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A Study on the Combustion and Emission Characteristics of JP-8 jet fuel in a CI Engine

압축착화 엔진에서 **JP-8** 제트연료의 연소 및 배기특성에 관한 연구

2014년 2월

서울대학교 대학원

기계항공공학부

이 정 연

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지도교수 민 경 덕

이 논문을 공학석사 학위논문으로 제출함
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A Study on the Combustion and Emission Characteristics of JP-8 jet fuel in a CI Engine

Jungyeon Lee
Department of Mechanical and Aerospace Engineering
Seoul National University

Abstract

Many recent studies aim to reduce pollutant emissions and improve efficiencies in CI engines by adopting the state of art combustion strategies to meet the more stringent regulations as years go by. Among the noble combustion strategies, homogeneous charge compression ignition (HCCI) uses well mixed fuel-air mixture to reduce NOx and PM simultaneously. Diesel-gasoline blending fuel was also studied for NOx and PM simultaneous reduction by prolonging ignition delay of diesel fuel. However, those studies have critical defects. Therefore, JP-8 combustion in a CI engine was investigated as one of the methods to forming homogeneous fuel-air

mixture. Since JP-8 jet fuel has lower Cetane Number than that of diesel fuel, ignition delay is extended despite higher volatility and low viscosity of the fuel. Although JP-8 has already been used at both military aircrafts and ground vehicles by NATO nations as a part of Single Fuel Concept (SFC) through sufficient studies, further studies are needed to understand combustion process of the fuel. In this study, JP-8 and diesel fuel were combusted in a CI engine with four cylinders and two pilot injection. And the effect of boost pressure, injection pressure, main injection timing, and EGR rates under the same torque condition on combustion and emissions were investigated to determine combustion optimization. Results show that JP-8 has similar combustion characteristics to diesel fuel except for longer ignition delay caused by higher Cetane Number. Therefore, PM emission is considerably decreased without noticeable NOx increase and efficiency losses. Moreover, simultaneous reduction in NOx and PM would be achieved by increasing EGR rate.

Keywords: CI engine, diesel fuel, JP-8, NO_x, PM

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Acronym

BTDC	Before Top Dead Center
CA	Crank Angle
CI	Compression Ignition
CO	Carbon Monoxide
DOC	Diesel Oxidation Catalyst
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
FSN	Filtered Smoke Number
HCCI	Homogeneous Charge Compression Ignition
HRR	Heat Release Rate
JP-8	Jet Propellant type 8
NATO	North Atlantic Treaty Organization
NOx	Nitrogen Oxides
PM	Particulate Matter
SOC	Start of Combustion
SOI	Start of Injection
THC	Total Hydro Carbon

Chapter 1. Introduction

1.1 Background

With the increasing concern about the environmental pollution and more stringent emission regulations, many recent studies have made efforts to reduce exhaust emissions and improve thermal efficiency. Exhaust emission reduction has been attempted by two primary methods; one is reducing engine out emissions from cylinders by adopting advanced combustion strategies and the other is reducing exhaust gas by using after-treatment devices such as DPF and DOC.

Homogeneous Charge Compression Ignition (HCCI) recently has been studied among the various noble combustion strategies to reduce NOx and PM emissions simultaneously. HCCI has a characteristic that fuel and air are mixed before combustion starts, thereby makes homogeneous mixture. Although HCCI has several defects such as higher CO/HC emissions and combustion phasing control difficulty [1], forming homogeneous mixture is still promising method for break through the NOx-PM trade-off relation.

Prolonging ignition delay period is an effective way to make homogeneous mixture. Ignition delay can be extended by adding different kind of fuel with lower Cetane Number to diesel fuel, which provides sufficient mixing time for homogeneous mixture formation. For example, diesel-propane blending was investigated and its ignition delay was prolonged with the increase of propane fraction [2]. Gasoline-diesel blending

was also investigated for prolonging ignition delay. Reactivity Controlled Compression Ignition (RCCI) is a kind of dual-fuel PCCI, which blends air and fuel in a cylinder. In this concept, gasoline is injected through the port fuel injectors and diesel fuel is injected into the cylinders directly at advanced timing. The ignition delay of gasoline-diesel mixture is prolonged as a result of the gasoline addition to diesel fuel [3]. Gasoline-diesel blending prior to the injection was also studied and the ignition delay of the mixture was prolonged with the increase of gasoline fraction [4].

Blending two fuels are effective way to extend ignition delay and reduce NOx and PM. However, using two fuels in road vehicles is impractical because of complex fuel distribution system needs and high cost. But extension of ignition delay by lowering Cetane Number is worth investigating. Therefore, JP-8 jet fuel was considered in this study as a single fuel because of its lower Cetane Number than diesel fuel and has similar characteristics to gasoline-diesel blending fuel. Moreover, JP-8 is being used in military vehicles as well as military aircrafts by NATO nations as a part of Single Fuel Concept (SFC).

SFC is a policy which was arisen to solve fuel coagulation problem of diesel fuel at low temperature, and to make convenience of logistics because a vast amount and various types of fuel are consumed for military usage. In terms of management and logistics, dealing with different kinds of fuel requires extra cost, time and labor. Moreover, military vehicles and equipment that used diesel fuel experienced fuel coagulation at low temperature due to their high paraffin hydrocarbon content. Therefore, JP-8

(NATO F-34) was used in military vehicles as well, due to its lower freezing point and lower viscosity than that of diesel fuel. This policy designated as the Single Fuel Concept by U.S. Department of Defense (DOD) in 1988 and NATO adopted the concept in 1998 [5, 6].

Before the decision to adopt the SFC, the NATO nations have carried out sufficient experimental studies in Compression Ignition (CI) engines to find out if there were any problems in replacing the fuel from diesel to JP-8. However, further studies are needed for better understanding about combustion characteristics, in order to prevent problems caused by replacement of fuels. Moreover, it may contribute for military vehicles to meet the emission regulations, even though the military vehicles are granted a waiver for the greenhouse gas standards by EPA [7]. Thereby, SFC quality can be improved and pollutant emissions would be reduced.

1.2 Objective

The main objective of this study is to investigate the effects of JP-8's basic properties on combustion and emission characteristics. Then, by evaluating the possibility of combustion optimization for JP-8 in a direct injection CI engine, to give a reference to researchers who are going to study about JP-8 combustion is the aim. As mentioned above, JP-8 combustion in a CI engine has already been studied by many researchers of many countries. However, papers or reports which studied the effect of combustion parameter variations on JP-8 combustion were not found. Especially, a study on either EGR rates or multiple injection strategy variations is nonexistent.

