Analysis of Emission Characteristics in a Common Rail Diesel Engine Fueled with Biodiesel

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Abstract

Global warming is a major concern, and the realization of carbon neutrality is leading to the strengthening of air environment policies. The automotive industry is shifting towards electrification because of environmental pollution caused by exhaust gas from vehicle, because of the depletion of fossil fuels and fluctuating oil prices. However, in this rapidly changing situation, it is being reported research that the pure internal combustion engine market will still be the main driving force for the next 10 years. This is because electricity produced by relying on thermal power and nuclear power generation cannot be a key solution to air pollution. Biodiesel can be produced by recycling energy resources and can also be extracted from animal or vegetable sources. Therefore, it is emerging again as an eco-friendly alternative fuel in the internal combustion engine market.

In this study, changes in emission gas characteristics were studied using biodiesel blended fuel. The common rail type diesel engine used in the experiment was used without any modification. First, exhaust emissions gas was measured under normal operating engine conditions. Secondly, exhaust emissions gas was measured even under abnormal conditions in which a cylinder misfire occurred with the same engine. On no-load operating condition, in an engine operating normally, used pure diesel and a biodiesel mixture (BD20) from three type each (Soybean, Coconut, Waste cooking oil) as fuel. As a result, biodiesel has significantly reduced PM and CO emissions compared to pure diesel. Especially, Soybean BD20 biodiesel showed the largest decrease. However, NO_x showed an increasing trend for biodiesel. In terms of HC, it was only emitted by pure diesel, and none of the three types of bio diesel was emitted HC. In the abnormal engine conditions where cylinder misfire occurred, bio diesel fuel of waste cooking oil was used and compared with pure diesel. As a result, it was confirmed that PM, CO, and HC were equally significantly reduced.

***Keywords**:* Biodiesel, Soybean, Coconut, Waste cooking oil, CRDI, Cylinder misfire, PM, CO, NOx, HC

1. Introduction

The main cause of environmental pollution today is global warming. Carbon-neutral practices to overcome this are situation and a lot of strong environmental policies are being developed for improving environment. That is why the automotive industry is rapidly changing from internal combustion engines to electrified zero emission systems. The reasons of increasing demand for electric vehicles include environmental pollution caused by exhaust gasses from the IC engine, depletion of limited fossil fuels, and rapidly changing oil prices. In addition, the government is encouraging users to purchase electric vehicles through various subsidy policies. A lot of investment is also being made in building charging infrastructure for electric vehicles [1,2].

However, even in this rapidly changing situation, it is reported that for the next 10 years, the internal combustion engine will occupy 40% of the market, and internal combustion engines including hybrids will still cover about 70%~80% as a main power source [3]. The reason is that electric vehicles (BEV / PHEV / PCEV) have very high CO2 reduction costs compared to internal combustion engines with current vehicle technology. In terms of economic cost, therefore the internal combustion engine is still more advantageous. CO2 emission being the main source of the global warming, is also produced in large quantities by electricity production companies, which relies on thermal power and nuclear power generation. Therefore, there are reports that this cannot be a solution to the fundamental air environment policy [4]. Recently, It has been raised again the need for high-efficiency investment in internal combustion engines, which is an existing main field. It is a time when new and renewable energy policies for biofuels are emerging again as an alternative to the rising oil price change and the recycling of limited energy resources [5].

Currently, as of 2022 in South Korea, the blended ratio of mandatory use of biodiesel, a new and renewable energy, was raised to 3.5%. The government policy for this biodiesel mandatory mixture started at 0.5% in 2006 and was gradually raised to 3.5% of the current standard. It also announced that it would raise it to 5.0% in stages by 2030 [6]. Therefore, interest in biodiesel, which is a low-carbon fuel, is becoming popular again. It is a time when the efficiency improvement of the internal combustion engine and the supply of eco-friendly vehicles are required for a balanced development.

Currently, many studies have been reported on the analysis of engine performance and emission change using biodiesel in diesel engines. However, there were not many previous studies on the change in the characteristics of the exhaust emission of biodiesel under abnormal engine operation, that is, failures caused by engine aging. In this study, the change of exhaust gas was compared and analyzed when pure diesel and biodiesel mixed fuel were applied to a common rail diesel engine during the 1st experiment. The proportion of biodiesel blended fuel was BD20 (20% biodiesel, 80% pure diesel), and three types of bio diesel (soybean oil, coconut oil, and vegetable oil) were used as fuel. In the second experiment, the change in the characteristics of exhaust gas emissions was studied when the waste cooking oil biodiesel was applied under abnormal conditions by reproducing the environment in which the cylinder misfire occurred with the same experimental engine.

