

Diesel Engine Emissions and Performance Optimization for Neat GTL Fuel

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ABSTRACT

The emissions reduction potential of neat GTL (Gas to Liquids: Fischer-Tropsch synthetic gas-oil derived from natural gas) fuels has been preliminarily evaluated by three different latest-generation diesel engines with different displacements. In addition, differences in combustion phenomena between the GTL fuels and baseline diesel fuel have been observed by means of a single cylinder engine with optical access. From these findings, one of the engines has been modified to improve both exhaust emissions and fuel consumption simultaneously, assuming the use of neat GTL fuels. The conversion efficiency of the NO_x (oxides of nitrogen) reduction catalyst has also been improved. The desirable properties of GTL fuels for diesel combustion, namely high Cetane number and absence of PAH (Poly-Aromatic Hydrocarbons) contents have been fully utilized to enhance the conventional diesel combustion limits to show the possibility to meet the anticipated future emission regulations without any deterioration of fuel economy. The results of this study indicate not only the superior emission characteristics of the GTL fuels, but also evidence that higher EGR (Exhaust Gas Recirculation) and lower excess air ratio will be a key concept of both engine and aftertreatment optimization.

INTRODUCTION

GTL fuels have many advantages as an alternative cleaner diesel fuel. Higher Cetane number and the absence of PAH content, which are the principal properties of GTL fuels, have potential to reduce Particulate Matter (PM) emissions. This distinguishing

characteristic has a potential to reduce NO_x emissions by increasing the EGR ratio without any smoke penalty. Furthermore, the absence of sulfur content will result not only in a PM emissions reduction, but also, in the case of NO_x adsorber catalyst use, in a fuel consumption improvement by reducing the desulfurization process frequency due to the reduction of deterioration of the aftertreatment catalyst. For the above mentioned reasons, GTL fuels have been expected to have a potential to achieve low emissions without any major engine modifications [1-5]. On the other hand, fuel densities of GTL fuels are generally several percents lower than diesel fuel resulting in the deterioration of the volumetric fuel consumption in comparison with the conventional diesel fuel. Most previous researches has not discussed the way to improve both volumetric fuel consumption and exhaust emissions simultaneously with some engine modifications [6-7].

Since the total amount of GTL fuels will not drastically increase in the near future, the use as a blend fuel will be one of the likely short-term strategies to penetrate into the market. In that case, there is no need to consider the deterioration of the volumetric fuel consumption in exchange for the most low-emissions potential of the neat GTL fuels [8]. However, if engines are optimized to adapt to the distinctive specifications of the neat GTL fuel, assuming its use in restricted (urban) areas, there could be a possibility to improve not only exhaust emissions, but also fuel consumption.

This study has two purposes resulting from better understanding of the GTL fuel combustion characteristics. One is to clarify the combustion and emissions characteristics of the GTL fuels by means of

three diesel engines with different engine displacement. And the other is to optimize the four-liter engine hardware specifications and engine control parameters assuming the use of neat GTL fuel. The target of this study was to achieve half of the maximum emission levels of the current Japanese New-Long-Term Regulations (1.0g/kWh of NO_x, 0.0135g/kWh of PM) while maintaining the same volumetric fuel consumption as the base diesel fuelled engine.

COMBUSTION AND EMISSIONS CHARACTERISTICS OF THE GTL FUELS

Three different GTL research fuels were prepared to analyze not only the difference between the GTL fuel and the conventional diesel fuel, but also the effects of the GTL fuel properties. In this preliminary test, three engines were used to confirm the generality of the results. These are direct-injection turbocharged-and-aftercooled diesel engines equipped with an electronically controlled high pressure common-rail fuel injection system and the High Pressure Loop (HPL) cooled EGR system, which are the most common emission reduction strategies in the world.

