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# Application of Canola Oil Biodiesel/Diesel Blends in a Common Rail Diesel Engine

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**Abstract:** In this study, the application effects of canola oil biodiesel/diesel blends in a common rail diesel engine was experimentally investigated. The test fuels were denoted as ULSD (ultra low sulfur diesel), BD20 (20% canola oil blended with 80% ULSD by volume), and PCO (pure canola oil), respectively. These three fuels were tested under an engine speed of 1500 rpm with various brake mean effective pressures (BMEPs). The results indicated that PCO can be used well in the diesel engine without engine modification, and that BD20 can be used as a good alternative fuel to reduce the exhaust pollution. In addition, at low engine loads (0.13 MPa and 0.26 MPa), the combustion pressure of PCO is the smallest, compared with BD20 and ULSD, because the lower calorific value of PCO is lower than that of ULSD. However, at high engine loads (0.39 MPa and 0.52 MPa), the rate of heat release (ROHR) of BD20 is the highest because the canola oil biodiesel is an oxygenated fuel that promotes combustion, shortening the ignition delay period. For exhaust emissions, by using canola oil biodiesel, the particulate matter (PM) and carbon monoxide (CO) emissions were considerably reduced with increased BMEP. The nitrogen oxide (NO*x*) emissions increased only slightly due to the inherent presence of oxygen in biodiesel.

**Keywords:** canola oil biodiesel; alternative fuel; ignition delay; combustion characteristics; emission characteristics

## 1. Introduction

Due to their high thermal efficiency, large power output, reliability, durability, and high fuel economy compared with gasoline engines, diesel engines are widely used in various sectors, such as industrial transportation, passenger cars, and agricultural applications, despite their disadvantages of noise and vibration. As their hydrocarbon (HC), carbon dioxide ($CO_2$), and carbon monoxide (CO) emissions have been decreasing in exhaust emissions, diesel engines are becoming more and more popular. However, because diesel engines burn fuel in their cylinders at high temperatures and high pressures, and because the air/fuel mixture and temperature distribution are nonuniform, a diesel engine exhausts more nitrogen oxide (NO*x*) and particulate matter (PM) emissions than a gasoline engine [1–7]. It has been estimated that the PM emission from a diesel engine per unit of travelled distance is over 10 times higher than the emission from a gasoline engine running on unleaded gasoline fuel at the same power output [8,9]. Furthermore, the PM and NO*x* emissions from diesel are strictly controlled as an important environmental issue. Because mutagens and carcinogens are present in both the gaseous and particulate components of exhaust, lung cancer has been a focus of attention as a related health risk in animal and human research [10]. Decreasing harmful exhaust emissions is becoming an increasing priority.

Researchers have made substantial efforts to develop new technology to address this problem, such as reducing the PM exhaust emissions by using diesel particulate filters (DPF) or alternative fuels [11,12], and reducing the NO*x* emissions by using selective catalytic reduction (SCR) [13–15] or exhaust gas recirculation (EGR) [16]. These treatment systems can effectively solve this problem, however, they reduce the diesel engine's advantages in fuel economy, and the complex settings are very expensive [17]. Hence, many researchers have become interested in studying alternative fuels.

Biofuels are alternative fuels that can effectively reduce engine exhaust emissions, such as CO and PM emissions, due to the oxygen they contain, which can promote combustion in the combustion chamber. Additionally, they have energy security, nontoxicity, local availability, and recyclability [18–20]. Usually, biofuels are obtained from plants, waste oils, and animal fats through a variety of processing methods, and their fuel properties change with the different feedstocks [21,22]. In particular, biodiesel as a fuel for diesel engines is widely appealing because it is biodegradable and nontoxic, and compared to standard fuels, it emits less greenhouse gases (GHG) and significantly reduces exhaust emissions and overall life cycle emissions of $CO_2$ from the engine when burned as a fuel. The research on biodiesel stability has been established as a top priority [23–25]. Biofuels can be used for diesel engines in a blended form with conventional diesel without modifications of the engine [26–28]. However, researchers have found a series of problems with the use of pure vegetable oils in diesel engines [29,30]. Vegetable oils have characteristics such as high density, high viscosity, high iodine content, and low volatility. These characteristics create a series of problems when using pure vegetable oils in a diesel engine, such as engine deposits, injector coking, and piston ring sticking [31–34]. These problems are prevented by mixing vegetable oil with diesel fuel, which can also improve the combustion characteristics. With transesterification, biodiesel can achieve almost the same performance as diesel fuel [35–37]. In addition, canola oil is one kind of vegetable biodiesel that can produce more oil per unit of land area compared to other oil sources [38].

