressure (P_{max}) changed slightly. Carbon monoxide (CO) and particulate matter (PM) emissions clearly decreased at BTDC 20° compared with BTDC 5°, but nitrogen oxide (NO_x) emissions increased slightly. With an increasing EGR rate, the combustion pressure and indicated mean effective pressure (IMEP) decreased slightly at BTDC 20° compared to other injection timings. However, the P_{max} showed a remarkable decrease. The BSFC and PM emissions increased slightly, but the NO_x emission decreased considerably.

Keywords: canola oil biodiesel blends; pilot injection timing; exhaust gas recirculation; combustion characteristics; exhaust emissions

1. Introduction

Economic growth and a drastic increase in the number of motor vehicles are causing environmental pollution and an energy shortage. Global warming is also resulting from the intense increase in greenhouse gases (GHG) produced by the burning of fossil fuels. Excessive vehicle exhaust from fossil fuels leads to frequent haze all over the world [1–3]. Thus, environmental pollution and energy shortages are two main factors restricting the development of the diesel engine industry. Developing green energy is a trend to solve those problems. Biodiesel has been a hot topic because of its environment-friendly characteristics and renewability [4,5]. Biofuels such as alcohols and biodiesel have been proposed as alternatives to fossil fuels for internal combustion engines. Research on biodiesel stability was voted a top priority at the Annual Biodiesel Technical Workshop held in Chicago in January 2005. In particular, biodiesels derived from vegetable oils have received wide attention as a replacement for diesel fuel because they emit fewer GHG and other pollutant emissions [6–8].

Diesel engines are mostly used in industrial transportation, passenger cars, and agricultural applications because of their high thermal efficiency, large power output, and reliability, despite their disadvantages of noise and vibration. However, a diesel engine emits more particulate matter (PM) and nitrogen oxide (NO_x) than a gasoline engine [9–11]. Furthermore, regulation of PM and NO_x emissions from diesel engines has been strengthened because those emissions are an important environmental issue [12]. Therefore, many researchers have studied how to reduce exhaust emissions such as PM and NO_x using diesel particulate filters, selective catalytic reduction [13,14], or alternative fuels [15,16]. Biodiesel can also be used to reduce exhaust emissions because the oxygen in biodiesel fuel promotes combustion [17]. It can be produced from various vegetable oils, waste cooking oils, and animal fats, and its fuel properties change with the different feed stocks [18–20]. It is well-known that diesel engines can run on biodiesel blended with conventional diesel without modification [21–23]. However, researchers investigating the use of raw vegetable oils in diesel engines found that they cause numerous engine-related problems [24,25]. Therefore, vegetable oils must be blended with pure diesel because the net calorific value of biodiesel is less than that of conventional diesel fuel, its viscosity, density, and iodine values are higher, and its volatility is poor. Those shortcomings lead to severe engine deposits, injector coking, and piston ring sticking [26–28] if vegetable oils are used on their own. Their high density, viscosity, and surface tension decrease the quality of atomization and combustion performance [29]. After transesterification, however, biodiesel can acquire properties closer to those of diesel [30]. Transesterification is clearly the best way to use vegetable oil as a fuel in existing diesel engines [31–33]. Choi and Rritz [34] reported that multi-stage injection and adjustment of the ignition timing when using a blended biodiesel fuel allowed soot and NO_x emissions to decrease. Lee *et al.* [35] found that a higher biodiesel blending rate increased NO_x emissions but decreased emissions of hydrocarbon (HC) and carbon monoxide (CO) in a common rail diesel engine. Grimaldi and Postrioti [36] reported on a method of injection using ultra low sulfur diesel (ULSD) and biodiesel in a common rail diesel engine. Higher biodiesel blending rates require higher injection pressure because of the higher surface tension of biodiesel. They found that increasing the injection pressure increased the break thermal efficiency (BTE) and reduced the brake specific fuel consumption (BSFC). Tsolakis [37] reported that the use of biodiesel made a significant reduction in NO_x emissions when the exhaust gas recirculation (EGR) rates were increased and reduced the mass and size of PM under all conditions. Precedent reports have verified that the use of biodiesel generally minimizes the quantity and size of PM emissions but increases NO_x emissions. Yoon *et al.* [38] found that BD20 (20 vol % canola oil and 80 vol % diesel fuel blend) offered the best combustion efficiency at an engine speed of 2000 rpm. Our literature review found that the effects of BD20 on combustion characteristics and exhaust emissions in a direct injection (DI) diesel engine with high-pressure injections have not been clearly studied. Therefore, in the present study, we experimentally investigated the effects of pilot injection timing and EGR rate on the combustion and exhaust emissions characteristics from burning BD20 in a common rail diesel engine at an engine speed of 2000 rpm.

2. Experimental Materials and Methods

2.1. Test Fuel and Operating Conditions

BD was blended with pure diesel at 20% volume. The fuel was characterized by determining its viscosity, density, pour point, distillation temperature, flash point, acid number, ester content, total free glycerin, and calculated index. In the United States, biodiesel must meet American Society of Testing and Materials (ASTM) specifications designated in ASTM D-6751; in Europe it must accord with EN-14214. To measure the fuel properties of BD20, we therefore used the ASTM-D6751 and EN-14214 standard test methods. The fuel properties of the pure diesel, neat biodiesel, and BD20 fuels are presented in Table 1.

Table 1. Properties of pure diesel, neat biodiesel, and BD20 (20 vol % canola oil and 80 vol % diesel fuel blend).

Properties (units)	Pure Diesel	Neat BD	BD 20	Test Method
Density (kg/m^3 at 15 °C)	836.8	880	846	ASTM D941
Viscosity (mm^2/s at 40 °C)	2.719	4.290	2.991	ASTM D445
Calorific value (MJ/kg)	43.96	39.49	42.71	ASTM D4809
Cetane index	55.8	61.5	-	ASTM D4737
Flash point (°C)	55	182	-	ASTM D93
Pour point (°C)	−21	−8	-	ASTM D97
Oxidation stability (h/110 °C)	25	15	-	EN 14112
Ester content (%)	-	98.9	-	EN 14103
Oxygen (%)	0	10.8	-	-

In this study, we used biodiesel-diesel (BD) and ULSD, which had a sulfur content of 0.005%, for comparison. To investigate the characteristics of combustion and exhaust emissions as the pilot injection timing and EGR rate changed, we carried out tests on the warming up condition of the engine under an engine speed of 2000 rpm. We held the coolant temperature at a constant 70 ± 3 °C and the intake air temperature at 20 ± 3 °C. A constant load of 30 Nm torque from the engine dynamometer was applied to the test engine at each pilot injection timing to ensure consistent test conditions when the main injection timing was fixed at top dead center (TDC) 0°. The experimental and operating conditions are summarized in Table 2.