Table 1. Fuel specifications

Fuel	Test Method	JIS#2	FUEL A	FUEL B	FUEL C
Density @15°C kg/m ³	JIS-K-2249	834	785	779	758
Distillation °C	JIS-K-2254				
IBP		166	209	199	156
10%		217	244	227	171
50%		286	295	270	204
90%		339	341	312	302
FBP		360	358	324	320
Cetane Number	JIS-K-2280	54	78	78	69
Cetane Index	JIS-K-2280	56.9	89.9	85.2	65.5
Viscosity @40°C cSt	JIS-K-2283	3.926	4.441	3.331	1.773
Pour Point °C	JIS-K-2269	-12.5	-2.5	-20	-50
Lower Calorific Value MJ/kg	JIS-K-2279	43.0	43.5	43.6	43.8
Sulphur %weight	JIS-K-2541	6	<1	<1	<1
Aromatics %weight					
Mono		15.8	-	-	-
Di		1.9	-	-	-
Tri		0.2	-	-	-
Total		17.9	-	-	-

TEST CONDITIONS

The GTL research fuel and the reference diesel fuel properties used for the test are shown in Table 1. JIS#2 is the reference diesel fuel with typical specifications of diesel currently sold and consumed in Japan. The GTL fuels, named FUEL A, FUEL B, and FUEL C are the neat synthetic diesel fuels made from natural gas by means of the Fischer-Tropsch method [9]. These fuels

are designed to improve fuel spray volatility by changing the distillation characteristics while maintaining the high Cetane number to be above seventy. It is generally known that higher fuel volatility will enhance the air-fuel mixture formation resulting in the soot emissions reduction [10]. The ninety percent distilled temperature (T90) of FUEL A was almost the same as JIS#2 fuel. T90 of FUEL B was about 30 degrees lower than FUEL A. Although the T90 difference between FUEL B and FUEL C was only about 10 degrees, the lower percent distilled temperature of FUEL C was about 70 degrees lower than FUEL B. More detailed distillation curves for each fuel are compared in Figure 1. As shown in this figure, all the distillation temperature properties of GTL fuels were almost within the reference diesel fuel property.

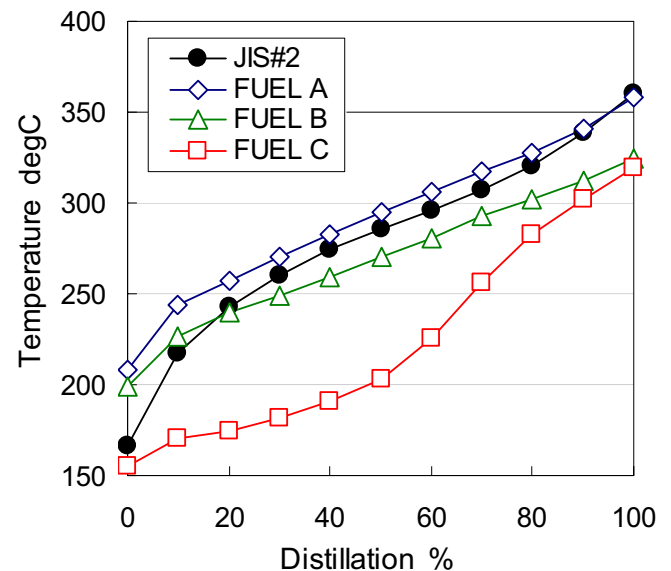


Figure 1. Comparison of distillation curve for the fuels

Three multi-cylinder engines having different displacement (2, 4 and 8 liters, named as 2L, 4L and 8L) were used in this study. Detailed specifications of the engines are shown in Table 2. The 2L engine conforms to the EURO 4 emission standards for passenger cars. The 4L and 8L engines conform to the Japanese New-Short-Term emission standards. Exhaust aftertreatment systems were used only in the transient emission tests. As for the exhaust aftertreatment systems, the 2L and 4L engines were equipped with Diesel Particulate-NO_x Reduction systems (DPNR) [11-12]. A Diesel Particulate active Reduction system (DPR: the same function as Oxidation catalyst + catalyzed DPF) [13] was originally fitted to the 8L engine, and was replaced by the combination of DPR and NO_x Storage Reduction (NSR) catalyst to execute the same function as DPNR.

Table 2. Engine and Aftertreatment system specifications

Engine	2L	4L	8L	Transparent Engine
Emissions Standard	Euro4	New Short Term Regulation 8-Capital Pref. Ultra-Low Emission Vehicle	New Short Term Regulation Re-Calibrated close to New Long Term NOx level	-
Engine Type	DI, Inline 4-cylinder	DI, Inline 4-cylinder	DI, Inline 6-cylinder	DI, Single cylinder (bottom-view)
Displacement	1.995 Liter	4.009 Liter	7.684 Liter	2.147 Liter
Bore x Stroke	82.2 x 94 mm	104 x 118 mm	112 x 130mm	135 x 150mm
Compression Ratio	18.2 : 1	18.0 : 1	18.0 : 1	16.5 : 1
Injection	Common Rail	Common Rail	Common Rail	Common Rail
Aspiration	TCA	TCA	TCA	External
EGR System	HPL Cooled	HPL Cooled	HPL Cooled	N2 and CO2 gases
Aftertreatment System	DPNR	DPNR	DPR (+ NSR)	-