Kurre et al. [39] found that using biodiesel can reduce engine wear than that of diesel fuel. Reham et al. [40] studied that with a method of injection in a common rail diesel engine fueled with ultra low sulfur diesel (ULSD) and biodiesel. They reported that higher biodiesel blending rates required higher injection pressure because of the high surface tension of biodiesel. Yoon et al. [41] reported that BD20 (20% canola oil blended with 80% ULSD by volume) was the best blend fuel on combustion and exhaust emission characteristics at an engine speed of 2000 rpm with a constant engine load compared with other blend fuels (BD0, BD10, and BD30). Subsequently, Ge et al. [16] presented the effects of pilot injection timing and EGR combustion and emission characteristics by using BD20 in a diesel engine. However, all these findings were revealed at a constant engine load.

Therefore, to further investigate the application effect of BD20 and pure canola oil (PCO) in a common rail diesel engine, we extended our study to include various engine loads (0.13 MPa, 0.26 MPa, 0.39 MPa, and 0.52 MPa of BMEP) in the experimental setup. By these research results, we can provide a reference value of research on the development and application of canola biodiesel in a common rail diesel engine.

## 2. Equipment and Experiments

### 2.1. Test Fuel and Operating Conditions

The test fuels were denoted ULSD (SK Gas Station, Jeonjusi, Korea), BD20 (20% canola oil and 80% ULSD fuel blend by vol.), and PCO. To measure the fuel properties of ULSD, BD20, and PCO, the standard test methods of ASTM-D6751 and EN-14214 were used. Table 1 shows the compositions and main properties of the test fuels. It can be seen that PCO has the highest viscosity and lowest calorific value.

To further investigate the effects of BD20 and PCO on combustion and exhaust emission characteristics as the brake mean effective pressure changed under an engine speed of 1500 rpm, the coolant (water) and intake air temperature were controlled at a constant 70 ± 3 °C and 20 ± 3 °C, respectively. A constant BMEP of 0.13 MPa, 0.26 MPa, 0.39 MPa, and 0.52 MPa was controlled from the engine dynamometer, and the pilot injection timing and main injection timing were fixed at top dead center (TDC) 0°. Table 2 shows the experimental and operating conditions.

**Table 1.** Properties of ULSD (ultra low sulfur diesel), BD20 (20% canola oil blended with 80% ULSD by volume), and PCO (pure canola oil) fuels.

| Properties | ULSD | BD20 | PCO |
|---|---|---|---|
| Density at 15 °C (kg/m$^3$) | 836.8 | 846 | 880 |
| Viscosity at 40 °C (mm$^2$/s) | 2.719 | 2.991 | 4.290 |
| Lower calorific value (MJ/kg) | 43.96 | 42.71 | 39.49 |
| Catane number | 55.8 | - | 61.5 |
| Flash point (°C) | 55 | - | 182 |
| Pour point (°C) | −21 | - | −8 |
| Oxidation stability (h/110 °C) | 25 | - | 15 |
| Ester content (%) | - | - | 98.9 |
| Oxygen (%) | 0 | - | 10.8 |

**Table 2.** Experimental and operating conditions.

| Test Parameters | Operating Conditions |
|---|---|
| Engine speed (rpm) | 1500 |
| BMEP [1] (MPa) | 0.13, 0.26, 0.39, 0.52 |
| Test fuels | ULSD, BD20, PCO |
| Cooling water temp. (°C) | 70 ± 3 |
| Intake air temp. (°C) | 20 ± 3 |
| Main injection timing (degree) | TDC 0 |

[1] BMEP: brake mean effective pressures.

## *2.2. Test Engine and Experimental Procedure*

In this study, a naturally aspirated high-pressure common-rail direct-injection diesel engine with a displacement volume of 1979 cm$^3$ and a compression ratio of 17.7 was used to investigate the combustion performance and exhaust emission characteristics of the test fuels. The basic data of the engine used are given in Table 3, and the experimental setup schematic is shown in Figure 1.

**Table 3.** Specifications of the test engine.

| Number of Cylinders | 4 |
|---|---|
| Cylinder diameter | 81 mm |
| Stroke | 96 mm |
| Displacement | 1979 cm$^3$ |
| Compression ratio | 17.7:1 |
| Max. power | 82 kW at 4000 rpm |
| Max. torque | 260 Nm at 2000 rpm |
| Max. fuel pressure | 145 MPa |

