Emissions from Premixed Charge Compression Ignition (PCCI) Combustion and Affect on Emission Control Devices

Jim Parks, Vitaly Prikhodko, Teresa Barone, Sam Lewis, and John Storey
Oak Ridge National Laboratory, TN 37831 (USA)

Introduction

In response to emission regulations and increased demand for fuel efficient vehicles, a large amount of research and development on clean diesel technologies has been conducted in the last ten years. Diesel vehicles have been commercialized with diesel particulate filter (DPF) technology to control particulate matter emissions and either lean NOx trap (LNT) or selective catalytic reduction (SCR) catalysts for control of NOx emissions. In order to reduce costs of catalyst systems and enable meeting lower emission standards, engine out emissions have been greatly reduced simultaneous with the emission control technology development. High exhaust gas recirculation (EGR) combined with advanced fuel injection control enables lower NOx emissions but also results in higher PM emissions. Currently, engines are being developed that operate in new combustion regimes that offer dramatic reductions in NOx and PM emissions simultaneously. One combustion mode of interest is Premixed Charge Compression Ignition (PCCI) which combusts a more homogeneous mixture of fuel and air to enable lower emissions [1]. Although both NOx and PM emissions are reduced with PCCI, CO and hydrocarbon (HC) emissions increase. Understanding the impact of these changes in engine out emissions on emission control devices will be critical for optimizing future diesel engine systems.

Materials and Methods

A 4-cylinder 1.7-liter diesel engine was operated in conventional and advanced (PCCI) combustion modes. The engine has two cooled EGR loops, a variable geometry turbocharger, and a common rail fuel injection system with full control of fuel injection events. PCCI operation was enabled by operating at high EGR rates with increased rail pressure and advanced timing of fuel injection to produce a more homogeneous combustion mixture in contrast to the stratified charge associated with conventional combustion. The engine was operated on an engine dynamometer at several steady-state engine load and speed points.

Two catalyst systems were studied. The first catalyst system contained a LNT catalyst with an upstream catalyzed DPF. The LNT volume was 2.5 liters which corresponded to space velocities in the range of 12,000 to 40,000/hr for the engine points studied. The LNT was a commercial prototype supplied by the Manufacturers of Emission Control Equipment (MECA) on a 47 cells/cm^2 cordierite substrate and contained 100 g/ft^3 platinum group metals (PGM). The emphasis of the LNT studies was to understand the effect of lower NOx emissions on catalyst performance and overall system efficiency. The second catalyst system was a diesel oxidation catalyst (DOC). Three different DOC formulations were studied: a model 100 g/ft^3 Pt/Al_2O_3 catalyst and a commercial DOC with two Pt loads (100 g/ft^3 and 50 g/ft^3). All DOCs were on 47 cells/cm^2 cordierite substrates, and two catalyst volumes (1.25 liter and 2.5 liter) were studied. The focus of the DOC studies was to characterize the ability of DOCs to control the increased CO and hydrocarbon emissions from PCCI combustion.

Results and Discussion

PCCI combustion reduces engine out NOx levels dramatically, but CO and HC emissions increase (**Figure 1.a.**). These emission changes from PCCI hold generally true for all load and speed points investigated. In addition to increased CO and HC emissions, increases in mobile source air toxics (MSATs) are also observed during PCCI combustion. **Figure 1.b.** shows increases in formaldehyde and acetaldehyde from PCCI at a low engine load. At this point, catalytic aldehyde oxidation is difficult since PCCI produces exhaust temperatures less than 150ºC

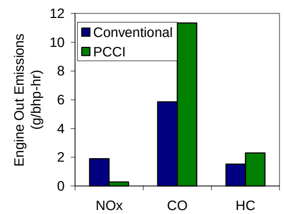
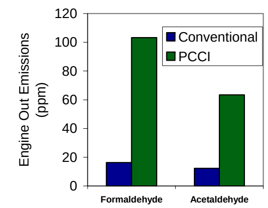


Figure 1. Engine out emissions from PCCI and conventional combustion at engine speed and load of **(a)** 1500 rpm and 2.6 bar BMEP [NOx, CO, HC at left] and **(b)** 1500 rpm and 1.0 bar BMEP [aldehydes at right].



As expected, lower engine out NOx emissions lead to lower tailpipe NOx emissions when using a LNT catalyst (see data from 1500 rpm and 2.6 bar BMEP in **Figure 2.a.**). The benefit can be used to reduce regeneration frequency (lower fuel penalty), reduce catalyst volume, or achieve lower emission regulation levels. Since PCCI fuel efficiency can vary from conventional cases, the system as a whole needs to be considered when optimizing for fuel efficiency. The higher CO, HC, and aldehyde emissions can be controlled via oxidation with a DOC, but the control is temperature dependent. **Figure 2.b**. shows a temperature sweep during PCCI combustion that highlights the temperatures at which CO, HC, and formaldehyde are oxidized. Data is shown for the model 100 g/ft^3 Pt/Al_2O_3 catalyst

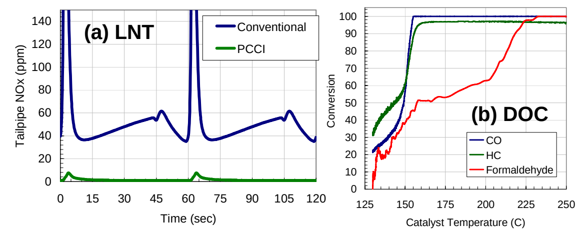


Figure 2.a. Tailpipe NOx for conventional and PCCI combustion downstream of the LNT catalyst. **Figure 2.b.** formaldehyde, CO, and HC conversion vs. temperature during PCCI.

Significance

Future engines will likely utilize advanced (PCCI) combustion. The effect of lower NOx and PM emissions and higher CO and hydrocarbon emissions from PCCI on emission control catalysts will be important for system optimization.

References

1. Sluder, C. S. and Wagner, R. M., *SAE Technical Paper Series No.* 2006-01-3311 (2006).