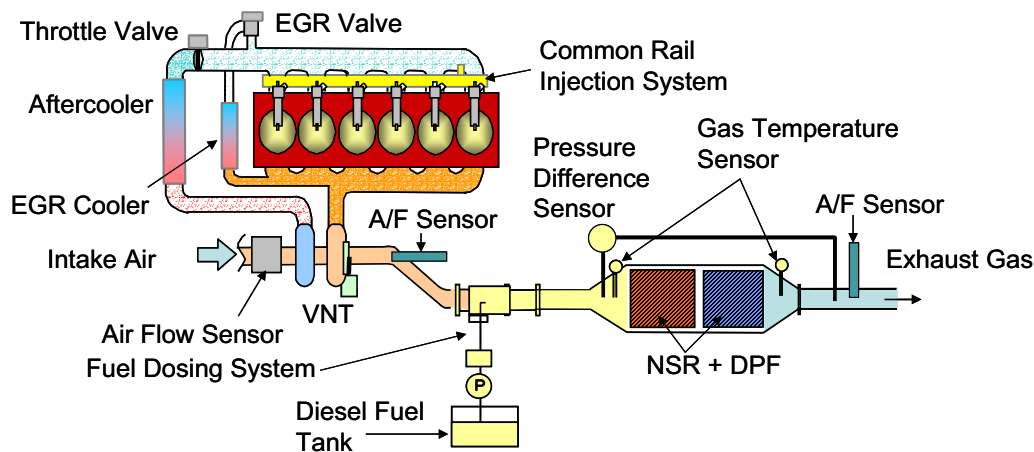


Figure 2. Engine and Exhaust Aftertreatment Schematics (8L engine)

Figure 2 shows the schematics of the 8L engine and exhaust aftertreatment system as an example. The other engines have the same EGR - air boost circuits and aftertreatment system (only the catalysts were replaced by DPNR).

In addition, a single cylinder engine with optical access from the bottom of the combustion chamber is used for the observation of combustion phenomena by means of a high-speed video camera. The engine was also equipped with the common-rail injection system. Boost pressure was controlled by the external compressed air supply, and CO₂ and N₂ gases were introduced into intake manifold as a substitute of EGR gas.

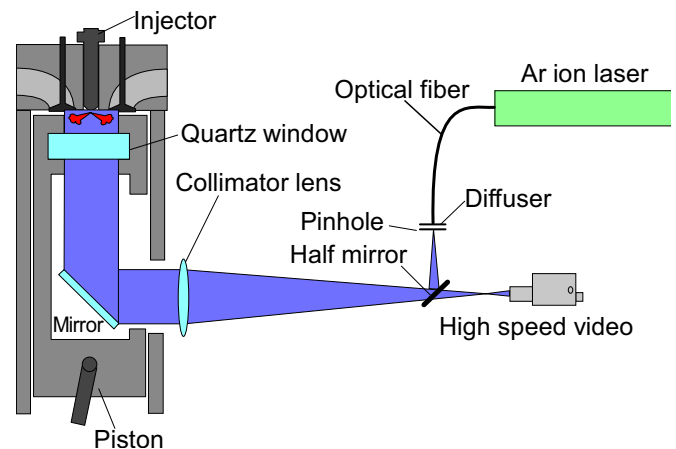


Figure 3. Schematics of combustion visualization system by means of the single cylinder engine with optical access (bottom view)

The schematics of the combustion observation system are shown in Figure 3. The laser shadow graph was used for the analysis of the unburned fuel spray structure. Furthermore, the ignition points and the growth of the luminous flame (soot oxidation region) are also observed from the images. An Argon-ion laser was employed with the laser shadow graph as an illuminant. The frame speed of the high speed video camera was 10,000 [fps] (frame per second). The combustion chamber is of a pancake type with a quartz glass window in the bottom.