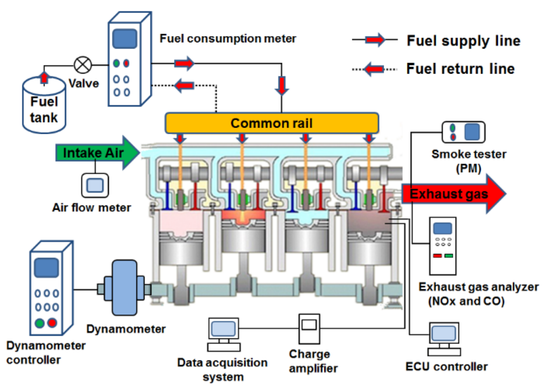



**Figure 1.** Schematic diagram of the experimental apparatus.

The experimental device was equipped with a turbocharger consisting of a four-cylinder diesel engine (2004 Hyundai Santa Fe, Ulsan, Korea), a fuel consumption meter (Hwanwoong Mechatronics Co., Ltd., Gyeongnam, Korea) was used to test fuel consumption by an electrical voltage of 220 V to provide power, the main and pilot injection timings were controlled by an electronic control unit (ECU) (Hyundai 3910027220, Bosch, Muenchen, Germany), the engine speed was controlled by an eddy-current-type EC dynamometer (HE-230, Hwanwoong Mechatronics Co., Ltd., Gyeongnam, Korea), and the combustion pressure was controlled by a piezoelectric pressure sensor (6056a, Kistler, Winterthur, Switzerland). Experimental data were acquired using a data acquisition board (PCI6040E, National Instrument, Austin, TX, USA). The combustion pressure in the combustion chamber was analyzed by a combustion analyzer. A multi-gas analyzer (GreenLine MK2, Eurotron (Korea) Ltd., Seoul, Korea) was used to measure the amount of $O_2$, CO, $CO_2$, NO, $NO_2$, and NO$x$. An opacity smoke meter (OPA-102, QROTECH Co., Ltd., Gyeonggi-do, Korea) with the partial flow sampling method was used to measure the amount of PM. To ensure high accuracy of the measured values, when changing the diesel engine to a new fuel, in order to burn out the remaining fuel as much as possible, the engine needs to run for sufficient time. Whenever the experimental conditions were changed, the engine ran long enough to achieve stability before we began to record the experimental data.

In this work, for each set of experimental conditions, we averaged the combustion pressure and heart rate over 200 cycles of the engine running through the combustion analyzer, and we calculated the rate of heat release (ROHR) of the test fuels in the engine using the following formula:

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

where $k$ is the specific heat ratio, $P$ is the combustion pressure, and θ is the crank angle. The brake specific fuel consumption (BSFC) is a measure of the fuel consumption that is used for comparing the efficiency of engines with the same brake power. It was calculated using the following formula:

$$\text{BSFC} = \frac{\dot{m}_f}{2\pi NT} \tag{2}$$

where $\dot{m}_f$ is the fuel consumption flow rate, $N$ is the engine speed, and $T$ is the brake torque.

The brake specific energy consumption (BSEC) is a measure of the energy consumption that is used for evaluating the efficiency of fuel energy. Which is calculated using the following formula:

$$\text{BSEC} = \frac{Q_{\text{LHV}} B_f}{2\pi NT} \tag{3}$$

where $Q_{\text{LHV}}$ is the lower heating calorific value, $B_f$ is the fuel consumption, $N$ is the engine speed, and $T$ is the brake torque.

To observe the combustion stability of the diesel engine, the coefficient of variation in indicated mean effective pressure ($\text{COV}_{\text{IMEP}}$) was defined as:

$$\text{COV}_{\text{IMEP}} = \frac{\left[\frac{1}{N}\sum_{i=1}^{N}\{\text{IMEP}(i) - X\}^2\right]^{\frac{1}{2}}}{X} \tag{4}$$

$$X = \frac{1}{N}\sum_{i=1}^{N} \text{IMEP}(i) \tag{5}$$

where $X$ is the average value of the indicated mean effective pressure over 200 cycles, $N$ is the number of engine cycles (here, $N$ = 200), IMEP($i$) is the indicated mean effective pressure (here, $i$ = 1, 2, 3, . . . , 200).

### 2.3. Ignition Delay in CI Engines

Figure 2 shows the four stages of combustion in compression ignition (CI) engines, which is the ignition delay period, a period of rapid combustion, period of controlled combustion, and period of after burning. The ignition delay period is also called the preparatory phase during which some fuel has already been admitted but has not yet ignited. This period is counted from point A (start of injection) to point B (start of combustion), which is shown in Figure 2. After the fuel is injected, with the pressure and temperature of combustion chamber increase to the fuel can be compression ignited, this consumption time is ignition delay rapid and exerts a very great influence on both engine design and performance; because it can affect the combustion rate, knocking, and engine starting ability, even including the presence of smoke in the exhaust. The ignition delay period can be divided into the physical delay and the chemical delay [42].

