Abstracts

Session 10 – Diesel Engine Exhaust Aftertreatment, Part I

LOW EMISSIONS POTENTIAL OF EGR-SCR-DPF AND ADVANCED FUEL FORMULATIONS: A PROGRESS REPORT

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One of the major projects of the Advanced Petroleum-Based Fuels – Diesel Emission Control (APBF-DEC) project is the demonstration of potential for selective catalytic reduction (SCR) and diesel particulate filters (DPF). This project is integrating several diesel emission control technologies for the purpose of demonstrating their capability in achieving the 2007 heavy-duty diesel engine (HDDE) standards. The project also includes the evaluation of several fuels with various sulfur contents.

The work is conducted on a Caterpillar C-12 HDDE. Two emission control systems will be calibrated to meet the 2007 HDDE standards. Each system consists of EGR, CB-DPF, and urea SCR. Once a satisfactory calibration is achieved, both systems will undergo 6,000 hours of durability with emission evaluations conducted at 2,000-hour intervals. Selected unregulated, toxic, and nitrogen compounds will also be sampled at regular intervals for both control systems. This presentation is a progress report on what the project has accomplished to date.

EVALUATION OF A NO_x ADSORBER SYSTEM ON A LIGHT-DUTY DIESEL VEHICLE

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and

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This paper presents the results of NO_x adsorber testing done under the FreedomCAR Program. A compact exhaust aftertreatment system (EAS) design was developed after various iterations of the catalyst formulation and system configuration. The EAS tested is dual leg and consists of sulfur trap, adsorber, and catalyzed soot filter (CSF). During regeneration, supplementary low-sulfur diesel fuel is injected upstream of the adsorber and CSF in the exhaust. The adsorber catalyst volume is 1.8 times the engine displacement. Steady-state and transient emission test results with and without the EAS are presented. Results of soot filter regeneration by injecting low-sulfur diesel fuel and slip of unregulated emissions, such as NH_3, are discussed. Effects of adsorber size and bypass strategy on NO_x conversion efficiency and fuel economy penalty are also presented in this paper. The results show that if the supplementary fuel injection is optimized, NH_3 slip is negligible. During the FTP cycle, injection of low-sulfur diesel fuel can create temperature exotherms high enough to regenerate a loaded CSF. It was observed that the adsorber size affects the NO_x conversion efficiency significantly, and the right catalyst size will need to be chosen based upon the application.

UREA SELECTIVE CATALYTIC REDUCTION AND DIESEL PARTICULATE FILTER SYSTEM FOR DIESEL SPORT UTILITY VEHICLE MEETING TIER II BIN 5

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Ford Motor Company is participating in the U.S. Department of Energy's (DOE) Ultra-Clean Transportation Fuels Program with the goal of developing an innovative emission control system for diesel sport utility vehicles. This program focuses on diesel vehicles because they currently offer 40-percent better volumetric fuel economy and 20-percent lower CO_2 emissions than comparable gasoline vehicles. We chose a selective catalytic reduction (SCR) catalyst that uses aqueous urea as the NO_x reductant and a catalyzed diesel particulate filter (DPF) for this program. We plan to demonstrate more than 90-percent reduction in particulate matter (PM) and NO_x emissions. We use very low sulfur diesel fuel (less than 15 ppm) to enable low PM emissions, to reduce the fuel economy penalty due to the emission control system, and to enhance long-term durability of the system. The end result will allow vehicles with diesel engines to be Tier II - emissions certified at a minimum cost to the consumer.

In the first year of the program, we have scaled up the exhaust system --which has an oxidation catalyst, urea SCR and a catalyzed DPF -- from a passenger car to a light-duty truck. We have achieved excellent mixing of the injected urea with the truck exhaust gas and 85-percent NO_x conversion on the Federal Test Procedure as predicted by modeling. We have also begun exploring rapid-warming procedures to increase NO_x conversion when exhaust temperatures are too low and modeling ammonia storage to maximize NO_x conversion while minimizing ammonia emissions. We have begun improving exhaust gas NO_x and ammonia sensors for more accurate control of reductant injection and on-board diagnostics. Finally, we have tested the on-road durability of the aqueous urea SCR system on a 2.4-liter transit van for 25,000 miles and separately improved the durability of both the urea SCR and DPF systems.

DURABILITY OF NO_x ADSORBERS

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NO_x adsorber catalysts can obtain NO_x reduction efficiencies greater than 90 percent in lean exhaust. The capability of the NO_x adsorber to perform the NO_x reduction with a diesel-fuel-based reductant coupled with the broad temperature range of operation makes NO_x adsorber catalysts well suited for diesel engine applications. However, durability issues need to be addressed for compliance with upcoming emission regulations.