Table 2. Experimental and operating conditions.

Test Parameters	Unit	Operating Conditions
Engine speed	rpm	2000
Torque	Nm	30
Test fuel	-	BD blended rate with diesel (vol %)
BD20	-	Diesel 80% + biodiesel 20%
Cooling water temp.	°C	70 ± 3
Intake air temp.	°C	20 ± 3
Gas recirculation (EGR) rate	%	0, 10, 20, 30
Injection pressure	MPa/rpm	45/2000
Pilot injection timing	Degree(°)	BTDC 5, 10, 15, 20
Main injection timing	Degree(°)	TDC 0

2.2. Test Engine and Experimental Procedure

In this study, the experimental apparatus consisted of the components shown in Figure 1. We used this apparatus to investigate the combustion and exhaust emission characteristics of various pilot injection timings and EGR rates in a four-cylinder common rail diesel engine. The experimental equipment consisted of a four-cylinder electronic common rail diesel engine equipped with a turbocharger, a fuel consumption rate tester with a fuel pump driven by an electrical voltage of 220 V, a control unit connected to an electronic control unit (ECU) to control the injection timing, and an eddy current type EC dynamometer (DY-230 kW, Hwanwoong, Korea) to control the engine speed. A piezoelectric pressure sensor (6056a, Kistler, Switzerland) was mounted onto the position of the glow plug to measure the combustion pressure. Data were acquired using a data acquisition board (PCI6040E, National Instrument, Austin, TX, USA). The combustion pressure in the cylinder was analyzed using a combustion analyzer. The main specifications of the four-cylinder common rail diesel engine used in this study are summarized in Table 3. The EGR rate (%) is defined as the difference between the quantity of fresh air induced without EGR (Q_0) and that of air with EGR (Q_{EGR}) divided by the quantity of fresh air induced without EGR (Q_0), as shown below:

$$EGR(\%) = \frac{Q_0 - Q_{EGR}}{Q_0} \times 100 \tag{1}$$

The exhaust gas was delivered to the intake manifold through a water-cooled unit by an EGR valve, and the gas flow rate was regulated by controlling the EGR duty ratio using a computer. The NO_x emissions were monitored in real-time using an exhaust analyzer. Exhaust measuring equipment was used for the exhaust component analysis. A multi-gas analyzer (MK2, Eurotron, Italy) was used to measure the O_2, CO, CO_2, NO, NO_2, and HC content of the exhaust gases. To detect PM, we used an opacity smoke meter (OPA-102, Qurotech, Korea) using the partial flow sampling method. The gas analyzer specifications, including the resolution, range, and accuracy, are summarized in Table 4. In this work, we calculated the heat release rate (HRR) of BD combustion in the engine using the following formula [39]:

$$\frac{dQ}{d\theta} = \frac{k}{k-1} P \frac{dV}{d\theta} + \frac{1}{k-1} V \frac{dP}{d\theta} \tag{2}$$

where $dQ/d\theta$ is the HRR, k is the specific heat ratio (assumed to be 1.35), $dP/d\theta$ is the rate of pressure change, and $dV/d\theta$ is the rate of change in the cylinder volume. The BSFC is defined as the ratio of the fuel consumption rate to the brake power of the engine. The value was calculated based on the fuel consumption, engine torque, and speed data using the following formula:

$$b_f = \frac{\dot{m}_f}{2\pi N T_e} \tag{3}$$

where b_f is the brake specific fuel consumption rate, $\dot{m}_f$ is the fuel consumption flow rate into the cylinder, N is the engine speed, and T_e is the brake torque, which was directly measured using an engine dynamometer. The brake specific energy consumption (BSEC) is the ratio of the energy consumption rate to the brake power of the engine, which is calculated from the fuel consumption and low heating calorific value using the following formula:

$$b_e = \frac{Q_{LHV} B_f}{2\pi N T_e} \tag{4}$$

where b_e is the brake specific energy consumption rate, B_f is the fuel consumption mass per hour, and Q_{LHV} is the low heating calorific value, which we measured directly with an engine dynamometer.