2. Test devices and methodology

2.1 Biodiesel production

Figure 1 shows the 4 types of fuel used in the experiment. (a) is pure diesel fuel, which was purchased at a general gas station. The fuels in (b), (c), and (d) were directly manufactured biodiesel and were extracted from coconut oil, soybean oil, and waste cooking oil. For the extraction method, an alkali catalyst of methanol (135ml) and potassium hydroxide (2.5g) were mixed in a certain ratio for transesterification. Then, it was diluted in 500ml of vegetable oil, which is a raw material for biodiesel, and rotated at 700rpm using a magnetic rotary bar at about 55℃ for 2 hours. After storage at room temperature for 24 hours, biodiesel and glycerine were separated [7-8]. Finally, the extracted biodiesel contains methanol, so to remove it, it was washed with water at about 70°C, 5 to 6 times. Waste cooking oil from fried chicken was first separated from foreign substances with the help of a paper filter, and then biodiesel was produced by the same extraction method.

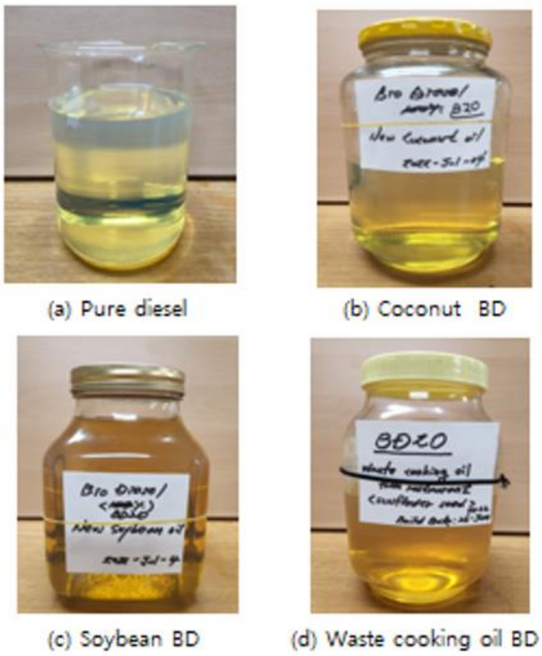


Figure 1. Classification Pure diesel and Bio diesel

2.2 Experimental set-up

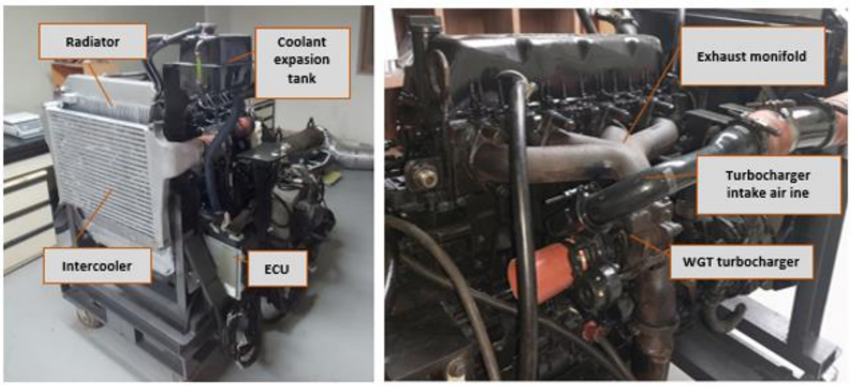
The engine used for the experiment was 168 BHP of diesel engine with a Common Rail 3.8L. it was equipped a WGT turbocharger. The detailed specifications are shown in Table.1 The engine used for the experiment was operated under no-load condition, and it was specially manufactured and installed on the test frame so that the engine speed could be controlled so that the experiment could be performed at various RPMs. The actual test engine is shown in Figure 2, and to create the real condition of the vehicle as much as possible, the radiator, intercooler, intake/exhaust line, etc. were installed on the engine using the same parts as the actual vehicle.