Specifically, sulfur in diesel fuel is a known masking agent, and over time sulfur accumulation directly on NO_x sorption sites degrades NO_x reduction performance. One method of controlling sulfur masking is by removal of sulfur compounds from the catalyst in a reducing environment; this process is referred to as desulfation and typically occurs at elevated catalyst temperatures. Here the effect of multiple repetitive sulfur loading and desulfation cycles on catalyst performance will be presented, and projections of NO_x performance over time will be made to predict catalyst lifetime.

NO_X ADSORBER DEVELOPMENT

Steve Faulkner
Caterpillar, Inc.

The development of the NO_x adsorber technology is one of the key challenges facing the heavy-duty diesel industry. Caterpillar will review recent progress with this technology and discuss some of the remaining challenges.

LEAN-NO_X CATALYST DEVELOPMENT FOR DIESEL ENGINE APPLICATIONS

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and

Chris Aardahl, Jerry Birnbaum, Ken Rappe, and Diana Tran
Pacific Northwest National Laboratory

Because of the inherently low hydrocarbon concentration in diesel exhaust, any NO_x reduction catalyst requires the addition of supplemental reductant to reduce NO_x. From a diesel engine user's standpoint, the best reductant to use in conjunction with aftertreatment systems is diesel fuel. However, the natural form of diesel fuel is not an ideal reductant to reduce NO_x over various catalysts.

Reformation of diesel fuel to create feasible reductant has been considered to improve NO_x reduction performance. In this study, catalyst materials demonstrated hydrocarbon reformation as well as NO_x reduction on the catalyst surface. The reformation active sites were identified independently from NO_x reduction sites in the catalyst formulation.

The research and development of catalysts suitable for lean-NO_x or non-thermal plasma applications to optimize NO_x reduction will be discussed.

PLASMA-ACTIVATED LEAN NOX CATALYSIS FOR HEAVY-DUTY DIESEL EMISSIONS CONTROL

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and

Paul Park
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NO_x reduction exceeding 90 percent has been demonstrated for a simulated exhaust stream in bench-scale experiments and in engine slip-stream tests using a plasma treatment step followed by catalytic lean-NO_x reduction. The effect of reducing agent on catalysis has been probed in some detail, and results show that a variety of hydrocarbons can be used to reduce NO_x. It is also demonstrated that optimal catalyst formulation, based on silver-doped ?-alumina, is highly dependent on the hydrocarbon species. Fuel-like hydrocarbons, such as iso-octane, can give high activity, but the level of silver in the catalyst must be increased above levels typically used for propene or other light hydrocarbons. Comparison between bench data and steady-state engine testing conducted in 2001 will also be provided.

A NON-THERMAL PLASMA APPLICATION FOR THE ROYAL NAVY

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U.K. Ministry of Defence

The worldwide travel of the British Royal Navy provides for a varied environment that naval vessels are accustomed and presents numerous challenges. Environmental legislation has become increasingly stringent for the marine industry and navies worldwide. The NO_x and particulate emissions reduction from diesel engines continues to be of importance to the U.K. Ministry of Defence (MOD). Evaluation of the feasibility of exhaust control technologies suitable for NO_x reduction is constantly being monitored. The Accentus plc proprietary and patented non-thermal plasma (NTP) system is presently in stage 2 development with U.K. MOD and is being applied to the naval environment. A stage 1 feasibility and analysis study has been completed, and a 1/10-scale demonstrator is a deliverable for stage 2. NTP compared to selective catalytic reduction (SCR) has the potential to offer significantly improved low load and shock performance over the conventional SCR without the inconvenience of using an ammonia-based reductant.

The primary objective of the paper is to discuss the Accentus NTP system application to a broad range of operational naval diesels and the recent engine trials conducted at MAN B&W. The secondary objective is to discuss U.K. policy and naval environmental strategy and to monitor, evaluate, develop, and advise future capital projects.

The NO_x reduction through primary means is preferred in U.K. MOD vessels. However, the vast array of engine types and imminent emission level change has focused the Royal Navy on secondary treatment such as NTP and SCR. Investment appraisal in secondary fits will increasingly support new technology engine after-treatment retrofit. The uncertain nature of NO_x and particulate level legislation has reinforced the Royal Navy commitment to remaining an informed customer on “green” issues.