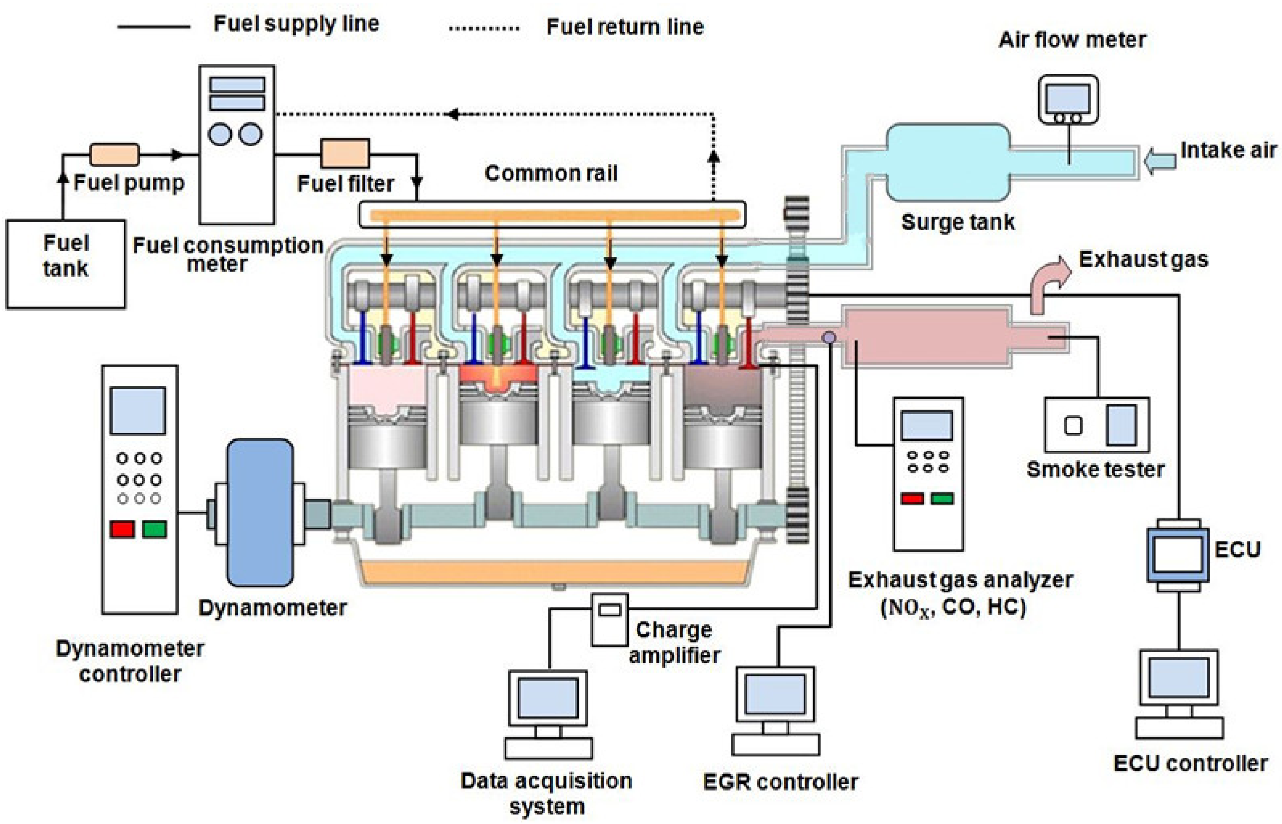


Figure 1. Schematic diagram of the experimental apparatus.

Table 3. Specifications of the test engine.

Test Model	Parameter (units)	Specification
Engine type	Engine type	4-cylinder
	Bore (mm)	81
	Stroke (mm)	96
	Displacement (cm^3)	1979
	Combustion type	Direct injection
	Injection procedure	1-3-4-2
	Compression ratio	17.7:1
	Maximum power (kW/rpm)	82/at 4000
	Maximum torque (Nm/rpm)	260/at 2000
	Maximum engine speed (rpm)	4500
Fuel injection system	Fuel control	ECU control
	Injection system	Common-rail
	Maximum fuel pressure (MPa)	145
	Number of injector nozzle holes	5
	Injector spray angle (degree)	150
	Injector hole diameter (mm)	0.17

Table 4. Specifications of the exhaust gas analyzer.

Method of Detection	Species	Unit	Range	Resolution	Accuracy
Electrochemical	O_2	%	0%–30%	0.1%	±0.57%
Electrochemical	CO	ppm	0–4000 ppm	1 ppm	±0.62%
Pellistor	HC	%	0%–5%	0.01%	±0.8%
Electrochemical	NO	ppm	0–5000 ppm	1 ppm	±0.25%
Electrochemical	NO_2	ppm	0–1000 ppm	1 ppm	±0.25%
Smoke opacity	PM	%	0%–100%	0.1%	±1%

3. Results and Discussion

3.1. Combustion Characteristics

In order to investigate the improvement of combustion stability, the experiment was performed under an engine speed of 2000 rpm and an engine load of 30 Nm and the main injection timing was fixed at TDC 0°. Figure 2 shows the effects of various pilot injection timings without EGR rate on the combustion pressure and HRR. It can be seen that the combustion was started faster as the pilot injection timing retarded. In addition, the ignition delay and the duration of combustion during was shorter when the pilot injection timing was closer to the main injection timing, because the pre-combustion of pilot injection can increase in cylinder temperature to promote combustion.

Figure 3 shows a comparison of combustion pressure for BD20 at various injection timings and EGR rates. As shown in Figure 3a,b, the combustion pressure gradually decreased slightly as the EGR rates increased. The oxygen concentration of the intake air is reduced because of the EGR, which causes a significant negative effect on combustion.

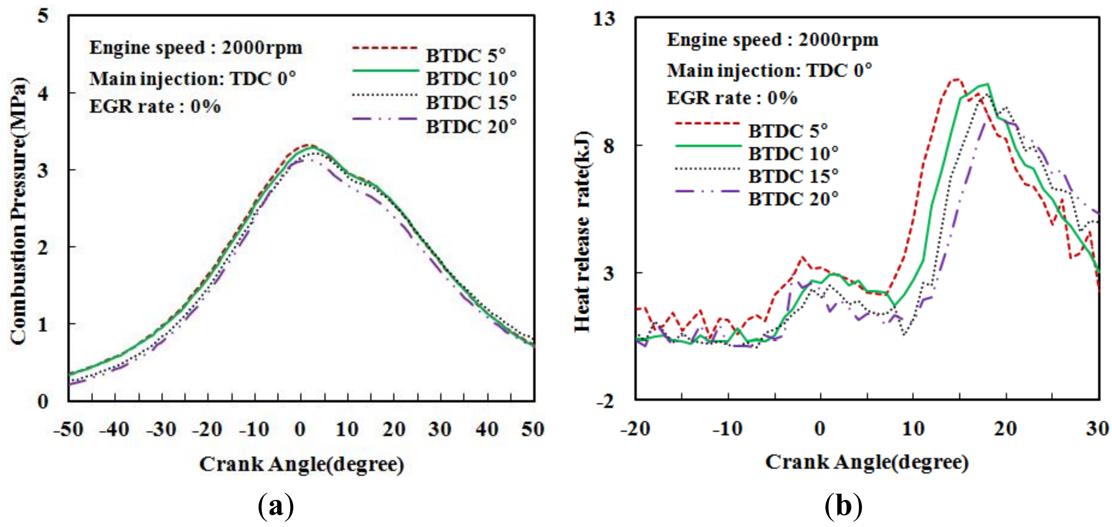


Figure 2. Effects of various pilot injection timings without EGR rate on the (**a**) combustion pressure, and (**b**) HRR.

Figure 4 shows the HRR for BD20 at various injection timings and EGR rates. The whole combustion process is composed of pilot heat release and main heat release, and the HRR changed slightly with the different pilot injection timings and EGR rates. As shown in Figure 4a, the HRR decreased gradually and the ignition delay was longer as the EGR rates increased at before top dead center (BTDC) 5°, because the oxygen concentration decreased as the EGR rates increased, which is a limiting factor for the pilot combustion. At other pilot injection timings, however, the HRR changed slightly as the EGR rate increased. Increasing the EGR rate slightly does not affect the pilot combustion because the biodiesel contains enough oxygen. These results demonstrate that if the rotational degree of the crankshaft between the pilot injection timing and the main injection timing was long, combustion activation in the main injection deteriorated because the effect of the pilot injection was lost.