Table 1. Key Specification on Simulation Engine

Parameter	Specification
Engine Brand	Cummins ISF3.8
Vehicle Application	Minibus (25 seats)
Fuel Type	Diesel

No. of Cylinders	4
Bore x Stroke	102 x 115
Displacement	3800 cc
Fuel injection	Common Rail Direct Injection
Fuel injection pressure	450bar ~ 1,600 bar
Max. overspeed capa.	3900 RPM (1,600bar)
Emission level	EURO5
Max. Power	168 HP / 2600 RPM
Max. Torque	443 ft-lb at 1300 RPM
Intake system	Inter-cooler
Injector type	Solenoid
No. of Injector hole	6
Standard modulating thermostat range	83 to 95 °C
After treatment device	SCR only

For the experiment, exhaust gas analyzer (Hebsiba, HG-550RT) and a diesel smoke tester (Jastec, CMS-2300) were used to acquire the data of the exhaust gas from the engine. For the measurement, the exhaust gas probe was inserted into the exhaust manifold at the front of the SCR to a depth of 30cm. An engine diagnostic device, Cummins INSITE-Inline6, was connected to the OBD connector of the engine wiring harness as a device for monitoring the operation status of the engine and logging data during the experiment. The schematic diagram of the experimental equipment installation location is shown in Figure 3.



(a) Engine fornt side (b) Engine Exhaust side

Figure 2. Test engine setup

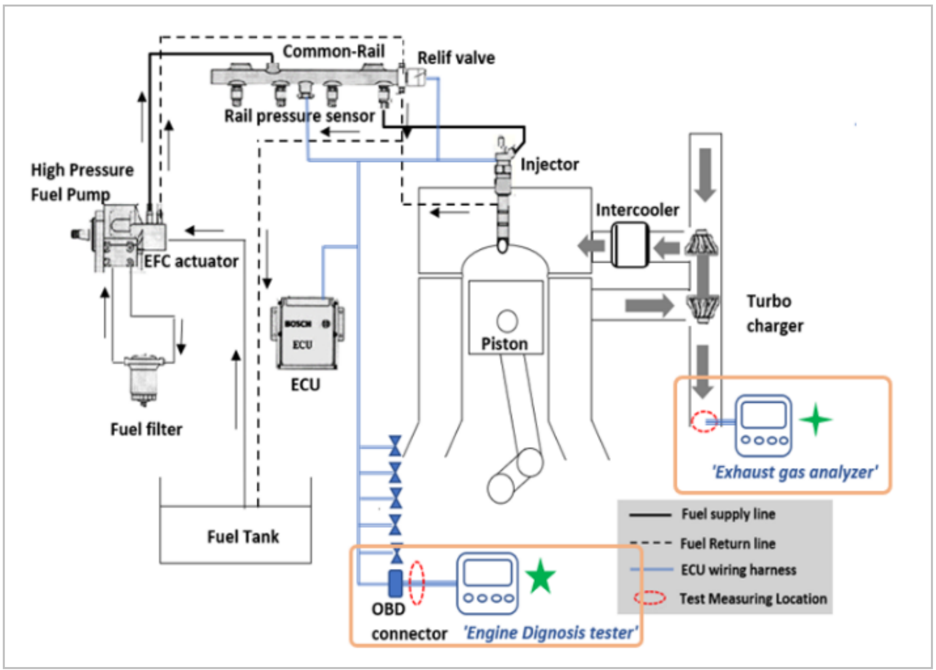


Figure 3. Schematic diagram of measuring apparatus

2.3 Methodology

We acquired each data from exhaust emissions of the engines fueled with pure diesel and biodiesel blended. For the experiment, the engine was preheated to 80~85℃. The data were measured repeating three times and used as the average value of the data obtained the PM/NO_x/CO/HC values in the engine rotation range of a total of 6 areas (750rpm, 1000rpm, 1200rpm, 1400rpm, 1600rpm, 1800rpm). The first experiment was conducted on the engine with no engine fault code on. In the second experiment, we conducted on two type of failure modes, which were condition of fault code FC322 (cylinder 1 misfire) and both FC322 and FC332 (cylinder 4 misfire) in the same engine. The fuel used in the first experiment was pure diesel and three types of BD20 biodiesel fuel (soybean oil, coconut oil, and waste cooking oil). In the second experiment, the exhaust gas was comparatively analyzed with pure diesel and waste cooking oil BD20 biodiesel fuel.