Therefore, test cases were determined to investigate as many as parameters are included.

1.3 Description of Fuels

Cetane Number (CN) is a measure of a fuel's ignition delay, which means time period between the start of injection (SOI) and the start of combustion (SOC). In compression engines, lower CN fuels have longer ignition delay than higher CN fuels. In other words, the lower the CN, the later the fuel ignites automatically at the compression stroke. This affects PM and NOx emissions. The longer the ignition delay, the longer the time for forming homogeneous mixture, so PM formation can be reduced. However, NOx emission is increased because increased mixing time result in higher combustion temperature.

Density affects injection pressure and injected fuel mass during the same injection period. Fuel injection during the same time period indicates that same volume of fuels are injected. However, injected fuel masses are different with respect to their densities. Fuel temperature also have to be considered when calibrate the injected fuel mass because fuel density varies with its temperature. Therefore, fuel density affects fuel efficiency and engine performance. Moreover, fuel density also affects the other fuel properties such as CN, viscosity and volatility indirectly [8].

Viscosity is a measure of its resistance to deformation by external forces. Fuel's viscosity depends on the size and shape of its particles and the attractions between the particles. Viscosity effects on the other properties such as volatility and density to some degrees. Lower viscosity results in easier evaporation and shorter liquid spray length because it has weak surface tension. However, fuel pump of engine can be worn because lower viscosity fuel has poor lubricity.

Lower heating value (LHV) is the amount of heat released by combusting a specified quantity. Higher LHV makes the tendency to higher pressure rise rate and higher engine output. However, the effect of density on the heating value on a volume basis also needs to be considered. Although JP-8 has higher LHV compared to that of diesel fuel on a mass basis, LHV on a volume basis is lower than that of diesel fuel due to its lower density.

Higher volatility means that the fuel boils at lower temperature. For example, 50% distillation temperature indicates that the temperature where 50% of the fuel will be boiled off. Usually, the higher is volatility, the shorter is the ignition delay. However, JP-8 has longer ignition delay than diesel fuel despite its higher volatility due to its lower CN. It shows that volatility has minor effects on the ignition delay compared to CN.

JP-8(Jet Propellant type 8) is a kerosene type turbine fuel which

contains static dissipator, corrosion inhibitor, lubricity improver, fuel system icing inhibitor, antioxidant and metal deactivator. It is specified by MIL-DTL-83133G technical specifications and is equivalent to commonly used civil Jet-A1, except for the already mentioned additives for military purpose. It is designated as the official aviation fuel by US army, US Air Force and Republic of Korea Air Force (ROKAF) to use less hazardous fuel for better safety and combat survivability.

Both JP-8 and diesel fuel were refined to given specifications for their fuel class, but there are variations even within a certain fuel specification. Therefore, the fuels used in this study do not cover the entire range of other JP-8 and diesel fuel. But there are significant differences in the characteristics between the two fuels.

JP-8 used in this study was supplied by the ROKAF and diesel was common use fuel. The basic characteristics of the fuels are given in Table 1. The table was filled with data on the basis of test report provided from the manufacturer, MIL-DTL-83133G, and [8]. As showed in Table 1, JP-8 has a lower Cetane Number, density, and viscosity, whereas slightly higher LHV and higher volatility than diesel fuel.

Table 1. Basic characteristics of JP-8 and Diesel fuel

	JP-8	Diesel
Cetane Index	45.9	53.6
Density (15℃ kg/㎥)	792.4	832.4
Freezing Point (°C)	-48.5	-7.5
Flash Point (PMCC °C)	44.0	45.5
Viscosity (40°C cSt)	1.4	2.6
LHV (MJ/kg)	43.3	42.5
Distillation		
50% (°C)	195.7	275.0
90% (°C)	236.5	344.4

Chapter 2. Experimental Setup and Test Cases

In order to evaluate engine performance and exhaust emissions of JP-8 and diesel fuel combustion, experiments were conducted on a direct injection CI engine at the author's laboratory.

2.1 Experimental Setup

The specifications of the engine used in this experiment are listed in Table 2. The engine used is a common use four-cylinder CI engine which is named as R-engine with a displacement volume of 2.2L. The engine is equipped with turbo charger and exhaust gas recirculation (EGR) with EGR cooler. A common rail injection system with Bosch piezo injectors which enable the fuels to be injected by 1,800bar was used. Fuel is injected three times at the conventional condition as shown Figure 1(a). The case with one pilot injection and a main injection is shown Figure 1(b).

The fuels used were stored in separated fuel tanks. The fuel pipes and tanks were used only with the designated kinds of fuels. The residual quantity of fuels in common rail and injectors were completely removed by sufficient washing, not to mix with the other fuel. The lubricity improver produced by Infineum International Ltd. was added to JP-8 to compensate for its lower lubricity, which is attributed to its lower viscosity for preventing abrasion on the fuel pumps. However, the lubricity improver didn't effect on the engine performance and emissions because its quantity is

very small quantity about 250 ppm. The engine was coupled to a 190kW AC dynamometer and it was controlled by torque so as to be the same engine output. The coolant temperature was controlled to maintain approximately 363K.

CO_2, CO, THC and NO_x were measured via HORIBA 7100DEGR. PM was measured via AVL 415S smoke meter and fast particulate spectrometer DMS-500. A mass burette type flow meter, ONO SOKKI FX-203P, was used to measure the rate of the fuels.

The EGR rate was calculated by measuring the concentration of CO_2 in the exhaust gas and the intake gas. Sonic orifices and pressure regulators were used to control the amount of air and maintain constant flow. An absolute pressure transducer (Kistler 4045A5) and relative pressure transducer (Kistler 6055Bsp) were used, in order to measure external pressures and cylinder pressure, respectively. The schematic diagram of experimental setup is shown in Figure 2.