NOXTECH'S PLASMA-ASSISTED CATALYST PROGRAM

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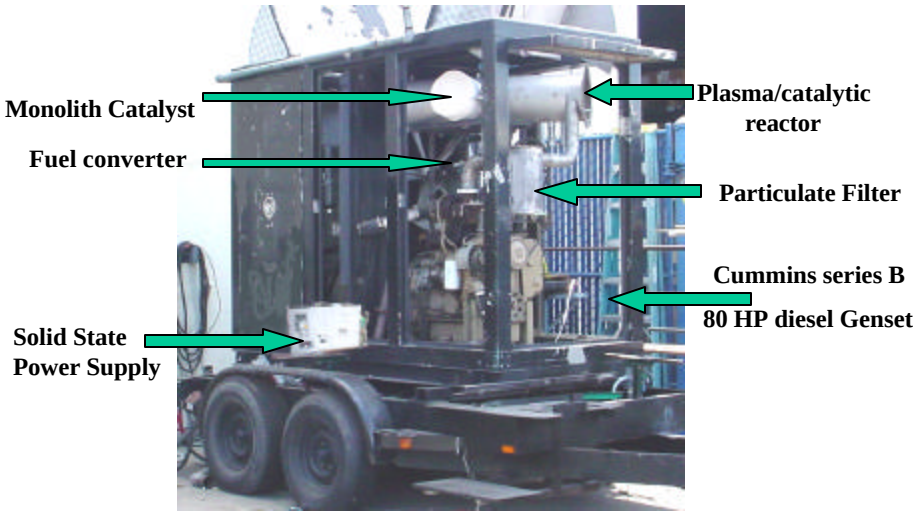
Diesel emissions reduction technology remains a key obstacle in achieving cleaner and healthier environmental standards. It is estimated the diesel emissions will have to be reduced by as much as 90 percent from current levels to meet the 2007 and beyond standards being sought by the U.S. Environmental Protection Agency and the California Air Resources Board.

Non-thermal plasma-assisted catalyst (NTPAC) technology being developed at Noxtech, Inc., continues to focus on achieving the 2007 and beyond standards. Noxtech's NTPAC technology utilizes an efficient non-thermal plasma reactor working in harmony with a solid-state pulsed power supply to efficiently convert NO to NO_2 in the presence of a suitable hydrocarbon generated on-board from diesel fuel. NO_2 is then converted to N_2 in the presence of an A9 monolithic sulfur-tolerant catalyst.

Noxtech has made major progress in the development and enhancement of the NTPAC system under the U.S. Department of Energy-sponsored program. Noxtech has designed, built, and demonstrated an 80-HP NTPAC system with up to 94-percent NO_x reduction from an 80-HP diesel engine genset using a diesel as a source of reductant for the NTPAC system.

Major improvements have been made in the Noxtech's NTPAC system components. Noxtech has successfully designed, built, and tested a diesel fuel converter, which uses the exhaust energy to convert diesel into a suitable gaseous hydrocarbon so it can be used by the NTPAC system as a reductant. The NO_2 conversion catalyst performance has been improved, and the ceramic spheres have been replaced with a monolithic unit. Noxtech continues to screen additional catalysts to find more active and better catalysts than A9. The efficiency of the pulser and reactor has been enhanced, and their size and components have been greatly reduced.

Noxtech plans to demonstrate its advanced 80-HP NTPAC system at the DEER 2002 Conference. The system developed at Noxtech will be integrated with an 80-HP series B diesel engine genset. This system will be operated with a load bank and a NO_x analyzer. Metered diesel fuel will be used as a reductant for the NTPAC system demonstration. The plasma reactor will be powered by a solid-state power conditioner/pulser, and the system will be operated at steady state with manual controls.


Monolith Catalyst
Fuel converter
Solid State
Power Supply
Plasma/catalytic
reactor
Particulate Filter
Cummins series B
80 HP diesel Genset

TEMPERATURE TRANSIENT EFFECTS IN PLASMA CATALYSIS

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and

Paul Park
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Plasma discharge is used together with a combination of catalysts for simulated diesel exhaust NO_x removal. A transient evaluation is made using a programmed temperature ramp between 100°C and 500°C, and using FTIR to measure the gas composition before and after the treatment. Although the temperature transient is not directly related to any driving cycle, it has provided useful insight on plasma-catalyst system issues.

A controller was made that holds constant plasma-specific energy deposition (J/L) over the temperature range. It is necessary to vary both frequency and amplitude of the AC excitation in the dielectric barrier discharge. Surface conductivity effects on the barrier affect the discharge NO_x at higher temperatures.

Zeolite-based catalysts, such as NaY and BaY, have both steady-state NO_x conversion and significant NO_x storage. The stored NO_x can be released during catalyst heating. By themselves, these catalysts have poor conversion over the temperature cycle.

An alumina-based catalyst provided by Caterpillar has higher temperature operation than the zeolite-based catalysts. When placed downstream of BaY, the cycle average NO_x efficiency is greatly improved. This is partly because the desorption of NO_x from the BaY occurs at a temperature near the lower operating range of the alumina-based catalyst, and partly because the zeolite-based catalyst increases the concentration of formaldehyde, which is a useful NO_x reductant over the alumina-based catalyst.