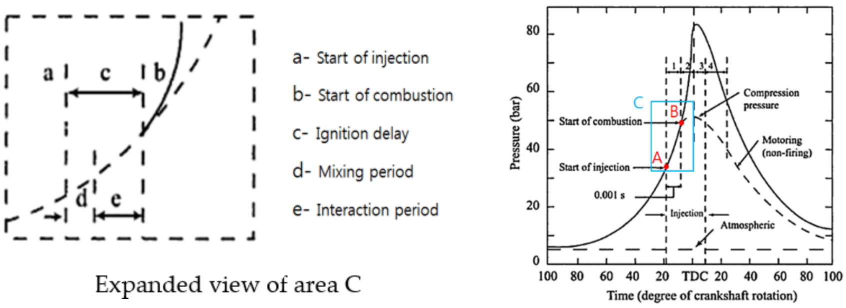



**Figure 2.** Stages of combustion in compression ignition (CI) engines.

#### 2.3.1. Physical Delay

The physical delay period is the time between the beginning of injection and the attainment of chemical reaction conditions. It depends on the physical properties of the fuel. Because, during this period, in order to achieve the chemical reaction conditions, the fuel must be atomized, vaporized, mixed with air and raised to its self-ignition temperature. So, in general, the physical delay period of high density and viscosity of fuel is longer than that of low density and viscosity of fuel [42,43].

#### 2.3.2. Chemical Delay

The chemical delay is the time between the attainment of chemical reaction conditions and start of combustion. It depends on the temperature and pressure of the surroundings and oxygen concentration of fuel. Generally, the chemical delay is larger than the physical delay due to the chemical reactions being faster, and higher a cetane number of fuel indicates a shorter chemical delay time [42,44].

## 3. Results and Discussion

### 3.1. Combustion Characteristics

#### 3.1.1. Combustion Pressure and Rate of Heat Release (ROHR)

Combustion characteristic analysis is an important index to measure engine performance. In general, the combustion characteristic is analyzed by using cylinder gas pressure, rate of heat release, ignition delay period, combustion durations, coefficient of variation in indicated mean effective pressure, and brake specific fuel consumption. Figure 3 shows the effects of ULSD, BD20, and PCO on the combustion pressure and ROHR at various brake mean effective pressures. At 0.13 MPa, 0.26 MPa, 0.39 MPa, and 0.52 MPa, the PCO's combustion pressure decreases 43.5%, 28.6%, 12.6%, and 8.4% compared with ULSD, respectively. In addition, as shown in Figure 3a,b, the combustion pressure decreased successively with the proportion of canola oil in the blends is increased. At 0.26 MPa, the combustion pressures of three kinds of test fuels were closer than that of at 0.13 MPa. It can be explained that the high density and viscosity of PCO, compared to ULSD, leads to PCO's less easy atomization at low BMEP (0.13 MPa). Increasing the value of BMEP has the effect of improving atomization and fuel burning. Another reason is that the lower calorific value of PCO is lower than that of ULSD and BD20 (see Table 1). These similar results were also observed by other researchers [41,43].

However, as shown in Figure 3d,c, it can be observed that the combustion pressure of BD20 is the highest, and the three kinds of test fuels' combustion pressures are very similar. It can be noted from the Table 1 that BD20 is an oxygenated fuel and can be burned more completely with a higher oxygen concentration at middle and high engine loads (0.39 MPa and 0.52 MPa). Although the PCO is the highest oxygenated fuel, high density and high viscosity are its main disadvantage (at about 1.5 times that of ULSD; see Table 1).

For the ROHR of three kinds of test fuels, as shown in Figure 3, the peak value of the ROHR occurred at crank angles over 0°, which is an inherent characteristic of a diesel engine's ignition delay. In addition, from Figure 3a–d, it can be clearly observed that the ignition delay periods of BD20 and PCO are faster by about 3° and 5° of crank angle (CA), respectively, compared with ULSD. It can be explained that the cetane number (61.5) of PCO and viscosity (4.29) is higher than that of ULSD (see Table 1), and it leads to the compressibility of PCO fuel being lower and the combustion of PCO fuel starting faster than that of ULSD [41,43]. At middle and high engine loads (0.39 MPa and 0.52 MPa), the ROHR of BD20 is the biggest compared with ULSD and PCO, it is again verified that the influence of the oxygen content is great [43,44].