STEADY-STATE TEST

GTL fuels and JIS#2 fuel were evaluated to clarify the effects of the GTL fuel properties on engine performance such as torque, power, fuel consumption and exhaust emissions characteristics of the three multi-cylinder engines under steady-state conditions. The engine calibration data were not modified for each fuel for the test.

Figure 4 shows the comparison of the full load engine performance test results for the three neat GTL fuels and JIS#2 fuel in each engine (only with the 8L engine, FUEL A was not evaluated). The result shows a 2 to 5 percent decrease in the maximum power output and 4 to 7 percent decrease in the peak torque with the GTL fuels. This tendency is obvious considering the effect of lower density fuels. Since the neat GTL fuels have different density, viscosity, and lower calorific value to a JIS#2 fuel, it is necessary to calibrate the ECU maps to compensate the engine performance for these differences between the fuels.

Figure 5 shows the comparisons of the partial load emissions and the fuel consumption in the middle engine speed for each engine. It is obvious that there weren't any effects on the NO_x emissions with different fuels. Only in the case of the 2L engine under highest load,

there was slight increase of NO_x emissions with FUEL C, caused by the difference in fuel density. Since the engine control system estimates the engine load condition from the volume of injected fuel, it will overestimate the engine load in the case of GTL fuels. So, the engine control parameters, that have an effect on the emission characteristics, fuel injection parameters, EGR valve set position, and etc. were not properly chosen from the calibration map on engine speed and load conditions. Regarding the comparison of fuel consumption figures, the brake specific energy consumption (BSEC [MJ/kWh], the same meaning as break thermal efficiency), was selected to take into account the difference of both fuel density and lower calorific value. This figure shows that there was no significant difference in the energy consumption ratio between the fuels including in JIS#2 fuel. On the other hand, Smoke emissions were obviously reduced with the GTL fuels, with FUEL C in particular reduction of more than fifty percent in comparison with JIS#2 fuel was observed in all the engines. However, FUEL A did not have significant effect on the Smoke emissions in the 4L engine, especially under low load conditions. It is assumed that the unsuitable burned gas distribution by the higher pilot fuel quantity with the 4L engine and by the higher viscosity of FUEL A will cause the deterioration of Smoke emissions. HC emissions were also decreased with the GTL fuels except for FUEL C. The 4L and 8L engines emitted the same or slightly higher HC than JIS#2 fuel, even though FUEL C has the higher Cetane number. As shown in this figure, the relative characteristics of each fuel on Smoke and HC emissions were almost the same in the engines. However there were slight differences in emissions trends for the engine loads (BMEP) between the engines. It will be partly caused by the difference in the in-cylinder temperature conditions. In addition, it should be noted that all the engines used pilot injection to reduce combustion noise in most operating conditions. The pilot injection parameters (timing and quantity) of each engine should also result in the different emissions trend.