Table 2. Specification

Displacement (L)	2.199
Stroke (mm)	96
Bore (mm)	85.4
Cylinder Number	4
Compression ratio	16.0
Fuel injection system	Piezo (P_{max}=1,800bar)

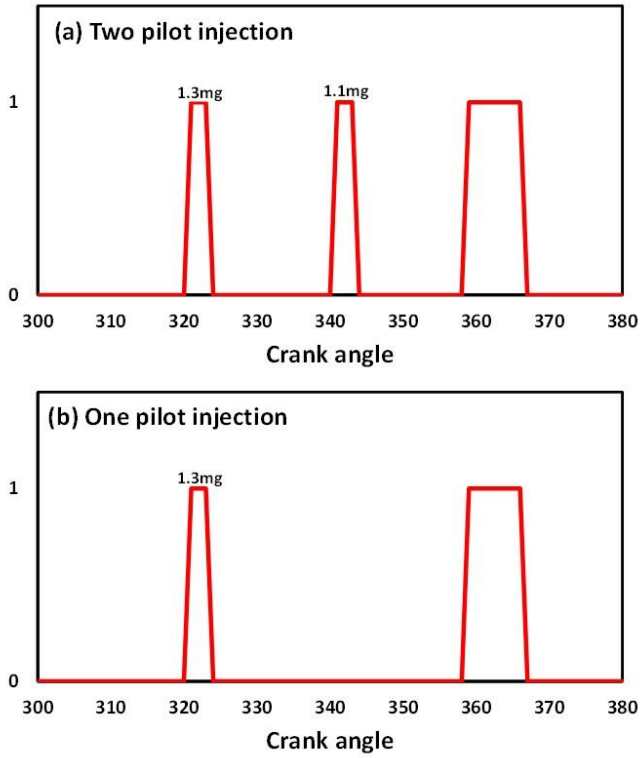

Figure 1. Injection parameters: (a) 2- pilot injections and a main injection, (b) 1-pilot injection and a main injection

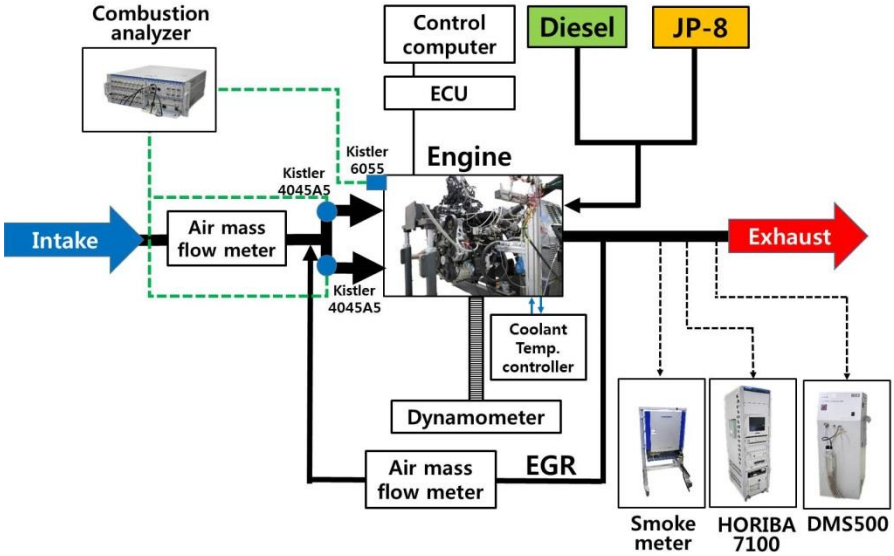

Figure 2. Schematic diagram of experimental setup

2.2 Test Cases Examined

The experiments were performed as following stages:

1. Preliminary diesel fuel combustion tests were performed at the conventional engine operation modes and by adjusting operation conditions of the modes, in order to analyze engine operating characteristics and emission tendencies as the comparison group. All of the preliminary test cases are listed in Table 3.
2. Single injection combustion was tested for investigating engine performance and emission characteristics of CN difference between JP-8 and diesel fuel. And main injection timing was adjusted to maintain the same MFB50 of both fuels, in order to optimize with the single injection strategy.
3. One pilot injection combustion was tested to evaluate the differences of the engine performance and emissions from two pilot injections.
4. In a decision to experiment with the two pilot injection strategy from the above evaluations, JP-8 combustion test were performed at the same cases with diesel combustion test in order to determine optimal JP-8 operation conditions. Tests were adjusted by variation of boost pressure, injection pressure, main injection timing, EGR rates and engine load in order to determine optimal operation conditions of JP-8.

All test cases were measured for many consecutive cycles and the data were calculated as average values.

Table 3. Test cases examined

	1,500rpm / 4bar	2,000rpm / 6bar
Main SOI (BTDC, °)	1.1, 3.1, 5.1	3.2, 5.2, 7.2
Rail Pressure (bar)	528, 628, 728	-
Boost Pressure (bar)	1.04, 1.08, 1.13	-
EGR (%)	27, 30, 32, 33	23, 25, 27, 30
Under bar : Conventional operation condition		

Chapter 3. Results and Discussion

To analyze the effects of fuel's basic properties on fundamental combustion characteristics, both JP-8 and diesel fuel were tested at the conventional operating conditions of the engine (1,500rpm / 4bar / 30% EGR / 1.1 ^{o}BTDC main injection timing). Only the injection parameter was changed from two pilot injection to single injection without pilot.

Figure 3(a) shows the heat release curves of JP-8 and diesel fuel at the conventional operating conditions. Since JP-8 has longer ignition delay due to its lower CN, the heat release rate (HRR) of JP-8 combustion is retarded compared to that of diesel fuel combustion. As shown in figure 3(b), PM and NOx emissions for JP-8 are decreased compared to those of diesel fuel. PM reduction is attributed to prolonged ignition delay and higher volatility of JP-8, which reduces soot formation. Since late auto ignition caused by prolonged ignition delay on the expansion stroke process contributes to lower combustion temperature, NOx emission is also reduced. However, as shown in Figure 3(d), fuel conversion efficiency is decreased due to late start of combustion. In the case of the same MFB50, as illustrated in Figure 3(b), fuel conversion efficiency is slightly increased, while NOx and PM emissions are increased as plotted at Figure 3(b).