3. Test results and analysis

3.1 Test under no-load, normal engine conditions

3.1.1 Smoke (PM)

As a result of measuring the engine RPM at 6 areas, as shown in Figure 4, PM showed a tendency to increase overall in all fuels as the engine speed increased, and all three types of biodiesels (BD20) fuel have reduced PM emissions compared to pure diesel. Biodiesel using soybean oil showed the largest decrease at 77% compared to pure diesel, followed by waste cooking oil by 53%, and coconut oil by 17% at the 1400rpm area. It is analyzed that the oxygen element contained in biodiesel improves combustion and promotes compared to pure diesel, resulting in a decrease in PM [9-10].

3.1.2 Nitrogen oxide (NO_x)

As shown in Figure 5, NO_x tends to decrease in all fuels as the RPM increases. The use of all three types of biodiesels (BD20) had a higher NO_x emission value than pure diesel. Particularly, biodiesel using waste cooking oil showed an increase of 120%, more than double that of pure diesel. It was followed by soybean oil with an increase by 83% and coconut oil with the lowest overall increase of 25% at 1000rpm of engine speed. It is judged that the increase in the combustion speed leads to an increase in the combustion temperature, under the influence of higher oxygen in the biodiesel, there is an increase in NO_x emission

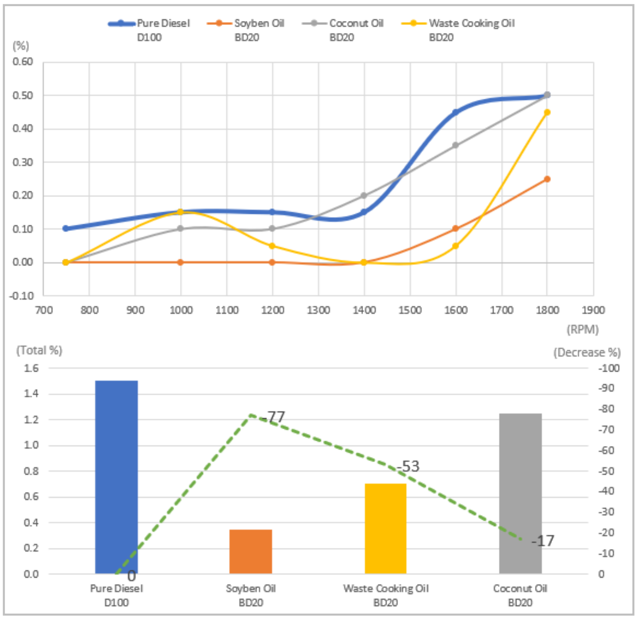


Figure 4. Soot emission characteristics on various engine speed

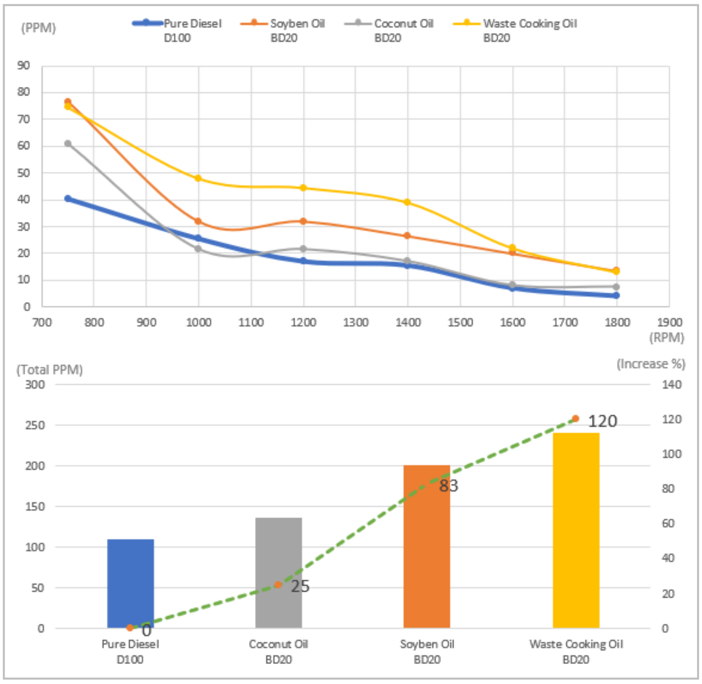


Figure 5. NOx emission characteristics on various engine speed

3.1.3 Carbon monoxide (CO)

