Fuel Effects on Diesel-Based Advanced Combustion Regimes

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Objectives

- Determine the impact of cetane rating on the ability for petroleum-based fuels to transition from normal to advanced combustion regimes.
- Determine the whether biodiesel behaves differently than petroleum-based fuels when entering advanced combustion regimes.

Approach

- Utilize a Mercedes 1.7L diesel engine at ORNL as a test platform to support this research.
- Using production-like hardware and control strategies, transition the engine from normal to advanced combustion.
- Characterize the performance and emissions from the engine when using several petroleum-based fuels and biodiesel.
- Analyze the resulting data to determine fuels impacts on advanced combustion regimes.

Accomplishments

- Showed that 3 petroleum-based fuels exhibited similar transitions into advanced combustion regimes.
- Showed that soybean-based 100% biodiesel did not exhibit a transition into advanced combustion.
- Showed that PM and NO_X emissions at a given EGR level increased (even in advanced combustion regimes) as the cetane rating of the fuel increased.

Future Directions

- For fiscal year 2005, evaluate biodiesel blends and additives (such as tripropylene glycol monomethyl ether) as a means of increasing the oxygen content of petroleum-based fuels to determine the impact of fuel oxygen content on advanced combustion regimes.

Introduction

Diesel-based advanced combustion regimes are combustion regimes that result in much lower NO_X and PM emissions than traditional combustion processes. They can generally be achieved by reducing the quantity of fuel that burns in a hot diffusion flame. Most methods focus on reducing the diffusion burn by increasing the amount of fuel burned in a pre-mixed combustion event. This type of combustion generally does not lead to the formation of problematic pollutants. Formation of a fuel-lean, pre-mixed region inside the fuel jet may be influenced by several fuel properties, including the oxygen content, viscosity, and boiling range. Initiation of combustion inside such a region may also be influenced by fuel properties such as the cetane rating. Hence, there may be opportunities for tailoring the fuel properties in a way that results in increasing the operating envelope where advanced combustion can be utilized reliably. This may be realized either through fuel reformulation or through the use of additives.

Approach

A Mercedes 1.7-liter diesel engine at ORNL was utilized for this study. The engine was fueled with three hydrocarbon fuels plus a soybean-based biodiesel fuel. The three petroleum-based fuels were: California Air Resources Board (CARB) certification diesel fuel, U.S. Environmental Protection Agency (EPA) certification diesel fuel, and Arco ECD1 diesel fuel. The two certification fuels are currently-available fuels. The ECD1 diesel fuel is a low-sulfur, full-boiling range diesel fuel that is similar to what might be in the marketplace in 2007.

The engine utilized only production-like hardware to achieve advanced combustion. The emissions and efficiency of the engine were studied at a well-characterized operating condition (1,500 RPM, 26 ft-lbs) that is typical for a highway-cruise driving scenario. The exhaust gas recirculation (EGR) rate was increased to reduce in-cylinder O_2 levels until the engine entered an advanced combustion regime. The fuel injection strategy (timing, number of injections, duration, fuel rail pressure) remained constant for the EGR sweeps for each fuel. The overall fueling rate was different based on the energy content of each fuel. The fueling rate was governed by holding the engine brake output and speed constant for all 4 fuels, producing slightly different fuel injection durations for each fuel.

Results

The three petroleum-based fuels (ECD1, CARB, CERT) behaved very similarly, exhibiting a transition from normal to advanced combustion at an EGR level of approximately 47%. This EGR level resulted in in-cylinder bulk O_2 concentrations of approximately 13-14%. B100 did not exhibit a transition into advanced combustion during this study. This is somewhat surprising because increasing the fuel oxygen content is believed to be one means of aiding in establishing a lean pre-mixed region in the fuel jet. It is possible that other physical properties of the B100 fuel were offsetting this benefit.

The PM emissions of these three petroleum-based fuels were generally increased as the cetane rating of the fuel increased (from 46 to 62). Similar results were observed in the NO_X emissions as EGR was increased. B100 had the lowest PM emissions, though it had a cetane rating that fell between the CARB and CERT fuels. This is probably due to the high (~11%) oxygen content of the B100 fuel. NO_X and PM emissions from all 4 fuels are shown in Figure 1. The ECD1 fuel had the highest cetane of the 4 fuels and exhibited the highest PM emissions. The PM emissions for ECD1 were also considerably higher than the other fuels even as the fuel passed the onset of advanced combustion. ECD1 fuel produced PM emissions equivalent to the other fuels, but at higher EGR levels (Figure 2). This suggests that the higher fuel ignitability associated with higher cetane rating may require reducing the in-cylinder oxygen content further than for lower cetane fuels for equivalent emissions performance.

Hydrocarbon and carbon monoxide emissions were noted to increase as EGR was increased for all 4 fuels. A fuel economy penalty associated with non-optimized combustion and operation at high EGR levels was observed. The fuel efficiency for the three petroleum-based fuels is shown in Figure 3. A related project has demonstrated that recovery of the fuel efficiency during advanced combustion to baseline levels is achievable under some circumstances.

Conclusions

- ECD1, CARB certification diesel, and EPA certification diesel fuel exhibit transitions into advanced combustion regimes at very similar EGR levels that are attainable with production-like hardware.
- B100 was not found to enter an advanced combustion regime at the same engine output as the 3 petroleum-based fuels, despite its 11% oxygen content.
- PM and NO_X emissions at a given EGR level increased with increasing fuel cetane rating, but the effect was greatest for PM emissions.
- HC and CO emissions increased with EGR levels for all fuels.
- All fuels exhibited a fuel economy penalty that arose from non-optimized combustion because the fuel injection strategy was held constant regardless of EGR level.

FY 2004 Publications/Presentations

1. "Exploring Low-NO_X, Low-PM Combustion Regimes," Presented at the 2004 DOE Advanced Combustion and Emissions Merit Review.
2. "Achieving High Efficiency Clean combustion in Diesel Engines," Presented at the 2004 Diesel Engine Emissions Reduction (DEER) Workshop.

Figure Captions

Figure 1. NO_X and PM emissions for the 4 fuels.
Figure 2. PM emissions as a function of EGR level for the 3 petroleum-based fuels.
Figure 3. Fuel consumption for the 3 petroleum-based fuels.