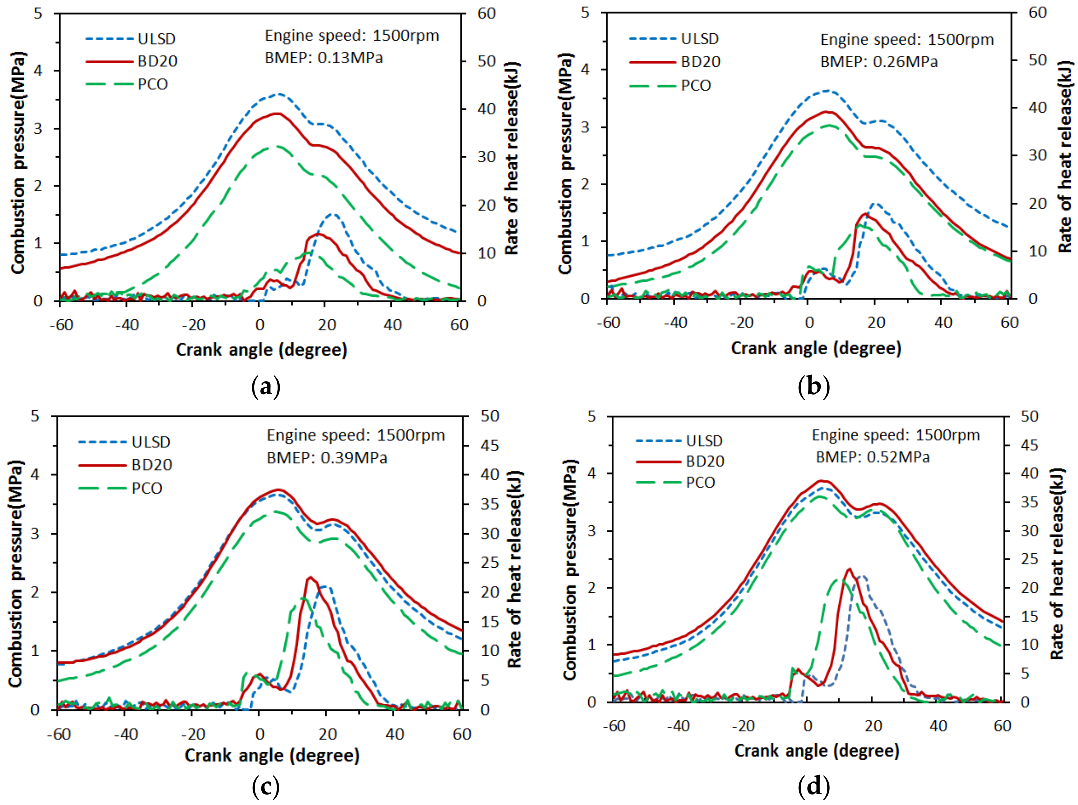
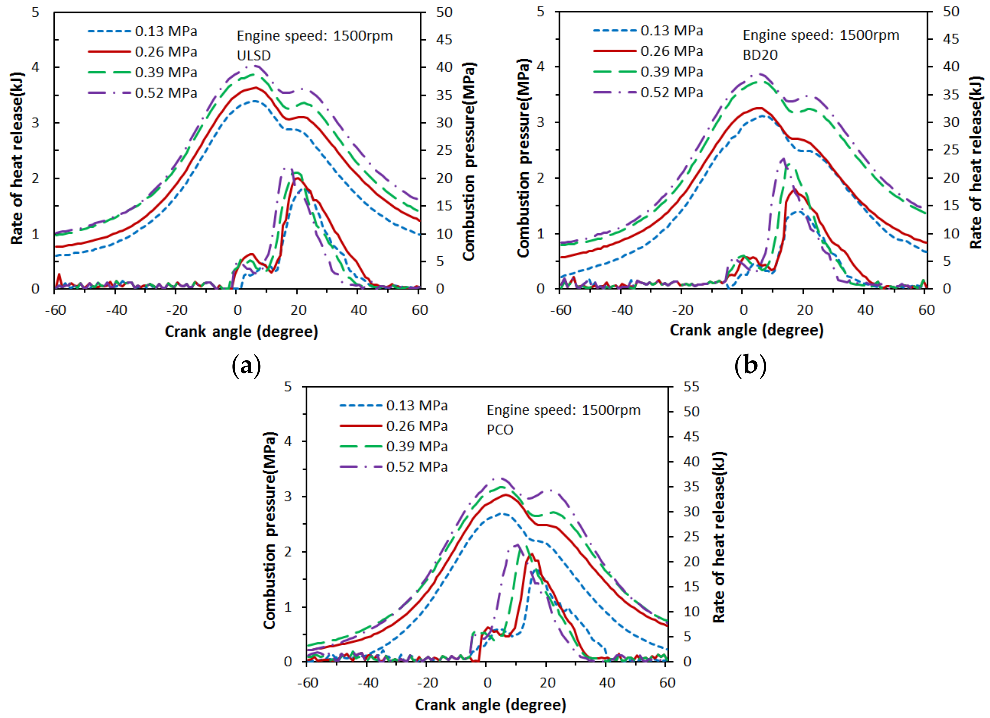



**Figure 3.** Effect of test fuels on combustion pressure and ROHR (Rate of Heat Release) at various BMEPs (brake mean effective pressures). (**a**) 0.13 MPa; (**b**) 0.26 MPa; (**c**) 0.39 MPa; (**d**) 0.52 MPa.

In order to comprehensively investigate the application of canola oil in a common rail diesel engine, the combustion pressure and ROHR for each test fuel are shown in Figure 4. For each kind of fuel, the combustion pressure increased clearly with increasing BMEP. At high engine load (0.52 MPa), the combustion pressure of ULSD, BD20, and PCO increase 34.6%, 47.1%, and 72.4% compared with that of at low engine load (0.13 MPa), respectively. In particular, for BD20 and PCO, this combustion pressure increased effect is very significant. This because the BD20 and PCO are high density and high viscosity fuels, they can be burned fully at high engine loads. With increasing BMEP, the injection pressure of the fuel and the turbulence intensity in the combustion chamber increased, which built a better atomization environment. In contrast, with increasing BMEP, the ROHR increased and the ignition delay period shortened, which occurs because the air and fuel are mixed fully at higher values of BMEP, leading to faster-starting combustion.