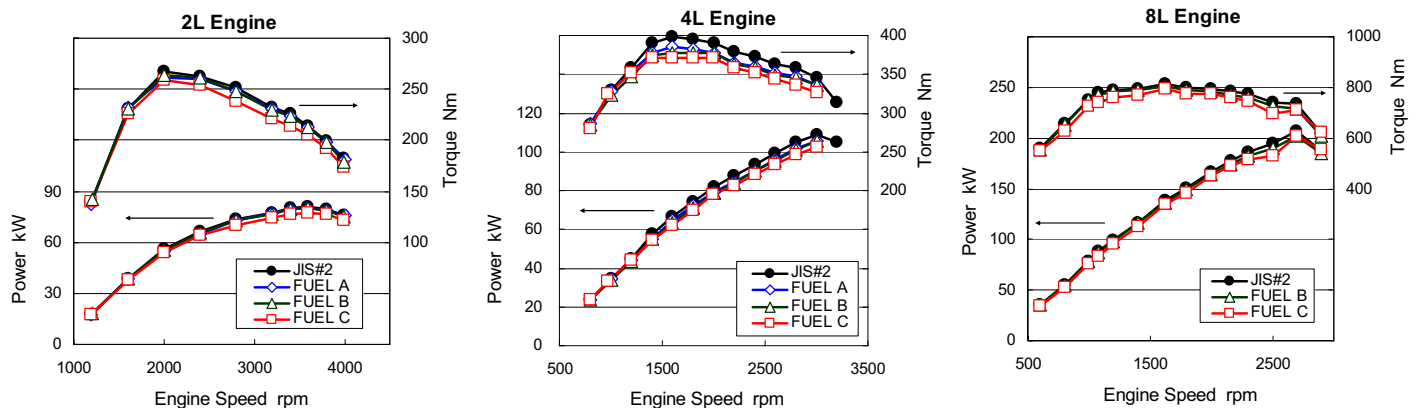


Figure 4. Comparisons of full load engine performance with different fuels

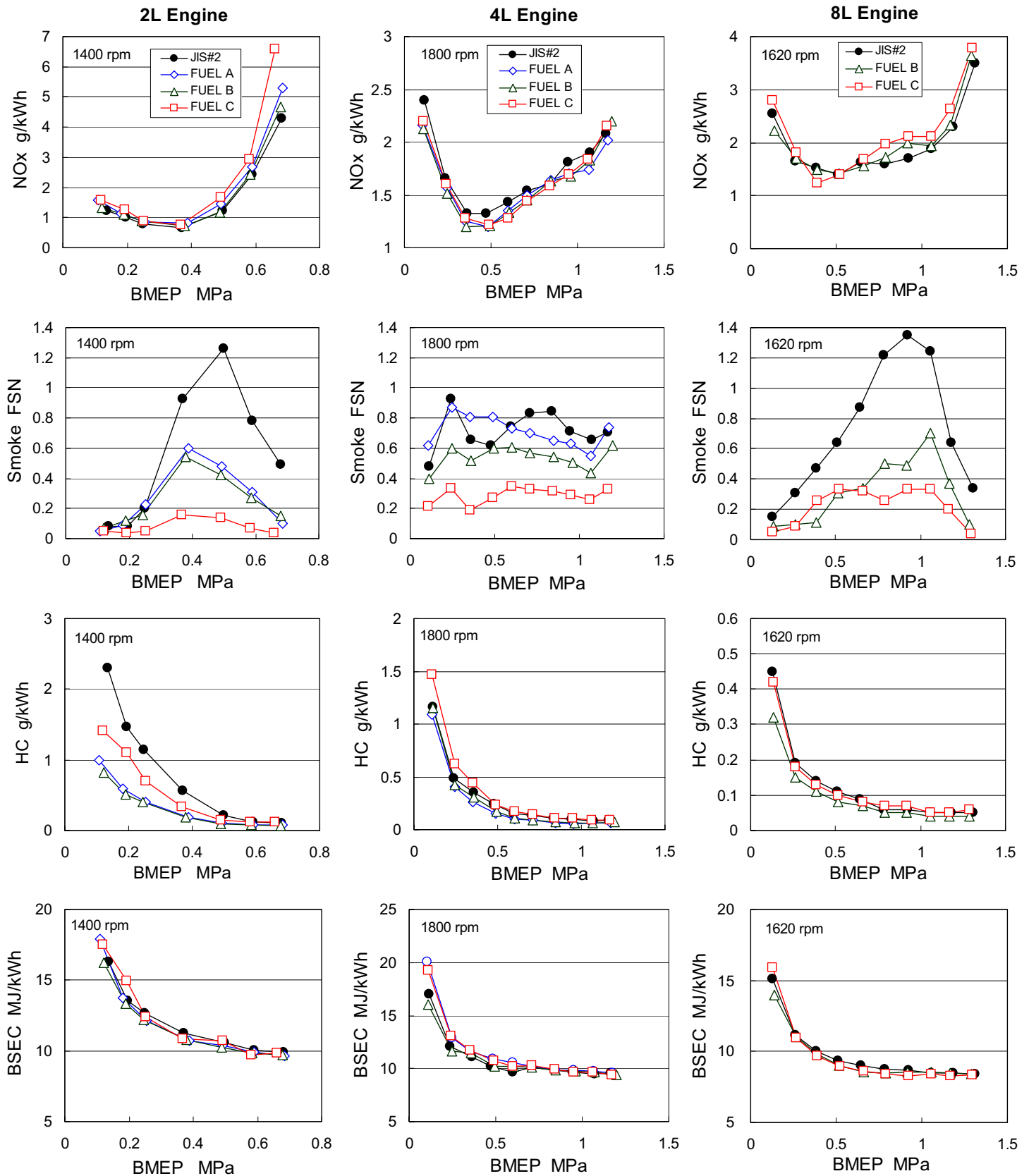


Figure 5. Comparisons of emissions and break specific energy consumption under middle speed and partial load condition with different fuels (with pilot injection)