As shown in Figure 6, the CO emission showed a constant and gradually increasing trend in all fuels as the RPM increased. All three types of biodiesels (BD20) had lower CO emissions than pure diesel. Biodiesel using waste cooking oil showed a reduction rate of up to 93% compared to pure diesel. Soybean and coconut biodiesel showed similar results, with declines of 76% and 73%. This is confirmed a result of promoting combustion because biodiesel has a higher oxygen content than pure diesel

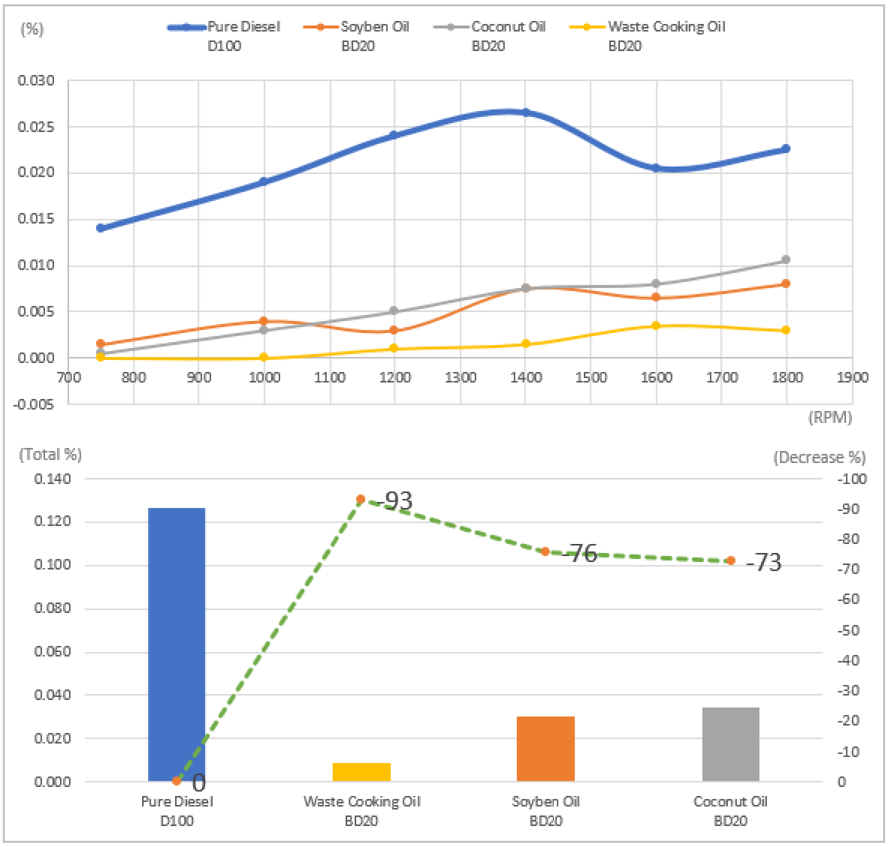


Figure 6. CO emission characteristics on various engine speed

3.1.4 Hydrocarbons (HC)

HC was measured only in the pure diesel test, and no emissions were produced in the remaining three types of biodiesel tests. It is judged that the biodiesel fuel under the no-load test condition did not reach the minimum condition for HC to be generated. In addition, the cetane number in biodiesel is higher than that of pure diesel oil, so it is analyzed that HC emission is significantly reduced due to improved combustibility.

3.2 Test under no-load, abnormal engine conditions: FC322 (Cylinder #1 misfired), FC322 & FC332 (Cylinder #1 & #4 misfired)

3.2.1 Smoke (PM)

As shown in Figure 7, even under abnormal engine, misfire conditions, when WCO-BD20 biodiesel was used, less PM was emitted than pure diesel. In the engine under normal conditions, WCO-B20 showed a 53% reduction compared to pure diesel. However, in cylinder

#1 misfired condition, PM increased overall compared to the normal engine condition, but when the two fuels used in the #1 misfire condition were compared relatively, the WCO-BD20 fuel decrease by 32%, compared to the pure diesel. Under the condition of cylinder #1 & #4 misfired, the PM emission was similar to about 5% for both pure diesel and WCO-BD20. As a result, it was confirmed that WCO-B20 fuel emitted relatively less PM than pure diesel oil even under abnormal conditions where engine misfire occurred.