(**a**) (**b**) (**c**)

**Figure 4.** Effect of BMEP on combustion pressure and ROHR according to test fuels. (**a**) ULSD (ultra low sulfur diesel); (**b**) BD20 (20% canola oil blended with 80% ULSD by volume); (**c**) PCO (pure canola oil).

In order to further study the effect of ignition delay of ULSD, BD20, and PCO with the variations of BMEPs, the results are presented in Figure 5. It can be seen that the ignition delay of BD20 and PCO is shorter than that of ULSD. Increasing the biodiesel blend will lead to increasing the oxygen concentration of fuel and then promoting chemical reactions, reducing the chemical delay. Those results are similar to [43]. Although increase the canola oil in their blends will cause increased the density and viscosity of mixed fuel and then delay the ignition time. However, the cetane number of canola biodiesel (61.5) is higher than that of diesel (55.8). The high cetane number has an appreciable effect on ignition delay for canola biodiesel compared with high density and viscosity. On the other hand, the ignition delay of the test fuels is shortened with increased BMEP, because the temperature and pressure of the surroundings of test fuels are increased as engine load increases. From the Figure 5, It can also be seen that ignition delays of PCO and BD20 are shorter than that of ULSD by about 5.5° CA and 3.25° CA. It is very similar to the results of ignition delay in Figure 3 by ROHR (see the result of ignition delay in the Section 3.1.1).

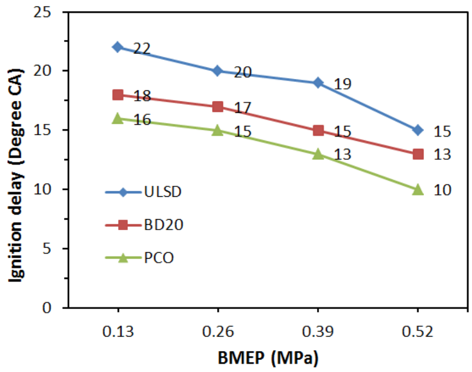
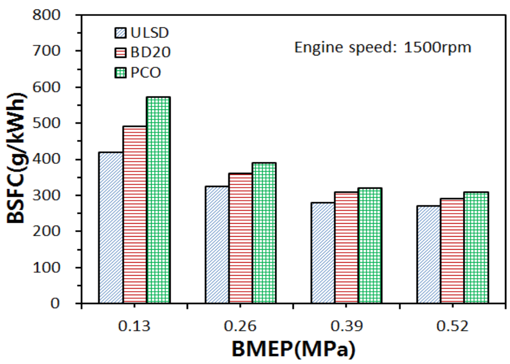


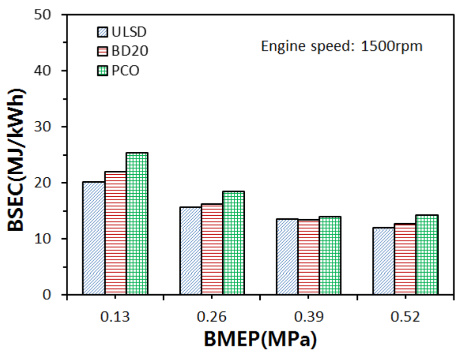

**Figure 5.** Effect of BMEP on ignition delay for test fuels.

### 3.1.2. Brake Specific Fuel Consumption and Brake Specific Energy Consumption

Brake specific fuel consumption is a measure of the fuel efficiency of an internal combustion engine that burns fuel and produces output power. Figure 6a shows the effects of the use of ULSD, BD20, and PCO fuels on BSFC at various brake mean effective pressures. As shown in Figure 6, the BSFC decreased as the BMEP increased, because at low engine loads, the fuel injection pressure and turbulence intensity in the combustion chamber are lower than at high engine loads. The effects of fuel atomization and the air/fuel mixture are not better at higher engine loads, so the fuel consumption is its largest at the lowest BMEP. These results are similar to [45]. In contrast, for BD20 and PCO, the BSFC increased as the BMEP increased because the lower calorific value of canola oil is lower than in ULSD, which leads to BD20 and PCO fuels' consuming more fuel to produce the same power, compared with ULSD. At 0.13 MPa, from ULSD to PCO, the increase in BSFC is the largest. In particular, the BSFC of PCO increases because the density and viscosity of PCO is high, making it difficult to atomize. In addition, the BSEC is another important engine parameter to evaluate its capability when using fuels with different calorific values. As shown in Figure 6b, under different combustion conditions, the average BSEC for ULSD, BD20, and PCO fuels are 15.34 MJ/kWh, 16.08 MJ/kWh, and 18.01 MJ/kWh, respectively. For BD20 and PCO fuels, the BSECs were 4.8% and 17.42% higher, respectively, compared with ULSD. The lower calorific value and higher viscosity of canola oil biodiesel leads to increases in the BSEC. However, with increasing BMEP, the BSEC had a decreasing trend due to higher power output.




