Effects of EGR and ethanol additive on combustion and emission characteristics in a CRDI diesel engine

Gui-Rong Wu*, Jun-Cong Ge*, Min-Soo Kim*, Nag-Jung Choi*,†
*Dept. of Mechanical Design Engineering, Jeonbuk National University
† e-mail: njchoi@jbnu.ac.kr

CRDI 디젤기관에서 EGR 및 에탄올 첨가제가 연소와 배기특성에 미치는 효과

무귀영*, 갈준총*, 김민수*, 최낙정*†
*전북대학교 기계설계공학과
† e-mail:njchoi@jbnu.ac.kr

Abstract

In this study, ethanol additive and 10% EGR were respectively applied to a common rail direct injection (CRDI) diesel engine fueled with biodiesel to test the emissions characteristics at 750 rpm under different loads. The results showed that EGR can reduce NOx and increase PM emissions. On the contrary, the NOx increased by adding ethanol to biodiesel fuel while the PM emissions decreased.

1. Introduction

Biodiesel is considered to be an effective alternative to petroleum diesel. Biodiesel has high oxygen content, high cetane number, good lubricity, versatility, and other advantages, which can effectively reduce the main greenhouse emissions such as carbon dioxide (CO2), hydrocarbon (HC) and particulate matter (PM) from diesel engines without any modification [1]. Meanwhile, the NOx emissions produced by biodiesel will increase to a certain extent.

In addition, the high viscosity, density and corrosiveness of biodiesel may cause the blockage of fuel injection nozzle and the aging of some rubber materials, which affect the engine performance [2]. In the theory and technology of reducing vehicle NOx emissions, adding proper ethanol to fuel and applying EGR technology are two of effective means. The properties of ethanol, such as lower cetane number, lower calorific value and lower density, can effectively make up for the short board of biodiesel, realize complementary advantages, and improve engine emissions. However, the effect of ethanol additives on biodiesel is not decisive, for instance, [3] found that ethanol can reduce NOx and PM emissions, while [4] found that NOx increased. On the other hand, EGR technology is a means to introduce a part of exhaust gas back into the cylinder, control the combustion effect by controlling the amount or temperature of fresh air, and achieve lower NOx emissions. Most of the previous studies have combined the two methods with fuel or other technologies to improve the combustion performance. There are few studies on the advantages and disadvantages of the two methods applied to pure palm biodiesel to discuss its emission reduction. Both [5] and [6] found that EGR has a good NOx reduction effect.

Based on pure palm biodiesel, EGR technology and ethanol additive were separately used in this experiment. to explore the combustion and emission characteristics of pure palm biodiesel under different loads, and to compare the effects of ethanol and EGR Technology on NOx and PM emissions.

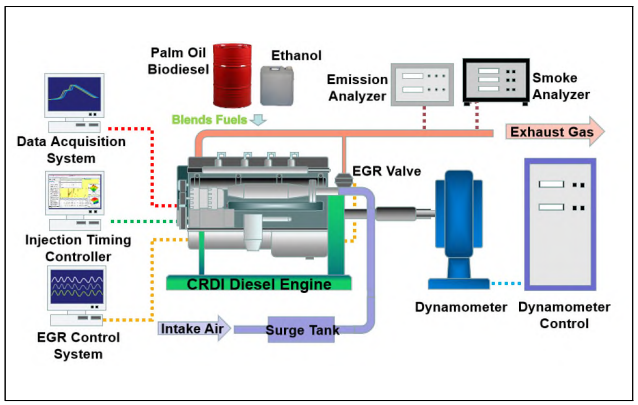
2. Experimental setup and method

2.1 Experiment apparatus and fuels

The test system is shown in Figure 1. The test engine

is a 4-cylinder 2.0L common rail direct injection (CRDI) diesel engine with EGR system. The engine specification are shown in Table 1. Injection timing, injection pressure is set by the engine electronic control unit (ECU) by contoling WinOLS software. The exhaust gas data is measured and recorded by a multi-gas analyzer (GreenLine MK2) and an emissions analyzer (HPC501), and the emitted PM is measured by an opaque smoke meter (OPA-102).

Pure palm oil biodiesel (B100) was used as the experimental fuel, and bioethanol was added to B100 as the mixed fuel. The properties of palm oil biodiesel and bioethanol are shown in the Table2.



[Fig. 1] Experimental system.

[Table 1] Engine specification

Engine type	In-line four-cylinder
Fuel injection system	Bosch common-rail direct injection
Air intake system	Turbocharger with WGT
Bore × stroke (mm)	83 × 92
Displacement (cc)	1991
Compression ratio	17.7/1
Maximum power (ps/rpm)	115/4000
Maximum torque (kgm/rpm)	26.5/2000

[Table 2] Fuel properties

Properties	Palm oil biodiesel	Bio ethanol
Density(kg/m3 15℃)	877	799.4
Viscosity(mm2/s 40℃)	4.56	1.1
Calorific value(MJ/kg)	39.72	28.18
Cetane index	57.3	8
Oxygen content(℃)	11.26	34.7