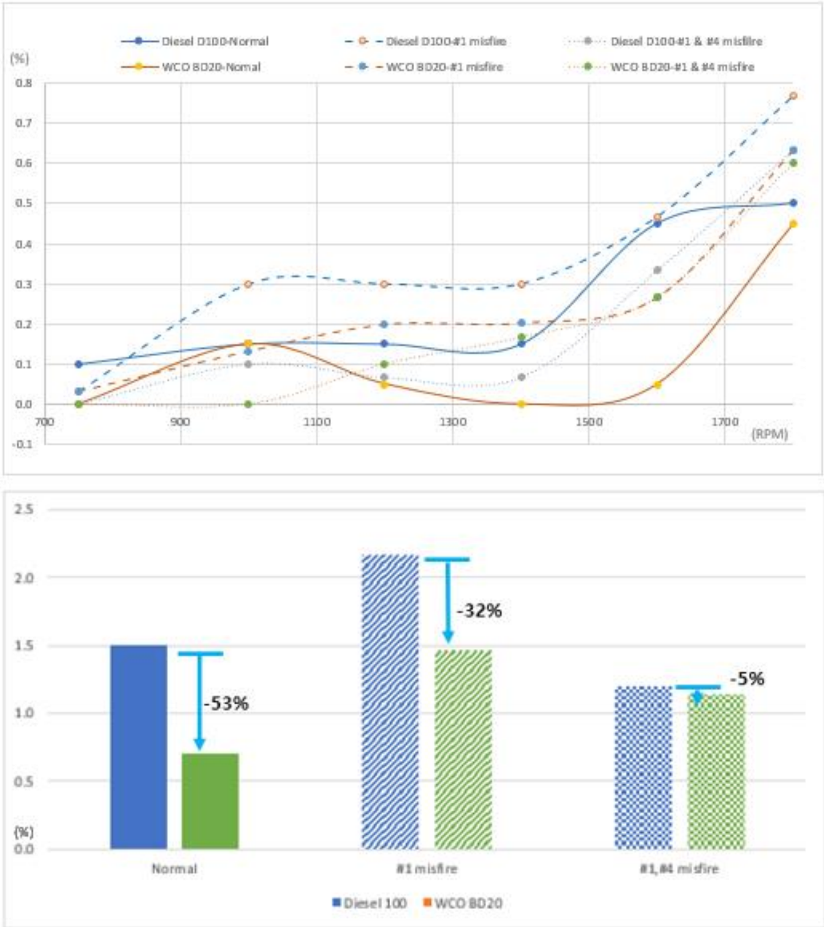


Figure 7. PM emission comparison in misfire condition

3.2.2 Nitrogen oxides (NOx)

As shown in Figure 8, the use of WCO-B20 biodiesel was measured to be relatively higher in NOx than in pure diesel under all three experimental conditions. In the engine under normal condition, WCO-B20 showed a high increase of about 120%, and in the case of cylinder #1 misfire, NOx was reduced for both fuels compared to the normal engine condition, but WCO-B20 emitted 35% more compared to pure diesel. In the case of misfiring of cylinders 1 and 4, WCO-B20 was still emitted higher than pure diesel by 27%.