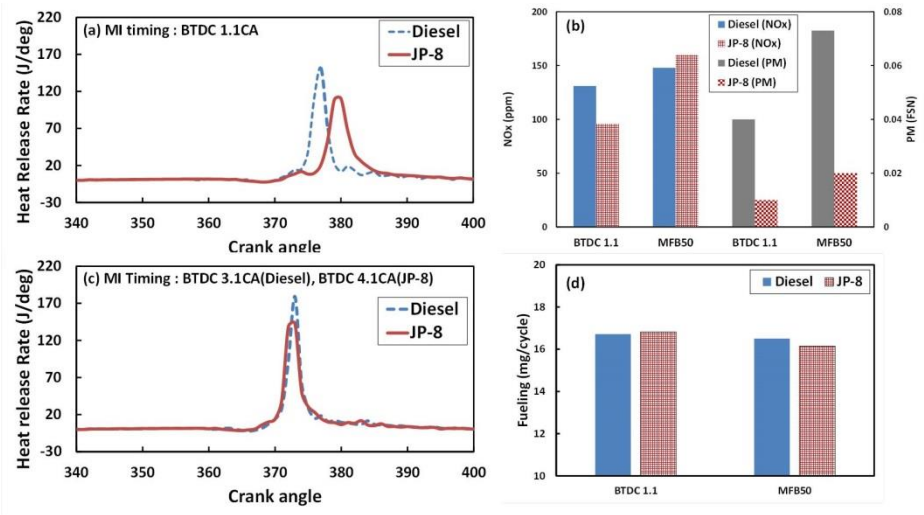

Figure 3. (a) Heat Release Rate for test fuels at the same injection timing (b) NOx and PM emissions for test fuels, (c) Heat Release Rate for test fuels at different injection timings, (d) Fueling rates of the test fuels at the same injection timing and at the same MFB50 values

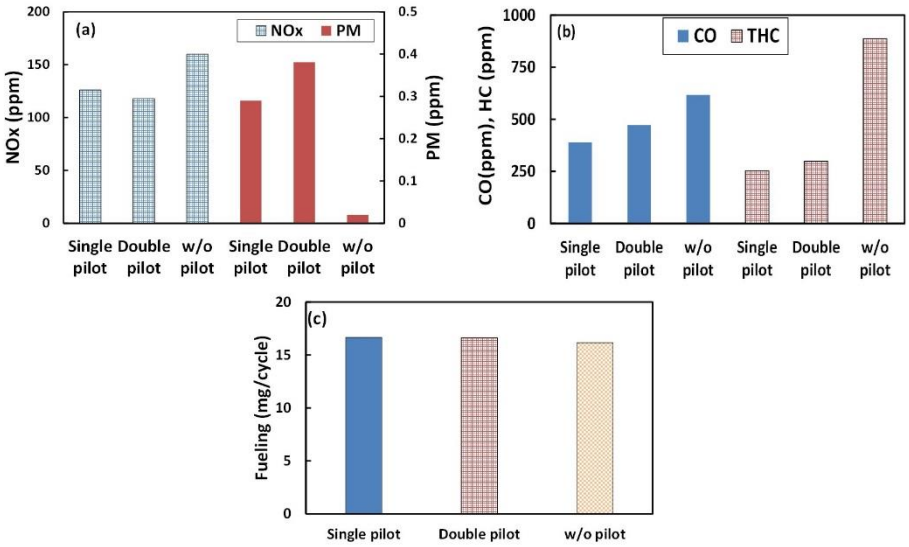

Figure 4. (a) NOx and PM emissions as injection parameter variations, (b) CO and HC emissions as injection parameter variations, (c) Fueling rates as injection parameter variations

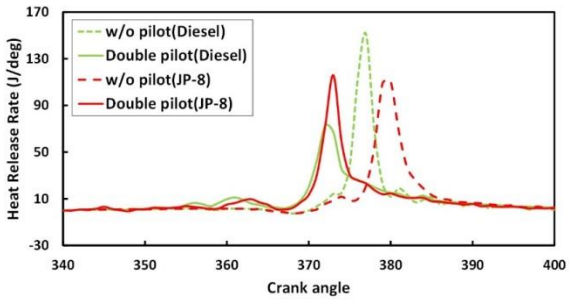

Figure 5. A comparison of Heat Release Rate curves with respect to injection parameter difference

Chapter 3. Results and Discussion

Figure 4(a)-(c) show emission characteristics and fuel conversion efficiencies of two pilot injections, one pilot injection and a single injection without pilot at equal MFB50 values. NOx emission is decreased with the two pilot injection strategy compared to one pilot injection strategy, while PM emission is increased. And there is subtle difference in fuel conversion efficiencies. These results are attributed to better sensitivity to pilot injection for JP-8 as shown in Figure 5. The peak of heat release rate of JP-8 is advanced by 7 CA degrees, while that of diesel fuel is less advanced by 5 CA degrees.

From above results, combustion optimization of JP-8 with two pilot injection strategy was attempted. Figure 6(a)-(d) present the behaviors of NOx and PM emissions over boost pressure variations at the same operating parameters with above conventional conditions. What's unique about NOx emission behavior is reduction of NOx emission for both fuels, when boost pressure is increased. Since NOx emission is reduced in the unit of mass (approximately 29% in g/kWh) as well as in the unit of concentration (approximately 32% in ppm), increase of oxygen concentration as the boost pressure increases is not the main reason of them. Even if NOx concentration reduction is affected by increase in air fraction, mass reduction means actual decrease in NOx emission. In the case of diesel fuel, this is attributed to ignition delay reduction caused by air concentration increase of in-cylinder with respect to boost pressure increasing. Therefore, combustion temperature is lowered. PM emission increment is also explained with the same reason. However, in the case of JP-8, the reason is different from that of diesel fuel.

It is likely due to the increment in A/F ratio caused by boost pressure increasing. The more air concentration is increased, the leaner the charge of in-cylinder. Since the extra air absorb released heat as buffer, in-cylinder temperature is lowered. Therefore, NOx formation is reduced along with low combustion temperature. Meanwhile, as a result of lower combustion temperature, PM emission is increased due to PM oxidation rates reduction. CO emissions for both fuels are almost equal and slightly increased with boost pressure increasing as shown in Figure 7(a). Although subtle differences are shown in fuel conversion efficiencies (Figure 7(c)) and HC emissions (Figure 7(b), the differences are in measurement error ranges.