A platinum-based catalyst is required downstream of the NO_x catalysts to remove remaining HC and aldehydes. At the same time, there is a narrow temperature range of NO_x conversion over the platinum, so that the cycle average NO_x conversion is highest when the three catalysts are used in combination.

ON-BOARD PLASMATRON GENERATION OF HYDROGEN-RICH GAS FOR DIESEL AFTERTREATMENT AND OTHER APPLICATIONS

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Plasmatron reformers can provide attractive means for conversion of diesel fuel into hydrogen-rich gas. The hydrogen-rich gas can be used for improved NO_x trap technology and other aftertreatment applications. Plasmatron reformers developed at MIT use a special low-power, low- current electrical discharge to boost partial oxidation conversion of hydrocarbon fuels into hydrogen and carbon monoxide. This reformer technology provides the advantages of:

- Rapid startup and response to transient conditions
- Efficient conversion
- Compact size
- Relaxation or elimination of reformer catalyst requirements
- Capability to process difficult-to-reform fuels.

Diesel plasmatron reformer technology can provide substantial throughputs with homogeneous reforming. The use of the special plasma facilitates robust, non-catalytic conversion of diesel fuel into hydrogen-rich gas with hydrogen yields that are sufficient for NO_x trap regeneration applications. Higher yields can be obtained with the use of a catalyst.

Plasmatron reformers could also be used for manufacturing of ethene, which could be useful as a selective reducing agent. In addition, plasmatron reformer technology can be used for converting a range of biofuels into hydrogen-rich gas. These fuels include various oils. This capability may improve the prospects for use of renewable fuels in a variety of vehicular applications. The status of plasmatron diesel-fuel reformers will be discussed.

PERFORMANCE EVALUATION OF THE DELPHI NON-THERMAL PLASMA SYSTEM UNDER TRANSIENT AND STEADY-STATE CONDITIONS

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and

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A non-thermal plasma (NTP) exhaust aftertreatment system, consisting of a diesel particulate filter (DPF), NTP reactor, power supply, controller, catalyst, and NO_x sensor, was developed to reduce the emission of oxides of nitrogen and particulate (PM) matter for diesel engines. The goal of the project was to reduce NO_x by 80 percent and PM by 90 percent with a maximum fuel economy penalty of 3 percent. System development was conducted on a 2.2-liter light-duty, common rail, diesel vehicle using steady-state and transient emission tests. The total NO_x emission reduction on transient testing over the European MVEG cycle averaged 15 percent, with a fuel economy penalty of 8 percent. DPF regeneration using the NTP was demonstrated under steady-state conditions at exhaust temperatures greater than 280°C. A comprehensive analysis of the vehicle emission data will be presented.

A PARAMETRIC STUDY SHOWING THE EFFECT OF TEMPERATURE AND HYDROCARBON SPECIES ON THE PRODUCT DISTRIBUTION FROM A NON-THERMAL PLASMA REACTOR

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Delphi Corporation

and

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In an attempt to better understand how the performance of a plasma reactor varies in actual diesel exhaust, its ability to (1) convert NO-to-NO_2 and (2) create chemically active oxygenates (e.g., acetaldehyde) was evaluated as a function of variables, such as gas temperature, hydrocarbon species, and hydrocarbon concentration. Simulated diesel exhaust conditions including O_2, CO_2, H_2O, CO, NO, and hydrocarbons were employed together with a single-cell plasma reactor in a bench system. The source of reductant species was one of nine lighter weight saturated or unsaturated hydrocarbons ranging in carbon number from 2 to 5. The gas temperature was varied between 125° C and 475° C. The resulting product distribution was then examined with an FTIR and a chemical ionization mass spectrometer (CIMS) to better clarify the role of hydrocarbon speciation in forming NO_2 and oxygenates.

In general, we find that higher hydrocarbon concentrations are essential at all gas temperatures to optimize NO-to-NO_2 formation. Unsaturated straight chain hydrocarbons appear superior at low temperatures, while saturated straight chain hydrocarbons perform better at higher temperatures. Longer chain hydrocarbons outperform shorter chain hydrocarbons at any temperature on a molar basis. A combination of saturated and unsaturated hydrocarbons can provide a broad temperature window for good NO_2 formation.

To maximize formation of oxygenates, like acetaldehyde, higher concentrations of longer chain hydrocarbons are superior. Unsaturated hydrocarbons show little temperature dependence, while saturated hydrocarbons work better at high temperatures. Some additional work was also done to examine the reactor performance as a function of NO concentration, reactor power, and space velocity. Modeling of the gas-phase chemistry in a plasma reactor supports many of these findings. Extensions of this work, using mixtures of gases present in actual exhaust, should allow for the determination of the optimal conditions at which to run a plasma reactor, depending on its application.