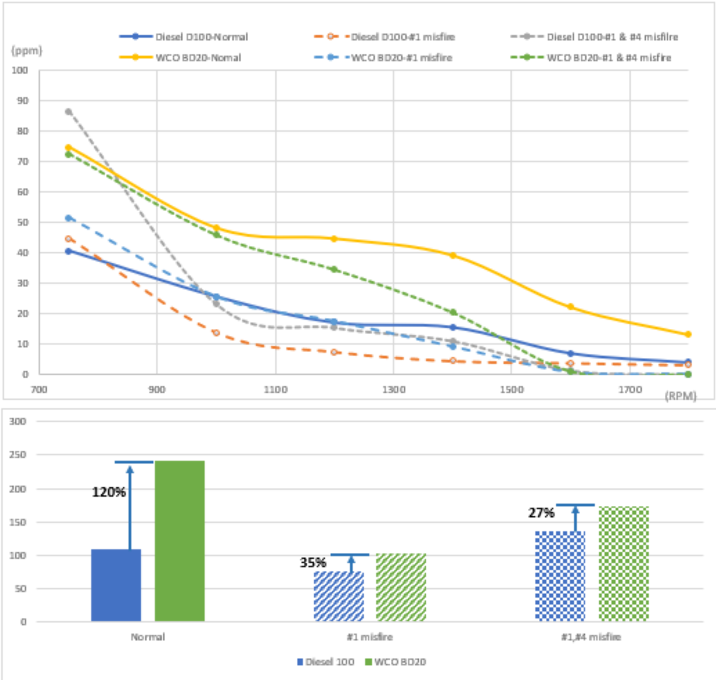


Figure 8. NOx emission comparison in misfire condition

3.2.3 Carbon monoxide (CO)

As shown in the graph in Figure 9, carbon monoxide emission for WCO-BD20 biodiesel was significantly reduced by 93% in the engine under normal conditions, and 57% in cylinder #1 misfire, 91% in #1 and #4 misfires respectively compared to conventional diesel. It is analyzed that the misfire of the experimental engine was made by blocking fuel injection into the cylinder, so incomplete combustion itself was not formed, and CO was emitted significantly lower than under normal conditions

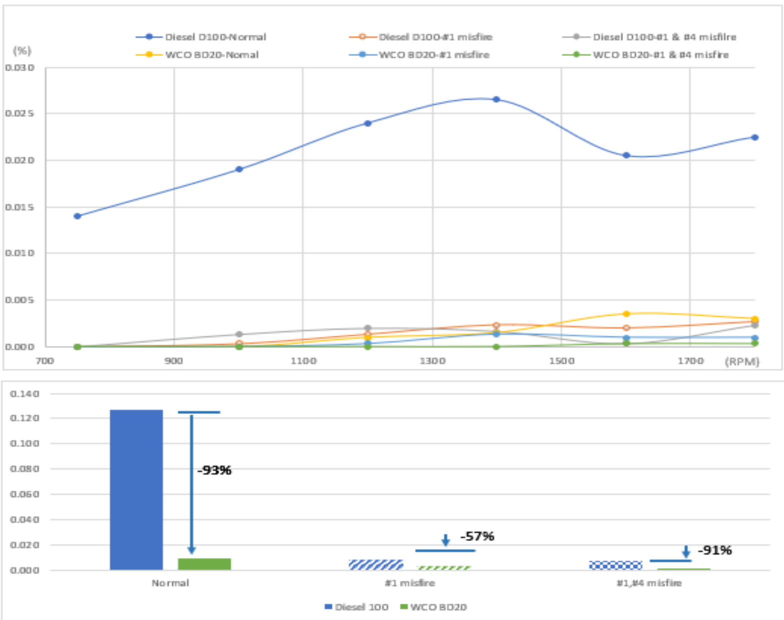


Figure 9. CO emission comparison in misfire condition

4. Conclusions

In this paper, as an experiment to analyze exhaust emissions using biodiesels (BD20) in a common rail diesel engine operating under no-load conditions, the following conclusions were drawn for the engine operating normally and the engine operating abnormally.

Under normal conditions, all three types of biodiesels (BD20) (soybean oil, coconut oil, waste cooking oil) showed that PM, CO and HC emission improved compared to pure diesel except for NOx emission. Especially, in the case of PM, soybean oil biodiesel showed reduction by 77%, and in CO, waste cooking oil showed reduction by 93%, and in NOx, waste cooking oil showed the increase by 120%.

Experimentation under one or two cylinders misfire condition, it could be confirmed that biodiesel from waste cooking oil had an reducing effect on PM and CO emission, except for NOx compared to conventional diesel. In the case of cylinder #1 misfire, PM was reduced to 32% and CO was /reduced to 57%. Under the condition that cylinder #1 and cylinder #4 are simultaneously misfired, PM is 5% and CO is 91%. It was confirmed that WCO emits less than pure diesel. However, NOx was measured to be high by 35% and 27%, respectively, under the above conditions

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