2.2 Experiment method

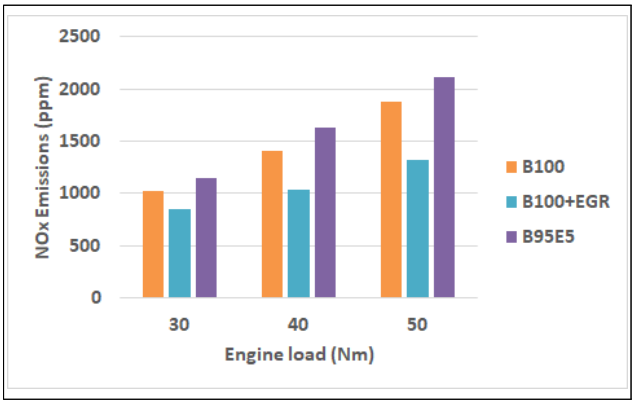
The experiment tested the emission characteristics of pure biodiesel (B100), biodiesel with 10% EGR (B100+10%EGR) and ethanol-biodiesel blend (5% volume ethanol + 95% volume palm oil biodiesel). The load conditions were set to 30, 40 and 50 Nm respectively, with constant engine speed at 750 rpm. The injection pressure was set at 350 bar while the pilot and main injection timing were set at 18° and 5° CA BTDC, respectively. The EGR rate is derived from the following:

$$EGR\ rate\ (\%) = \frac{V_1}{V_1 + V_2}$$

V1-exhaust gas introduced from EGR

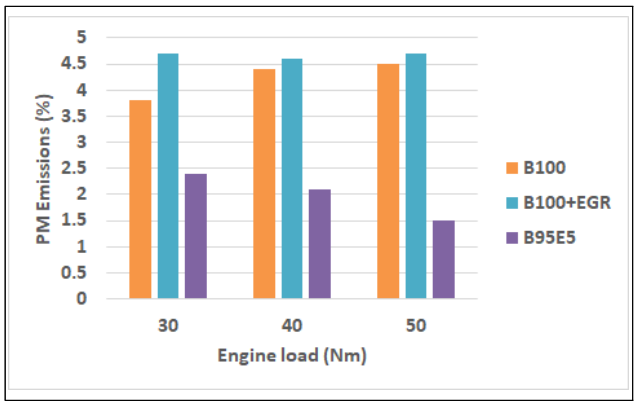
V2-fresh air introduced

3. Results and Discussion



[Fig. 2] NOx emissions at 30,40,50Nm.

The NOx generation mechanism is more complicated and often depends on the combustion temperature, oxygen concentration, reaction time and equivalence ratio in the cylinder. The result found that the use of EGR technology in B100 can reduce NOx emissions by 17.5%, 26.5% and 29.6% respectively at 30, 40 and 50 Nm. But the emissions of NOx increased because of the ethanol additive. In general, many researchers have found that ethanol has a lower calorific value and a larger latent heat of vaporization can effectively reduce the temperature in the cylinder and reduce the generation of NOx. However, higher oxygen content and lower cetane number of ethanol are likely to cause increased NOx emissions, which is also the dominant factor of the result in this study. In addition, due to the reduced compression modulus of the mixed fuel, the injection timing is not as sensitive as that of the B100, and the ignition delay is longer because of the lower cetane number of the blend. These factors are not conducive to the reduction of NOx.



[Fig. 3] PM emissions at 30,40,50Nm.

The PM emitted by diesel engines mainly comes from fuel, and is usually formed in a high-temperature fuel-rich area without sufficient oxygen concentration. As shown in the figure, the exhaust gas introduced into the cylinder by EGR reduced the local oxygen concentration, resulting in an increase in PM emissions. The addition of ethanol greatly increases the oxygen content in the fuel, increases the oxygen concentration in the fuel-rich area, and at the same time reduces the temperature in the cylinder to a certain extent, thereby alleviating the generation of PM. This effect is more obvious at 50 Nm.

4. Conclusions

The result of this study showed that under all load conditions, EGR reduces the NOx emissions of biodiesel, but slightly increases PM emissions. The addition of ethanol significantly reduced PM emissions but not NOx. NOx emissions have increased due to the addition of ethanol, and increased with increasing load. The effect of ethanol additives on palm oil biodiesel NOx emissions needs further study.

Acknowledgments

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. 2019R1I1A1A01057727) and the Korea government (MSIT) (No. 2019R1F1A1063154).

References

[1] SHAHIR, V. K.; JAWAHAR, C. P.; SURESH, P. R. Comparative study of diesel and biodiesel on CI engine with emphasis to emissions—a review. Renewable and Sustainable Energy Reviews, 2015, 45: 686-697.

[2] SORATE, Kamalesh A.; BHALE, Purnanand V. Biodiesel properties and automotive system compatibility issues. Renewable and Sustainable Energy Reviews, 2015, 41: 777-798.

[3] SHAMUN, Sam, et al. Performance and emissions of diesel-biodiesel-ethanol blends in a light duty compression ignition engine. Applied Thermal Engineering, 2018, 145: 444-452.

[4] TUTAK, Wojciech, et al. A comparative study of co-combustion process of diesel-ethanol and biodiesel-ethanol blends in the direct injection diesel engine. Applied Thermal Engineering, 2017, 117: 155-163.

[5] CAN, Özer, et al. Combined effects of soybean biodiesel fuel addition and EGR application on the combustion and exhaust emissions in a diesel engine. Applied thermal engineering, 2016, 95: 115-124.

[6] YASIN, Mohd Hafizil Mat, et al. Study of a diesel engine performance with exhaust gas recirculation (EGR) system fuelled with palm biodiesel. Energy Procedia, 2017, 110: 26-31.