(**a**) BSFC




(**b**) BSEC

**Figure 6.** Effect of test fuels on (**a**) BSFC (brake specific fuel consumption); and (**b**) BSEC (brake specific energy consumption) according to BMEP.

#### 3.1.3. Coefficient of Variation in Indicated Mean Effective Pressure

Next, we examined the combustion stability of the diesel engine. Figure 7 shows the effects of ULSD, BD20, and PCO fuels on the cycle-to-cycle coefficient of variation in the indicated mean effective pressure on the various brake mean effective pressures. As shown in Figure 7, the ULSD, BD20, and PCO fuels have values of $COV_{IMEP}$ under about 3.5% when the BMEP increases from 0.13 MPa to 0.52 MPa. So it seems that the common rail direct injection engine under running conditions is stable. In addition, the value of $COV_{IMEP}$ decreased as the BMEP increased from 0.13 MPa to 0.52 MPa. This can be explained in that higher BMEP could improve the combustion stability because the fuel injection pressure and turbulence intensity in the combustion chamber increased with increasing BMEP. In addition, from ULSD to PCO, the value of $COV_{IMEP}$ reduced gradually from 0.13 MPa to 0.325 MPa. However, from 0.325 MPa to 0.52 MPa, the ULSD had the smallest value of $COV_{IMEP}$. This can be explained in that canola oil is an oxygenated fuel that promotes combustion and improves the combustion stability at lower BMEP. At higher BMEP, the engine should produce more power, but the lower calorific value of canola oil is lower than for ULSD, so it cannot produce the same power as ULSD, which leads to combustion that is less stable than with ULSD.

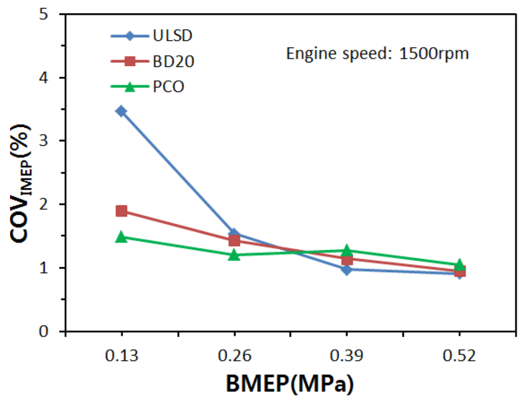



**Figure 7.** Effect of test fuels on $COV_{IMEP}$ according to BMEP.

### *3.2. Emission Characteristics*

The effects of ULSD, BD20, and PCO on CO, NO*x*, and PM emissions according to brake mean effective pressures under an engine speed of 1500 rpm are shown in Figure 8. As shown in Figure 8a, the CO emission decreased considerably as BMEP increased. In particular, the CO emission is almost zero above 0.39 MPa, which is the same as for the combustion pressure where the fuel injection pressure and turbulence intensity in the combustion chamber increased as BMEP increased. This improves the fuel atomization and air/fuel mixture, which promotes combustion. In addition, the CO emission was lower for PCO than for ULSD because the canola oil biodiesel is an oxygenated fuel that can combust more fully.

Figure 8b shows the effects of ULSD, BD20, and PCO on NO*x* emission according to brake mean effective pressures under an engine speed of 1500 rpm. As shown in Figure 8b, the NO*x* emission changed slightly as the brake mean effective pressures increased. As the value of BMEP increased from 0.26 MPa to 0.52 MPa, the NO*x* emission increased only slightly by 6% and 14% at 0.39 MPa and 0.52 MPa compared with 0.26 MPa. This can be explained in that the temperature increased as BMEP increased from 0.26 MPa to 0.52 MPa. In addition, changing from ULSD to PCO fuel, the NO*x* emission also increased because biodiesel is an oxygenated fuel with more intense combustion and increased temperature in the combustion chamber [41,46]. So, the NO*x* emission can be reduced by decreasing the temperature of the combustion chamber. The EGR was an effective way to reduce NO*x* emission that was reported in our previous studies [16,41].

Figure 8c shows the effects of ULSD, BD20, and PCO fuels on PM emission according to brake mean effective pressures under an engine speed of 1500 rpm. As shown in the Figure 8c, the PM emission decreased considerably as BMEP increased, especially at 0.39 MPa and 0.52 MPa of BMEP, respectively, where it decreased 59% and 65% of their values at 0.13 MPa of BMEP. In addition, the PM emission also decreased when changing from ULSD to PCO fuel. This phenomenon is similar to that for CO emission: increasing BMEP can change the combustion environment to promote combustion and burn the fuel more fully.