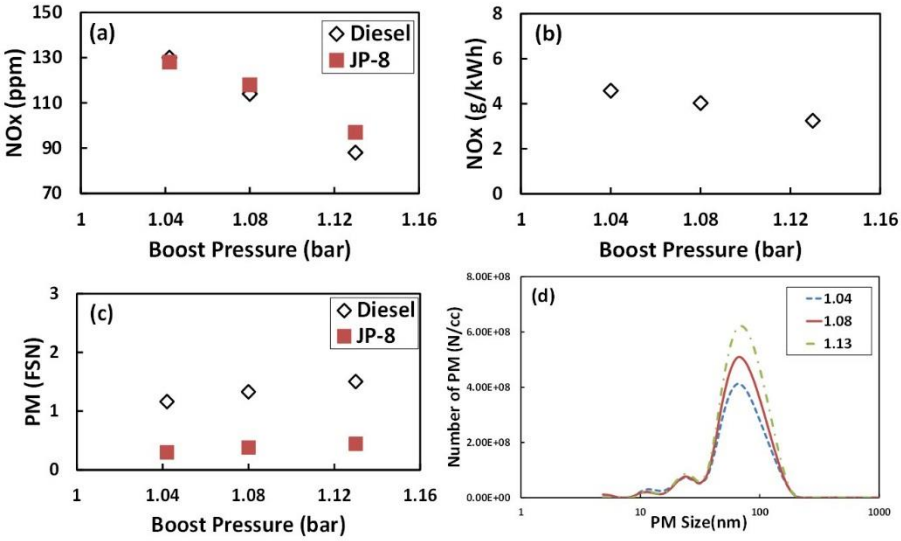

Figure 6. NOx and PM emission behaviors over boost pressure variations: (a)NOx emission behaviors in ppm, (b) NOx emission behaviors in g/kWh, (c) PM emission measured via smoke meter, (d) PM emission measured via DMS

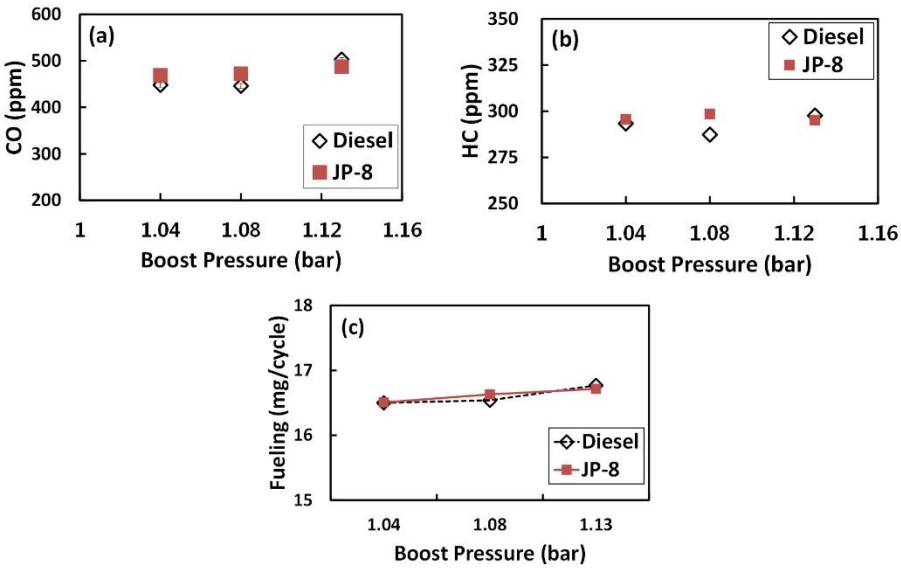

Figure 7. (a) CO emission behaviors, (b) HC emission behaviors, (c) Fueling rates as boost pressure variations

Chapter 3. Results and Discussion

Figure 8(a)-(d) shows emission characteristics as injection pressure increasing at 1,500 rpm and 4 bar bmep. NOx emission is increased due to rapid air-fuel mixing rate caused by higher injection pressure. Thus, PM emission is decreased due to shorter ignition delay. PM emission reduction rate of JP-8 is low, as well as its number is considerably low, while that of diesel fuel is high. This demonstrates that JP-8 is less sensitive to injection pressure than diesel fuel due to its lower CN. Combustion efficiencies for both fuels are to be deteriorated along with increase in the injection pressure. CO and HC emissions of diesel fuel are gradually decreased as the injection pressure increases, whereas those of JP-8 are not that significant.

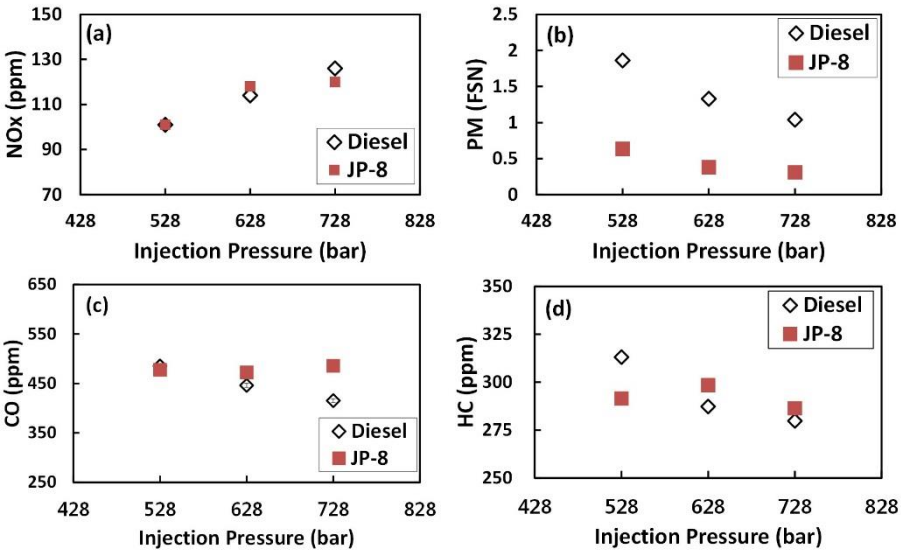

Figure 8. Emission characteristics as injection pressure variations: (a) NOx, (b) PM, (c) CO, (d) HC

