Off-highway Emission Control with High System Efficiency (CRADA with John Deere.)

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Objectives

- Evaluate the potential of NOx-reducing aftertreatment technologies to achieve interim Tier 4 NOx emission levels for off-highway heavy-duty diesel engines. The initial focus is to utilize a urea-based selective catalytic reduction to achieve brake specific NOx levels of 2 g/kW-hr over the ISO 8178 Off-highway test cycle.
- Optimize key injection parameters to achieve improvements in fuel efficiency while meeting the 2011 Tier 4 emission levels for NOx. The initial target value for brake specific fuel consumption is 195 g/kw-h.

Approach

- Install and setup a urea-SCR system in the exhaust system of a heavy-duty off-highway engine. The system consists of an oxidation catalyst, Bosch urea injector and dosing unit and a Johnson-Matthey urea-SCR catalyst.
- Evaluate the performance of the urea-SCR system to reduce NOx emissions for six modes of the ISO 8178 off-highway test cycle. Examine the slip of ammonia from the SCR catalyst during urea injection.
- Analyze the performance of the urea-SCR system to identify areas of further improvement.

Accomplishments

- Installed the urea-SCR system including the dosing unit and catalysts. This included the fabrication of wiring harnesses and switches, and the setup of software interface and drivers to operate the dosing system.
- Urea-SCR demonstrated to reduce NOx emissions to interim Tier 4 levels over the ISO-8178 off-highway test cycle. Conversion efficiencies over 90% were observed for modes 1, 2, 3, 5, and 6 at near stoichiometric delivery rates. Low exhaust temperatures for modes 4 and 8 prevented the application of the SCR system for these set points.
- Achieved apparent improvement in BSFC.

Future Directions

- Install and evaluate advanced engine control software. Initial focus will be to determine the influence of injection parameters on energy efficiency.
- Explore the potential for other NOx reduction strategies to meet final Tier 4 NOx and PM emissions.
- Conduct further urea-SCR studies to optimize NOx conversion with selected injection control strategies to lower BSFC.

Introduction

Tier 3 federal standards for new off-highway diesel engines require that NOx and PM levels be regulated to 4 g/kWh and 0.2 g/kWh, respectively, for engines between 130 and 560 kW. The phase-in period for Tier 3 compliance is set to begin in 2006 and to be completed by 2008. Urea-SCR has been shown to effectively reduce NOx emissions for on-highway applications, but needs to be thoroughly evaluated for off-highway engines since both engine design and operating conditions are different. The utilization of advanced injection systems and controls are to be evaluated for improvements in both PM emissions and BSFC. This project seeks to develop and evaluate emission control methodologies with the goal of identifying pathways to meet interim Tier 4 and retrofit solutions.

Approach

The principal activity for FY04 was to install and evaluate the performance of a urea-SCR system for reducing NOx emissions from a heavy-duty off-highway diesel engine. Upon receipt of the SCR system components, the system was installed. This required significant effort to make the urea dosing system operational. The urea-SCR evaluation was performed over a period of several weeks, and at the end of this period, the catalysts were sent to the manufacturer for refurbishment. The test protocol followed the ISO 8178 C1 test cycle for off-highway engines. Data were collected for a range of urea delivery rates, up to, and exceeding the stoichiometric value. The level of ammonia slip was measured using a photoacoustic spectrometer and analyzed for each operating mode. In addition, the NOx reducing performance was evaluated with and without use of a DOC to condition the NO to equilibrium levels of NO_2.

A second activity for this FY was to install an advanced fuel injection system and to evaluate its effect on energy efficiency. The data was collected (for each mode) and compared to an earlier study using the original fuel injection system.

Results

A photograph showing the arrangement of the catalysts in the engine exhaust line is shown in Fig. 1. Installation of the urea-SCR system was completed by February. During the urea-SCR evaluation, it was necessary to closely monitor the temperature profile of the exhaust, especially the SCR catalyst since performance is closely related to temperature. The temperature profile for each mode is shown in Fig. 2. As shown in this figure, the catalyst temperatures for modes 4 and 8 were too low to enable urea injection and were thus not considered during the evaluation.

For each mode, the baseline NOx emissions were monitored before application of the urea. When steady state was reached, the urea was applied at a low level (usually around 500 g/h) and the temperature and emissions were allowed to stabilize. The engine out, DOC out, and tailpipe emissions of NOx, HC, CO, CO_2, and O_2 were recorded for each setting. The urea level was gradually increased at selected values up to and slightly exceeding the stoichiometric level of urea required for theoretically complete conversion of the NOx level. This was performed with and without a DOC placed in the exhaust upstream of the urea injector. In general, for modes 1, 2, 3, 5, and 6, the DOC improved the NOx conversion significantly for urea delivery rates approaching the stroichiometric value, but was less effective at improving the conversion during low applications of urea. The utilization of the DOC during mode 7, however, improved the NOx conversion by 30% for all rates of urea injection. The NOx conversion results (using the DOC) for each mode are shown in Fig. 3. For modes 1, 2, 3, 5, and 6 the NOx conversion increased to levels exceeding 90%. The urea delivery rate at which conversion passed 90% usually corresponded to the stoichiometric value. At levels at or exceeding stoichiometry, the conversion began to level and ammonia began to slip past the catalyst.

Unlike the other modes tested, the exhaust conditions during mode 7 did not allow for greater than 90% NOx conversion. The highest value that could be attained was around 50%, which occurred significantly below the calculated stoichiometric value. As with the other modes, ammonia slip was observed for mode 7 once the rate of NOx conversion with urea flow decreased. The total brake specific NOx level obtained using this system was determined to be around 1g/kWh, which is well below the Tier 3 target level of 4 g/kWh and below the interim Tier 4 level of 2 g/kWh.

Conclusions

- Tier 3 NOx emission levels were reached using a urea-SCR system. The addition of a DOC significantly the NOx conversion efficiency of the system. However, the exhaust temperatures for modes 4 and 8 were too low to permit urea injection.
- The energy efficiency of the engine was improved through the application of an advanced fuel injection system. For all modes, except 4 and 8, the BSFC values were below the target level

Acronyms

BSFC – brake specific fuel consumption
DOC – diesel oxidation catalyst
NOx – oxides of nitrogen
PM – particulate matter
SCR – selective catalytic reduction

Figure Captions

Figure 1. Photograph of urea-SCR system in exhaust.
Figure 2. Key exhaust temperatures for each mode. Units are in degrees Celsius.
Figure 3. NOx reduction performance of the urea-SCR system for ISO 8178 modes 1, 2, 3, 5, 6, and 7.