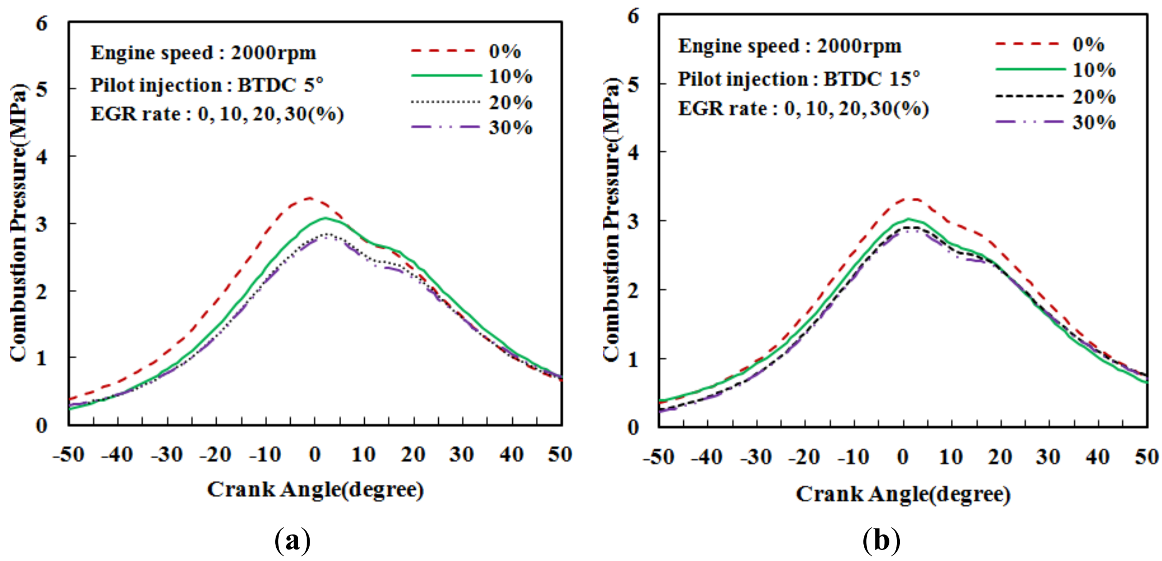


Figure 3. Comparison of combustion pressure at various pilot injection timings and EGR rates. (**a**) BTDC 5°; (**b**) BTDC 15°.