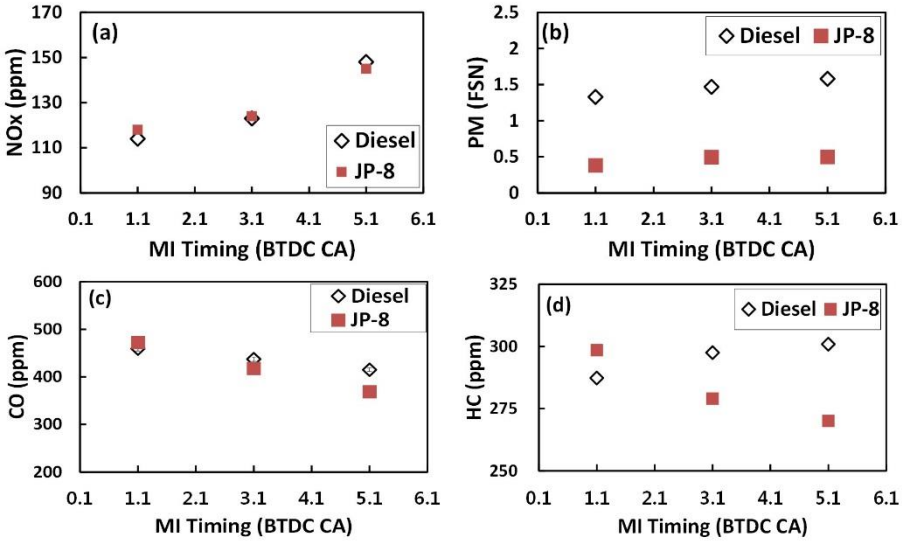

Figure 9. Emission characteristics as main injection timing variations at 1,500rpm / 4bar: (a) NOx, (b) PM, (c) CO, (d) HC

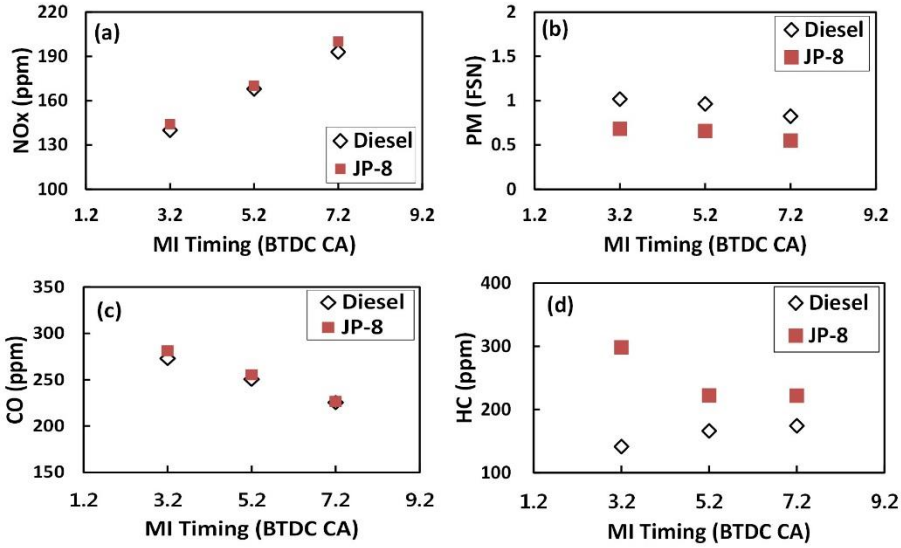

Figure 10. Emission characteristics as main injection timing variations at 2,000rpm / 6bar: (a) NOx, (b) PM, (c) CO, (d) HC

Chapter 3. Results and Discussion

Figure 9(a)-(d) depicts emission characteristics at 1,500 rpm and 4 bar bmep with variation of main injection timing. And Figure 10(a)-(d) shows the same kind of trend at 2,000 rpm and 6 bar bmep. The peak of heat release rate is advanced significantly with advanced main injection timing, while ignition delay is quite similar between two fuels. Since in-cylinder temperature is low at the earlier timing from TDC, fuel-air mixing is better to form the homogeneous mixture at that condition. Therefore, NOx emissions are increased as the main injection timing is advanced, and the amount of the emissions are almost the same. PM emission is also increased along with advanced injection timing. And PM emission of JP-8 is considerably lower than that of diesel fuel and nearly not affected by main injection timing. Fuel conversion efficiency is improved as the main injection timing is advanced due to extension of time for fuel-air mixing. CO emissions of both fuels are reduced with advanced injection timing. However, HC emissions of JP-8 and diesel fuel show opposite tendency, respectively. HC emission of JP-8 is reduced as injection timing is advanced, while that of diesel fuel is increased. According to the previous research [9], direct injection compression ignition engines have primary two reasons for forming HC. Over-lean mixture and rich mixture caused by sac volume are the reasons. In the case of injection timing variation with constant engine speed and constant sac volume, HC is primarily formed by over-lean regions. From the review of the previous research, HC emission of diesel fuel is likely due to over-lean mixture with regard to advanced injection timing. By the way, HC emission graph of JP-8 is likely due to decreased over-rich

regions with respect to advanced injection timing. Fuel conversion efficiencies of the fuels are almost equal in an error range of measurement devices and curves of them decline gradually with advanced injection timing. This indicates that fuel conversion efficiency is better at earlier injection timing. At 2,000 rpm and 6 bar bmep, the emission behavior and efficiency variation are quite similar to characteristics of 1,500 rpm and 4 bar bmep, as shown in Figure 10(a)-(d).

According to Heywood [10], Exhaust Gas Recirculation is used to reduce NOx emission by recirculating a portion of exhaust back to cylinders. EGR reduces flame temperature by increasing heat capacity of fuel-air mixture. Since NOx is formed primarily at high temperature, lower cylinder temperature caused by EGR reduces the amount of NOx formation. However, PM emission is increased due to reducing oxygen concentration and burnt gas temperature in the cylinder. The trade-off between NOx and PM is well known and the state of the art combustion strategies try to move the combustion curves to the lower left corner.

Figure 11(a)-(d) shows emission characteristics as a function of EGR variations at 1,500 rpm engine speed and 4 bar engine load at the same MFB50. NOx emission is reduced significantly with EGR rate increment, whereas PM emission is increased contrastively. However, the PM emission curve of JP-8 is inclined gently compared to that of diesel fuel due to its faster evaporation and longer ignition delay. CO and HC emission curves of both JP-8 and diesel fuel have similar tendencies, which are increased with increasing EGR rates. This is because lower oxygen concentration caused by

EGR results in rich fuel-air mixtures. This heterogeneous mixture does not combust completely and attributes to higher HC and CO emissions. Figure 12(a)-(d) shows emission characteristics of the same operation condition with above EGR variation case, except for engine speed and engine load as 2,000 rpm and 4 bar bmep. The results show almost the similar tendencies, more or less, between two operating conditions. Figure 13(a)-(d) shows fuel conversion efficiencies and total heat release for the fuels at both 1,500 rpm /4 bar and 2,000 rpm / 6 bar conditions. Fuel conversion efficiencies for both fuels are deteriorated with EGR rates increasing. However, as shown in Figure 13(d), fuel conversion efficiency for JP-8 is slightly lower than that of diesel fuel at 2,000 rpm / 4 bar condition.