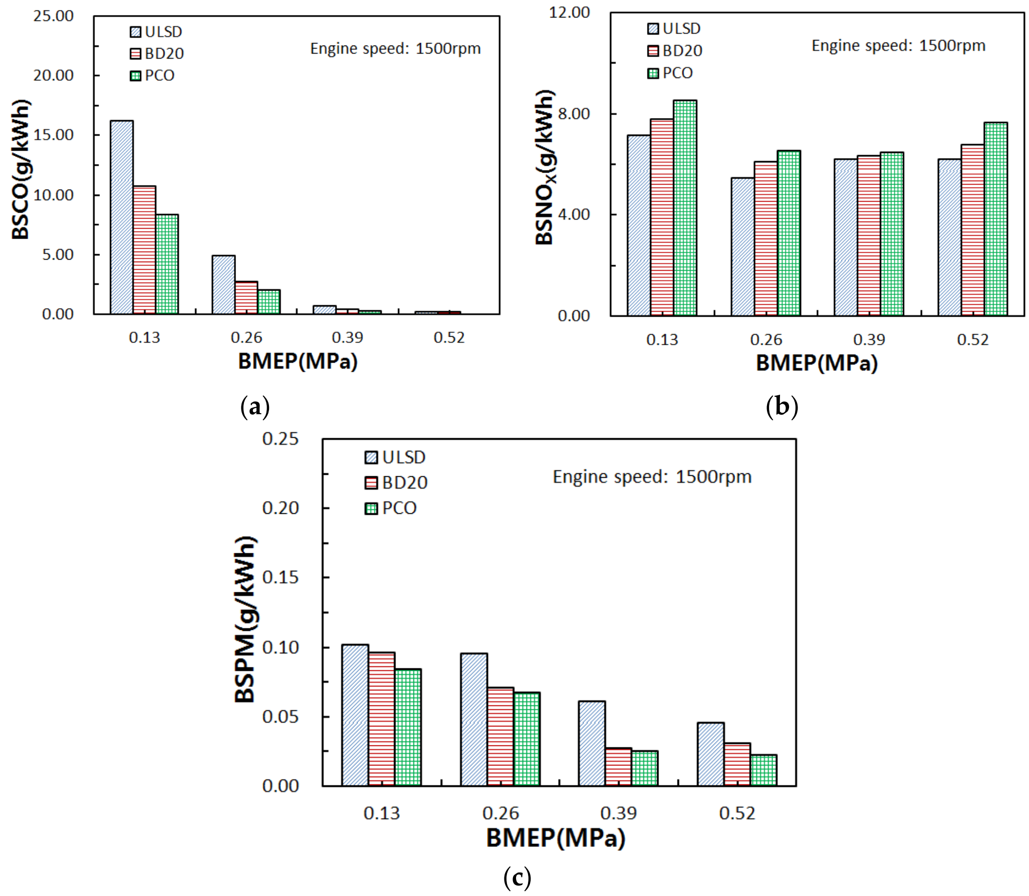



**Figure 8.** Effect of test fuels on exhaust emissions according to BMEP. (**a**) CO; (**b**) NO*x*; (**c**) PM (particulate matter).

## 4. Conclusions

Canola oil is characterized by high density and viscosity, a high cetane number, and low compressibility compared with diesel fuel. Due to its unique characteristics, the application effects of canola oil biodiesel/diesel blends in a common rail diesel engine was experimentally investigated in detail, by observing combustion characteristics, engine performance, and emission characteristics. The following summarizes the findings in this work:

- Canola oil biodiesel is an oxygenated fuel, and the oxygen components have played an important role in the combustion process.
- At high engine load (0.52 MPa), the combustion pressure of ULSD, BD20, and PCO increases 34.6%, 47.1%, and 72.4% compared with that of at low engine load (0.13 MPa), respectively.
- The ignition delay of PCO and BD20 are shorter than that of ULSD by about 5.5° CA and 3.25° CA.
- The CO and PM emissions decreased considerably, but the NO*x* emission increased only slightly by 6% and 14% at 0.39 MPa and 0.52 MPa compared with 0.26 MPa.

Through this study, we showed that the common rail diesel engine can run well on PCO without engine modification. In addition, by testing under different combustion conditions, we demonstrated that BD20 is the most optimal alternative fuel, compared with ULSD and PCO, based on the combustion, performance, and emission characteristics.

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**Author Contributions:** All authors designed the experimental apparatus, analyzed the data, discussed the results and implications and commented on the manuscript at all stages. Jun Cong Ge performed the experiments and wrote the paper. Sam Ki Yoon performed the experiments and contributed PM emission analysis tool. Min Soo Kim led the development of the paper. Nag Jung Choi performed the result analysis and discussion.

**Conflicts of Interest:** The authors declare no conflict of interest.

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