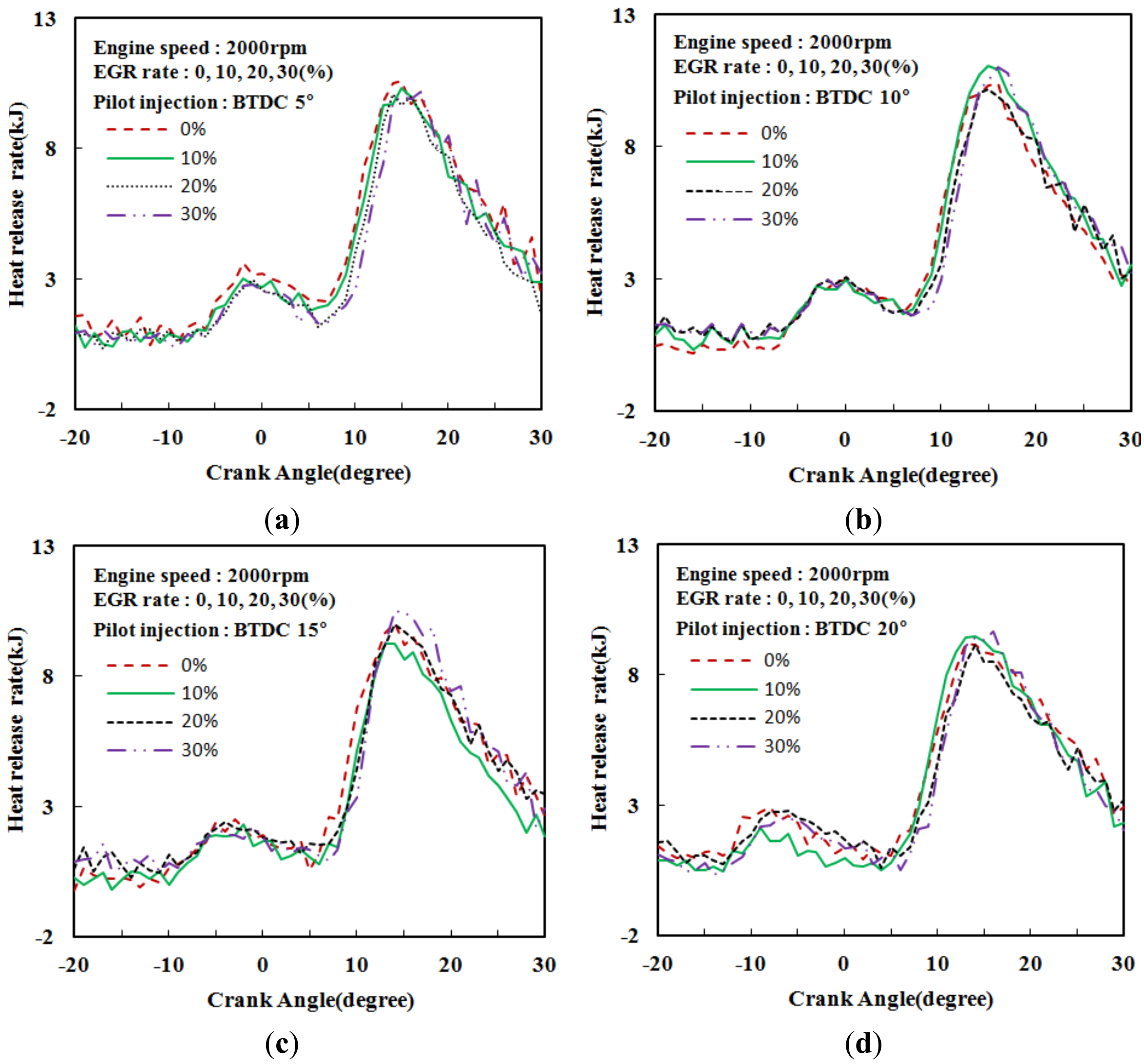


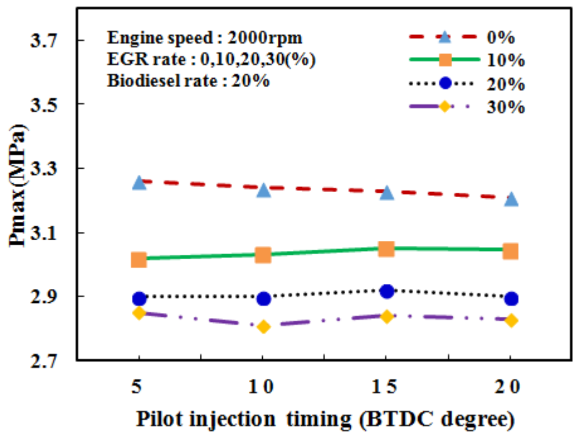
Figure 4. Comparison of HRR at various pilot injection timings and EGR rates. (**a**) BTDC 5; (**b**) BTDC 5; (**c**) BTDC 5; (**d**) BTDC 5.

3.2. Engine Performance

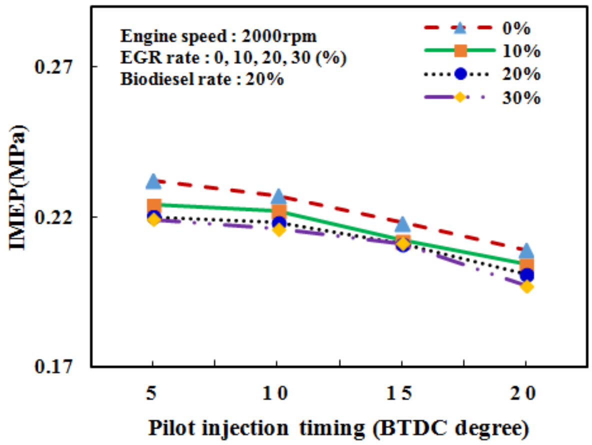
3.2.1. P_{max} and IMEP

Figure 5 shows the peak combustion pressure variation and indicated mean effective pressure (IMEP) with the different pilot injection timings and EGR rates at an engine speed of 2000 rpm. As shown in Figure 5a, as the pilot injection timing was advanced, the P_{max} increased slightly, and it decreased as the timing was retarded at all EGR rates. However, when we increased the EGR rate, the P_{max} showed a remarkable decrease: by 8.7% at 10% EGR, 12.4% at 20% EGR, and 13.6% at 30% EGR, compared to the 0% EGR rate at BTDC 15°. When maintaining the main injection timing at TDC 0° and advancing the pilot injection timing, the decrease ratio was the largest at BTDC 15°.

As shown in Figure 5b, the IMEP increased before BTDC 10° with the advance of pilot injection timing, and as the timing was retarded it decreased. On the other hand, with the increasing of EGR rate, the IMEP decreased slightly. Its highest value at each EGR rate occurred at BTDC 10°.



(**a**)



(**b**)

Figure 5. Effects of various pilot injection timings and EGR rates on the (**a**) P_{max} and (**b**) IMEP.

3.2.2. BSFC and BSEC

Figure 6 shows the variation of BSFC with pilot injection timing changes under EGR rates at an engine speed of 2000 rpm. The BSFC of a diesel engine depends on the relationship between the fuel injection system and fuel properties such as specific gravity, viscosity, and heating value. The BSFC decreased as the EGR rate was increased by 1.9%, 2.7%, 3.6% and 2.2% at BTDC 10° compared with that at BTDC 5°, 0.5%, 1.6%, 3.6% and 2.2% at BTDC 15°, and 3.2%, 3.7%, 4.2% and 3.5% at BTDC 20°. Thus, as the pilot injection timing advanced, the BSFC decreased. The lower BSFC at BTDC 20° means that a smaller amount of fuel was required to produce the same amount of power. This is expected because canola fuel has a higher density than pure diesel, so it can be fully burned through early injection and heating.

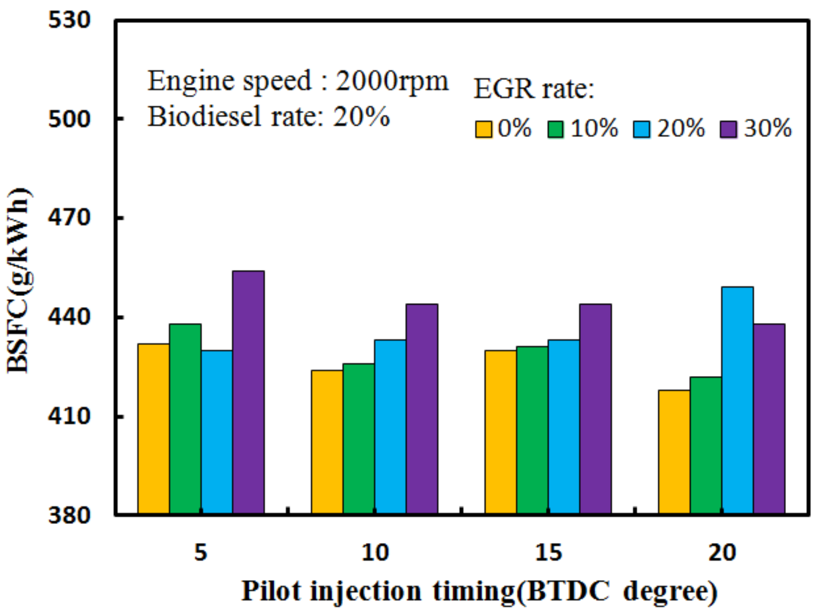


Figure 6. Effects of EGR ratio and pilot injection timing on the BSFC.