The trade-off curves between NOx and PM of 1,500rpm / 4bar and 2,000rpm / 6bar are illustrated in Figure 14(a) and Figure 14(b), respectively. NOx-PM trade-off curve for JP-8 is moved toward lower side in both cases. That is, compared to diesel fuel, NOx-PM simultaneous reduction would be achieved when EGR rate is increased at 1,500 rpm/4 bar condition. In the 2,000 rpm/6 bar condition, NOx reduction can be achieved along with EGR rate increasing from 25% to 27%, with the same PM emission level of diesel fuel.

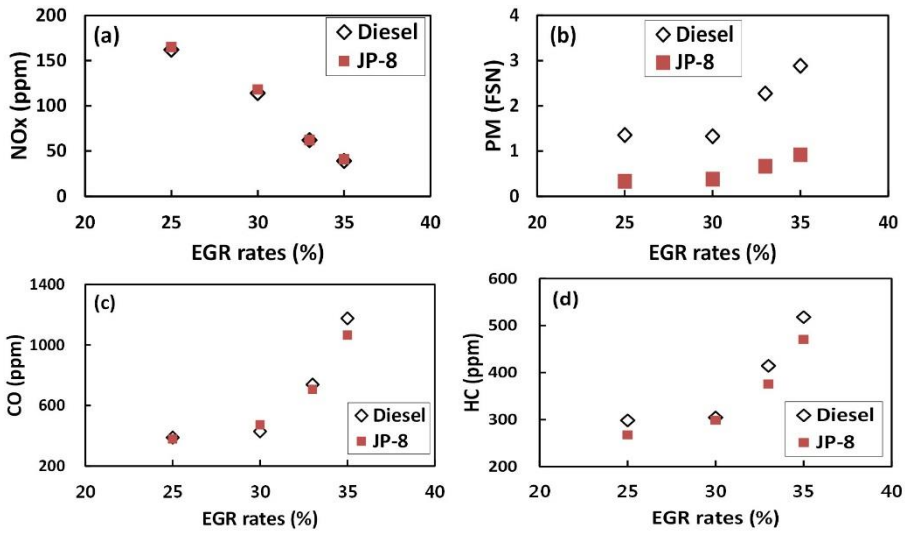

Figure 11. Emission characteristics as EGR rate variations at 1,500rpm / 4bar: (a) NOx, (b) PM, (c) CO, (d) HC

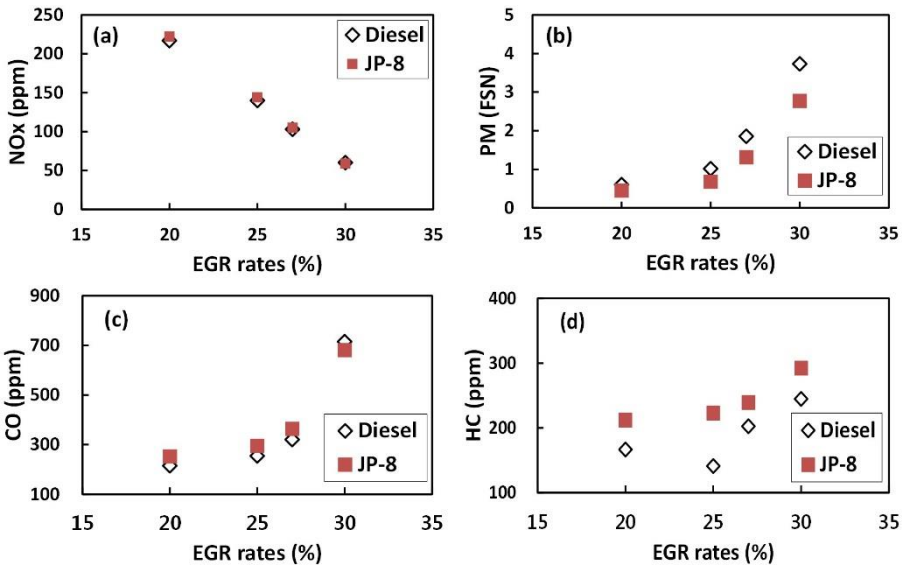

Figure 12. Emission characteristics as EGR rate variations at 2,000rpm / 6bar: (a) NOx, (b) PM, (c) CO, (d) HC

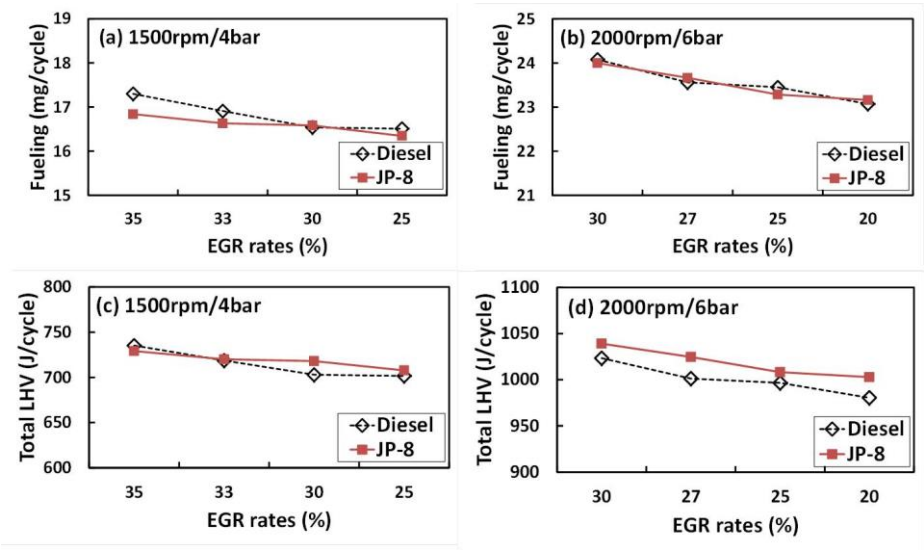

Figure 13. Fueling rates at (a) 1,500rpm / 4bar, (b) 2,000rpm / 6bar and Total LHV at (c) 1,500rpm / 4bar, (d) 2,000rpm / 6bar