Another important performance parameter is the BSEC. It is often used to compare fuel performance with different pilot injection timings. The BSEC is defined as the product of the BSFC and the heating calorific value of the fuel. It measures the amount of energy consumed to develop a unit of output power. Generally, the BSEC decreases as energy consumption increases. Figure 7 represents the variation of the BSEC under different EGR rates and pilot injection timings. It can be seen that the BSEC is slightly increased with EGR rate increasing. The exhaust gas increased in the combustion chamber that will lead to decrease the oxygen concentration when EGR rate increased, so more fuel is needed to produce the same power output. However, the BSEC changed slightly as pilot injection timing increased. It indicates that there is slight effect of pilot injection timing on the BSEC. This is because the combustion is mainly promoted by the oxygen in biodiesel.

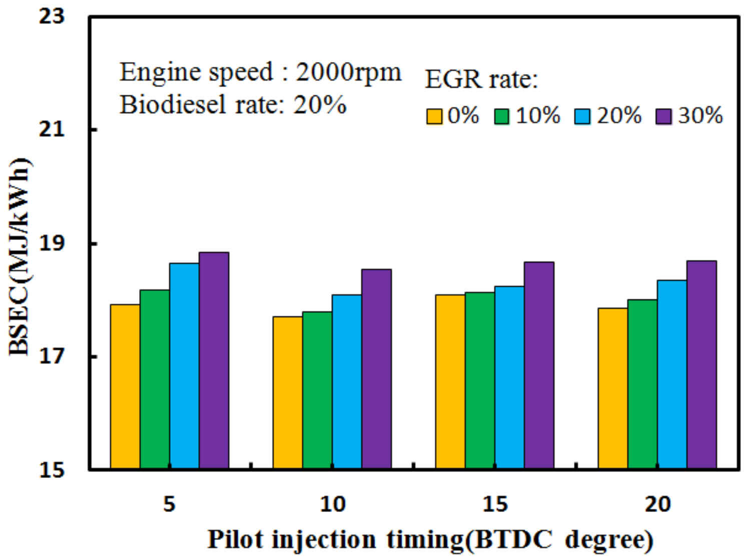


Figure 7. Effects of EGR ratio and pilot injection timing on the BSEC.

3.3. Exhaust Emissions Characteristics

Figure 8 presents the CO, CO_2, NO_x, and PM emissions of BD20 at an engine speed of 2000 rpm for the different pilot injection timings and EGR ratios. As seen in Figure 8a, CO emissions increased considerably as the pilot injection timing was advanced to BTDC 10° and BTDC 15° compared to BTDC 5°. The fuel burned incompletely because advancing the pilot injection timing by holding the main injection timing increases the rotational time between the two, which caused CO emissions to increase. In general, because the biodiesel has higher viscosity, density, and iodine value compared with diesel oil, biodiesel is difficult to burn. However, the minimum value of CO at BTDC 20° occurs. It is seen that the BD20 does burn fully due to pre-mixed of air-fuel because the pilot injection timing is long enough. On the other hand, as the EGR rate increases, CO emissions also increase.

As shown in Figure 8b, CO_2 emissions did not vary significantly with the advancing of the pilot injection timing, but they did increase with the EGR rate at the same injection timings. The increased EGR rate caused increased CO_2 emissions because of the unbound CO content in the recirculated exhaust gases, which increased in proportion to the EGR rate. That inhaled CO combined with the oxygen in fresh air and the biodiesel itself.

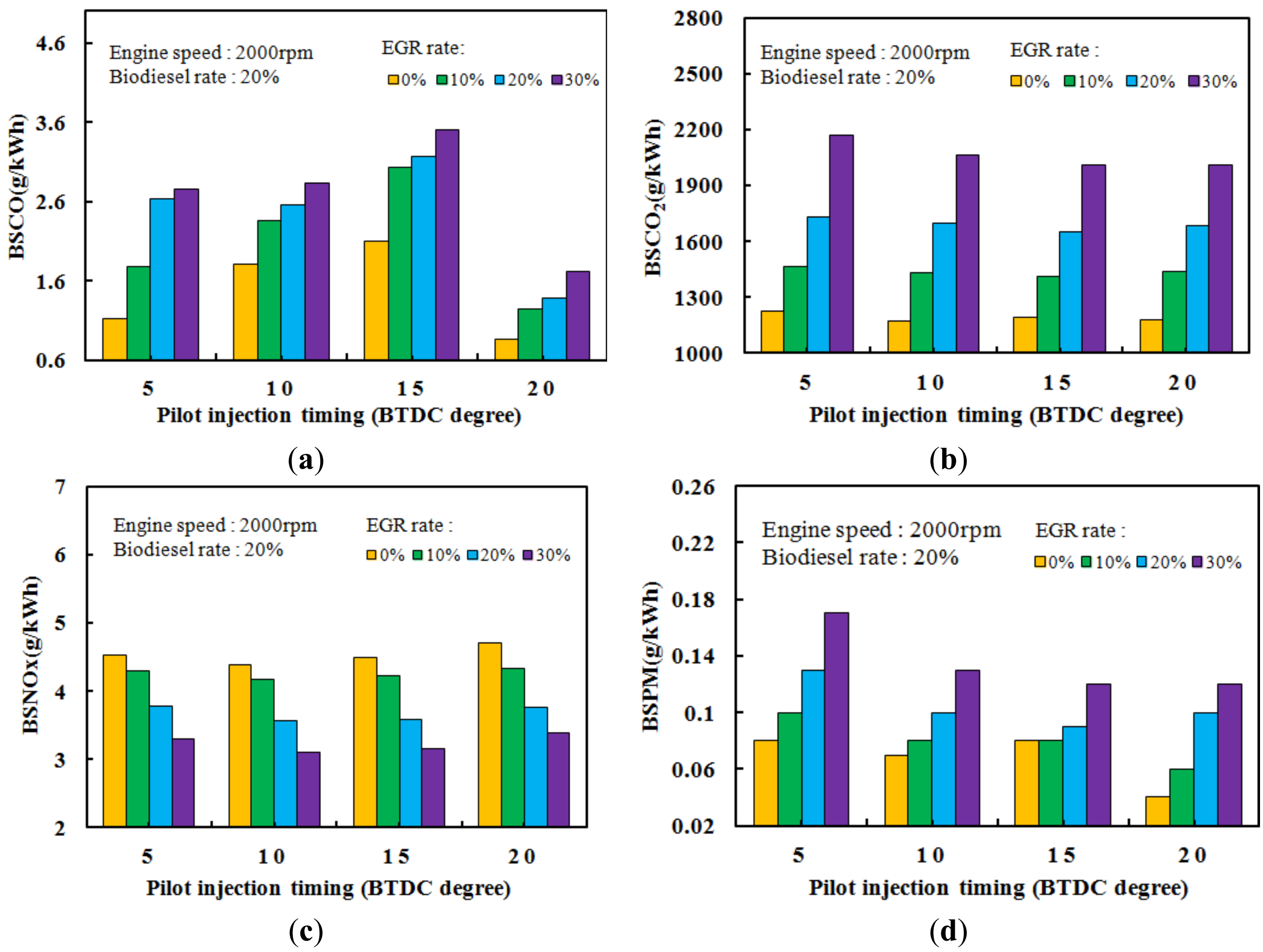


Figure 8. Effects of various pilot injection timings and EGR rates on the (**a**) BSCO; (**b**) $BSCO_2$; (**c**) $BSNO_x$; and (**d**) BSPM emissions.

As shown in Figure 8c, NO_x emissions tended to decrease as the EGR rate increased and showed a slight increase as the pilot injection timing was advanced while the EGR rate was held steady. The NO_x emission at an EGR rate of 30% decreased by 19.2% at BTDC 5°, 20.07% at BTDC 10°, 20.03% at BTDC 15°, and 19.29% at BTDC 20° on average compared to that at an EGR rate of 0%. If exhaust gases are recirculated, they play an important role in activating combustion by disturbing the newly inhaled gases.

As shown in Figure 8d, PM emissions decreased with the advancing of pilot injection timing and increased with the EGR rate when injection timing was held steady. When advancing the pilot injection timing, the PM emissions decreased by 16.35% at BTDC 10°, 11.03% at BTDC 15°, and 30.13% at BTDC 20° compared to PM emissions at each condition at BTDC 5°. In the case of advancing the pilot injection timing and keeping the main injection timing at TDC 0°, the PM emissions decreased because the advanced pilot injection timing was sufficient to oxidize the carbon in the cylinders and reduce the time available to produce PM.

4. Conclusions

In this study, we investigated the effects of pilot injection timing and EGR rate on the combustion, performance, and emissions from BD20 in a common rail diesel engine. From the current study, we draw the following conclusions:

- On the effects on combustion stability: the combustion was delayed as the pilot injection timing retarded. In addition, the ignition delay was shorter when the pilot injection timing was closer to the main injection timing.
- On the effects on engine combustion: as the pilot injection timing was advanced, the combustion pressure and HRR changed slightly. As the EGR rate was increased, the combustion pressure and HRR decreased slightly.
- On the effects on engine performance: as the pilot injection timing was advanced, the P_{max}, BSEC, IMEP and BSFC changed slightly. As the EGR rate was increased, the P_{max} and IMEP decreased slightly, and the BSFC and BSEC increased slightly.
- On the effects on exhaust emissions: as the pilot injection timing was advanced, CO and PM emissions decreased considerably, with a minimum value at BTDC 20°; NO_x emissions increased slightly; and CO_2 emissions decreased slightly. As the EGR rate was increased, NO_x emissions decreased considerably, and CO, CO_2, and PM emissions increased.

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Author Contributions

All authors contributed equally to this work. All authors designed the experimental apparatus, discussed the results and implications, and commented on the manuscript at all stages. Jun Cong Ge and Sam Ki Yoon performed the engine performance experiments. Min Soo Kim led the development of the paper. Nag Jung Choi performed the result analyses and wrote the discussion.

Conflicts of Interest

The authors declare no conflicts of interest.

References

1. Sun, Y.L.; Zhuang, G.S.; Tang, A.H.; Wang, Y.; An, Z.S. Chemical Characteristics of PM2.5 and PM10 in Haze-Fog Episodes in Beijing. *Environ. Sci. Technol.* **2006**, *40*, 3148–3155.
2. Kang, C.M.; Lee, H.S.; Kang, B.W.; Lee, W.K.; Woo, Y.S. Chemical characteristics of acidic gas pollutants and PM2.5 species during hazy episodes in Seoul, South Korea. *Atmos. Environ.* **2004**, *38*, 4749–4760.
3. Watson, J.G. Visibility: Science and Regulation. *Air Waste Manag. Assoc.* **2002**, *52*, 628–713.
4. Agarwal, A.K. Biofuels (alcohols and biodiesels) application as fuels for internal combustion engines. *Prog. Energy Combust. Sci.* **2007**, *33*, 233–271.
5. Demirbas, A. Progress and recent trends in biofuels. *Prog. Energy Combust. Sci.* **2007**, *33*, 1–18.
6. Alton, R.; Cetinkaya, S.; Yucesu, H.S. The potential of using vegetable oil fuels as fuel for diesel engines. *Energy Convers. Manag.* **2001**, *42*, 529–538.