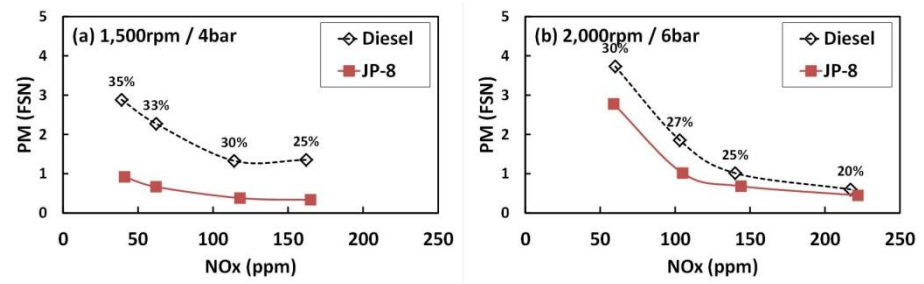

Figure 14. NOx-PM trade-off curves for (a) 1,500rpm /4bar, (b) 2,000rpm / 6bar

Chapter 4. Conclusions

To evaluate the possibility of combustion optimization for JP-8, experimental study was conducted by investigating the effects of JP-8's basic properties on combustion characteristics. Both diesel fuel and JP-8 were tested at conventional operating conditions without pilot injection to analyze the effects of fuel's basic properties on fundamental combustion characteristics. Then, the injection parameters were set to one pilot injection and two pilot injections by turns, to determine which injection method is better for JP-8 combustion. As a result of the preliminary tests, two pilot injection which is the original injection mode of the engine was confirmed as the most suitable injection mode. Therefore, experiments were conducted as controlling the following parameters with that injection mode.

1. As a result of experiments with boost pressure variation, NOx emission is decreased and PM emission is increased for both fuels. Both CO emission is almost the same level and slightly increases as boost pressure increasing, while HC emission is not affected by boost pressure variation. Fuel conversion efficiencies for both fuels are slightly decreased or also not affected by boost pressure.
2. As injection pressure is increased, NOx emission for both fuel are considerably increased and PM emission is decreased. PM emission of JP-8 is much lower and declined gradually than that of diesel fuel. CO and HC emissions of diesel fuel are gradually decreased as

injection pressure increasing, whereas those of JP-8 are not that significant.

3. Both NOx and PM emissions are increased as main injection timing is advanced. CO emissions for the fuels are reduced and JP-8 emits more. However, HC emissions of JP-8 and diesel fuel show opposite tendencies respectively. HC emission of JP-8 is reduced but that of diesel fuel is increased with respect to advanced injection timing.
4. NOx emissions are reduced significantly with EGR rates increasing, whereas PM emission is increased. However, the PM emission curve of JP-8 is inclined gently compared to that of diesel fuel. CO and HC emissions for both fuels are increased with increasing EGR rates. Fuel conversion efficiencies for both fuels are maintained at similar level of values.

Generally, JP-8 has considerable effects on PM reduction compared to diesel fuel at the same level of fuel conversion efficiencies and NOx emission. The NOx-PM trade-off curve for JP-8 is moved toward lower side. This means that NOx-PM simultaneous reduction would be achieved by adding more EGR to JP-8 combustion. Although fuel conversion efficiency is slightly worsen in this case, NOx-PM simultaneous reduction is possible with parameter control.

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초 록

최근의 많은 연구들은 갈수록 강화되는 배기규제 기준을 충족시키기 위하여 압축착화 엔진에 최신의 연소전략을 적용시킴으로써 대기오염 물질 배출량을 줄이고 효율을 향상시키는 것을 목표로 하고 있다. 그 중에서, 균일 급기 압축착화(HCCI) 방식은 질소산화물(NOx)과 입자상물질(PM)의 동시저감을 위해 공기-연료 혼합기를 균일하게 섞는다. 디젤-가솔린 혼소연소 또한 디젤유의 점화지연을 연장함으로써 NOx와 PM을 동시에 저감한다. 하지만 HCCI와 혼소연소는 몇 가지 치명적인 단점을 가지고 있다. 반면, 압축착화 엔진에서의 JP-8 제트연료 연소는 HCCI와 혼소연소의 단점을 극복하면서 균일한 혼합기를 생성하기 때문에 NOx와 PM을 동시에 저감하는 효율적인 방법 중의 하나로 연구되어왔다. JP-8 제트연료는 디젤유에 비해 세탄가가 낮기 때문에 높은 휘발성과 낮은 점도에도 불구하고 점화지연이 길다. 물론 JP-8이 NATO 국가들의 단일 연료 개념(SFC) 채용에 따라 충분한 연구를 거쳐 군사용 항공기 뿐만 아니라 차량에도 사용되고 있지만, 연료의 연소과정에 대한 이해를 위해서는 더 많은 연구가 필요한 실정이다. 따라서 본 연구에서는 이중 파일럿 분사방식을 사용하는 상용 4기통 엔진을 활용하여 JP-8 제트연료와 디젤유를 연소시키는 실험을 진행하였다. 그리고 토크 컨트롤을 통해 디젤유와 JP-8 제트연료 연소의 출력을 동일하게 한 상태에서 부스트압, 분사압, 분사시기, EGR율 변화가 연소와 배기특성에 미치는 영향을 파악하여 압축착화 엔진에서의 JP-8 제트연료 연소 최적화를 위한 연구를 진행하였다. 실험결과 JP-8 제트연료는 디젤유에 비해 높은 세탄가로 인해 점화지연이 길다는 것을 제외하고는 디젤연료와 비슷한 연소특성을 보였다. 하지만 길어진 점화지연과 높은 휘발성 때문에 동등 연료변환효율과 NOx 배출수준에서 PM 배출량이 크게 감소하는 것을 확인하였다.

더욱이, JP-8 제트연료 연소시 EGR율을 디젤유 연소시보다 증가시키면 NOx와 PM을 동시에 저감시킬 수 있다는 것을 확인하였다.