7. Basak, A.; Patra, J.; Ganguly, R.; Datta, A. Effect of transesterification of vegetable oil on liquid flow number and spray cone angle for pressure and twin fluid atomizers. *Fuel* **2013**, *112*, 347–354.
8. Sarin, R.; Kumar, R.; Srivastav, B.; Puri, S.K.; Tuli, D.K.; Malhotra, R.K.; Kumar, A. Biodiesel surrogates: Achieving performance demands. *Bioresour. Technol.* **2009**, *100*, 3022–3028.
9. Graboski, M.S.; McCormick, R.L. Combustion of fat and vegetable oil derived fuels in diesel engines. *Prog. Energy Combust. Sci.* **1998**, *24*, 125–164.
10. McCormick, R.L.; Tennant, C.J.; Hayes, R.R.; Black, S. Regulated emissions from biodiesel tested in heavy duty engines meeting 2004 emission standards. In Proceedings of the 2005 SAE Brasil Fuels & Lubricants Meeting, Rio De Janeiro, Brazil, 11–13 May 2005.
11. Yoon, S.H.; Park, S.H.; Lee, C.S. Experimental investigation on the fuel properties of biodiesel and its blends at various temperatures. *Energy Fuels* **2008**, *22*, 652–656.
12. Yoon, S.H.; Lee, C.S. Experimental investigation on the combustion and exhaust emission characteristics of biogas-biodiesel dual-fuel combustion in a CI engine. *J. Fuel Process. Technol.* **2011**, *92*, 992–1000.
13. Brian, S.; William, R.M.; Bend, B.; Winfried, D.; Stefan, F. Recent DPF/SCR results targeting US 2007 and EURO 4/5 HD emissions. In Proceedings of the SAE 2003 World Congress & Exhibition, Detroit, MI, USA, 3–6 March 2003.
14. Yongsheng, H.; David, B.B.; Shuguang, L.; Micheal, J.P.; Jianwen, L. Opportunities and challenges for cleaned 2-way SCR/DPF after treatment technologies. In Proceedings of the SAE World Congress & Exhibition, Detroit, MI, USA, 20–23 April 2009.
15. Kim, M.Y.; Yoon, S.H.; Lee, C.S. Impact of split injection strategy on the exhaust emissions and PM particulates from a compression ignition engine fueled with neat biodiesel. *Energy Fuels* **2008**, *22*, 1260–1265.
16. Kim, M.Y.; Yoon, S.H.; Hwang, J.W.; Lee, C.S. Characteristics of particulate emissions of compression ignition engine fueled with biodiesel derived from soybean. *J. Eng. Gas Turbine Power* **2008**, *130*, doi:10.1115/1.2906215.
17. Jaichandar, S.; Annamalai, K. Status of biodiesel as an alternative fuel for diesel engine—An overview. *J. Sustain. Energy & Environ.* **2011**, *2*, 71–75.
18. Oner, C.; Altun, S. Biodiesel production from inedible animal tallow and an experimental investigation of its use as alternative fuel in a direct injection diesel engine. *Appl. Energy* **2009**, *86*, 2114–2120.
19. Sahoo, P.K.; Das, L.M.; Babu, M.K.G.; Arora, P.; Singh, V.P.; Kumar, N.R.; Varyani, T.S. Comparative evaluation of performance and emission characteristics of *Jatropha*, *Karanja* and *Polanga* based biodiesel as fuel in a tractor engine. *Fuel* **2009**, *88*, 1698–1707.
20. Ozsezen, A.N.; Canakci, M.; Turkcan, A.; Sayin, C. Performance and combustion characteristics of a DI diesel engine fueled with palm oil and canola oil methyl esters. *Fuel* **2009**, *88*, 629–636.
21. Ziejewski, M.; Goettler, H.; Pratt, G.L. Comparative Analysis of the Long-Term Performance of a Diesel Engine on Vegetable Oil Based Alternate Fuels. *SAE Technical Paper* **1986**, doi:10.4271/860301.
22. Montagne, X. Introduction of Rapeseed Methyl Ester in Diesel Fuel-The French National Program. *SAE Technical Paper*, **1996**, doi:10.4271/962065.
23. İlkılıç, C.; Çılğın, E.; Aydın, H. Terebinth oil for biodiesel production and its diesel engine application. *J. Energy Inst.* **2015**, *88*, 292–303.

24. Korus, R.A.; Mousetis, T.L.; Lloyd, L. Polymerization of vegetable oils. In *ASAE Publication*, Proceedings of the International Conference on Plant and Vegetable Oils as Fuels, Fargo, ND, USA, 2 August 1982.
25. Yahya, A.; Marley, S.J. Performance and exhaust emissions of a compression ignition engine operating on ester fuels at increased injection pressure and advanced timing. *Biomass Bioenergy* **1994**, *6*, 297–319.
26. Clark, S.J.; Wagner, L.; Schrock, M.D.; Piennaar, P.G. Methyl and ethyl soybean esters as renewable fuels for diesel engines. *JAOCS* **1984**, *61*, 1632–1643.
27. Pestes, M.N.; Stanislao, J. Piston ring deposits when using vegetable oil as a fuel. *J. Test. Eval.* **1984**, *12*, 61–68.
28. Vellguth, G. Performance of Vegetable Oils and Their Monoesters as Fuels For Diesel Engines. In *SAE Technical Papers*, Proceeding of Off-Highway Metting & Exposition, Milwaukee, WL, USA, 12–15 September 1983.
29. Gülüm, M.; Bilgin, A. Density, flash point and heating value variations of corn oil biodiesel–diesel fuel blends. *Fuel Process. Technol.* **2015**, *134*, 456–464.
30. No, S.Y. Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review. *Renew Sustain Energy Rev.* **2011**, *15*, 131–149.
31. Perkins, L.A.; Peterson, C.L. Durability Testing of Transesterified Winter Rape Oil (Brassica Napus L.) as Fuel in Small Bore, Multicylinder, DI, CI Engines. In *SAE Technical Papers*, Proceeding of the International Off-Highway & Powerplant Congress & Exposition, Warrendale, PA, USA, 1991.
32. Puhan, S.; Vedaraman, N.; Ram, V.B. Mahua oil (Madhucaindica seed oil) methyl ester as biodiesel preparation and emission characteristics. *Biomass Bioenergy* **2005**, *28*, 87–93.
33. Chang, D.Y.Z.; Van Gerpen, J.H.; Lee, I.; Johnson, L.A.; Hammond, E.G.; Marley, S.J. Fuel properties and emissions of soybean oil esters as diesel fuel. *J. Am. Oil Chem. Soc.* **1996**, *73*, 1549–1555.
34. Choi, C.Y.; Reitz, R.D. An experimental study on the effects of oxygenated fuel blends and multiple injection strategies on DI diesel engine emissions. *Fuel* **1999**, *78*, 1303–1317.
35. Lee, C.S.; Park, S.W.; Kwon, S.I. An Experimental Study on the Atomization and Combustion Characteristics of Biodiesel-Blended Fuels. *Energy Fuel* **2005**, *19*, 2201–2208.
36. Grimaldi, C.; Postriot, L. Experimental Comparison Between Conventional and Bio-derived Fuels Sprays from a Common Rail Injection System. In *SAE Technical Papers*, Proceeding of the SAE 2000 World Congress, Detroit, MI, USA, 3–6 March 2000.
37. Tsolakis, A. Effects on Particle Size Distribution from the Diesel Engine Operating on REM-Biodiesel with EGR. *Energy Fuels* **2006**, *20*, 1418–1424.
38. Yoon, S.K.; Kim, M.S.; Kim, H.J.; Choi, N.J. Effects of canola oil biodiesel fuel blends on combustion, performance, and emissions reduction in a common rail diesel engine. *Energies* **2014**, *7*, 8132–8149.
39. Heywood, J.B. *Internal Combustion Engine Fundamentals*; McGraw-Hill Inc.: New York, NY, USA, 1988; pp. 509–510.