Abstracts

Session 11 – Aftertreatment

USE OF A DIESEL FUEL PROCESSOR FOR RAPID AND EFFICIENT REGENERATION OF SINGLE-LEG NO_x ADSORBER SYSTEMS

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ABSTRACT

NO_x adsorber or NO_x trap systems must be regenerated frequently to convert the adsorbed NO_x to N_2 and to regenerate the NO_x adsorption capacity of the NO_x trap. This regeneration requires a reducing environment and the presence of a reductant capable of reacting with the NO_x trap components. Recent reports have shown that "reactive" reductants such as H_2, CO, and oxygenated species can regenerate NO_x traps more rapidly and at lower temperatures. While this offers a clear potential advantage, providing a reductant in a cost-effective manner is problematic.

A diesel fuel processor has been developed that can operate from low loads to full loads and can produce periodic, high concentrations of a "reactive" reductant from diesel fuel as required during the regeneration portion of the cycle. Engine tests show that the fuel processor produces a "reactive" reductant over a wide exhaust-temperature range and with good control of reductant mass flux.

The benefits of a reactive reductant were demonstrated by tests in which the NO_x trap was regenerated with reductant pulses as short as 1 second. Steady-state tests have shown fuel penalties in the range of 3 percent for a single-leg system with high NO_x conversion. In addition, the fuel processor is designed to produce a desulfation cycle that includes raising the NO_x trap to the required desulfation temperature and then providing the required reducing environment to regenerate the NO_x adsorber system. The use of a "reactive" reductant should allow the desulfation cycle to occur at lower temperatures, thus increasing NO_x adsorber durability. The operating characteristics and performance of the diesel fuel processor will be presented.

BIFUNCTIONAL CATALYSTS FOR THE SELECTIVE CATALYTIC REDUCTION OF NO BY HYDROCARBONS

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ABSTRACT

Novel bi-functional catalysts combining two active phases, typically Cu-ZSM-5 and a modifier, were prepared and tested for the selective catalytic reduction of NO_x using propylene in order to overcome the hindering effects of water typically seen for single-phase catalysts, such as Cu-ZSM-5. The catalysts were made by typical preparation techniques, but parameters could be varied to influence the catalyst.

The physical characterization of the materials showed that the modification phase was added strictly to the external surface of the zeolite without hindering any internal surface area. Chemical characterization by temperature programmed reactions, diffuse reflectance infrared Fourier transform spectroscopy, and x-ray absorption spectroscopy indicated strong interaction between the two phases, primarily producing materials that exhibited lower reduction temperatures.

Two improvements in NO_x reduction activity (1000 ppm NO, 1000 ppm C_3H_6, 2% O_2, 30,000 hr^{-1} GHSV) were seen for these catalysts compared with Cu-ZSM-5: (1) a lower temperature of maximum NO_x conversion activity (as low at 250°C) and (2) an enhancement of activity when water was present in the system. The use of a second phase provides a way to further tune the properties of the catalyst in order to achieve mechanistic conditions necessary to maximize NO_x remediation.

LEAN NO_X CATALYSIS DEVELOPMENT FOR DIESEL ENGINES

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ABSTRACT

An attractive NO_x aftertreatment catalyst technology is one based on catalyst materials that utilize hydrocarbons in the diesel fuel to supply the required supplemental reductants, while operating in normal lean-combustion conditions. Thus, lean-NO_x technology still maintains its potential opportunity to reduce NO_x for meeting future NO_x emission regulations as engine technologies advance.

Through catalyst research and development programs with academia and industry (catalyst suppliers), we are able to study various aspects of catalyst technologies from fundamental understanding to applications.

In this presentation the various efforts devoted from Caterpillar on research and development of the lean-NO_x catalyst technology will be discussed.

FUEL-BORNE REDUCTANTS FOR NO_X AFTERTREATMENT

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ABSTRACT

One potential method for meeting stringent NO_x emissions standards involves blending reductants into the bulk fuel, then removing them on board, or perhaps at the pump, for use in selective catalytic reduction (SCR). One family of readily removed reductants is light alcohols.

By using ethanol as the reductant and silver-loaded alumina catalyst bricks, NO_x emissions were reduced by more than 90 percent and 80 percent for space velocities of 21,000/h and 57,000/h, respectively. These results were achieved for catalyst temperatures between 360°C and 400°C and for C1: NO_x ratios of 4-6; at lower temperatures, the NO_x conversion was less efficient.

A concept for utilizing ethanol (distilled from an ethanol-diesel micro-emulsion fuel) as the SCR reductant was included in this initial study to demonstrate fuel-borne reductant feasibility. In contrast to other catalyst technologies, NO_x conversion appeared to be enhanced by the initial catalyst aging, with the presumed mechanism being sulfate accumulation within the catalyst. We anticipate presenting follow-on efforts, which include assessing SCR performance for these catalysts using other reductant (alcohol) types.

HYDROGEN GENERATION FROM PLASMATRON REFORMERS AND USE FOR DIESEL EXHAUST AFTERTREATMENT

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ABSTRACT

The status of plasmatron reformers under development at the Massachusetts Institute of Technology (MIT) and ArvinMeritor will be presented. In these reformers, a special low- power electrical discharge is used to promote partial oxidation conversion of hydrocarbon fuels into hydrogen and CO. This very fuel-rich mixture reaction is hard to initiate, and the plasmatron provides continuous enhanced volume initiation. To minimize electrode erosion and electrical power requirements, a low-current, high- voltage discharge is used, with wide area electrodes. The reformers operate at or slightly above atmospheric pressure.

Plasmatron reformers provide the advantages of rapid startup and transient response; efficient conversion of the fuel to hydrogen-rich gas; compact size; relaxation or elimination of reformer catalyst requirements; and capability to process difficult-to-reform fuels, such as diesel and bio-oils. These advantages facilitate use of hydrogen-manufacturing reformation technology for diesel exhaust aftertreatment. Plasma-enhan-ced reformer technology can provide substantial conversion even without the use of a catalyst.

Recent progress includes substantial decrease in electrical power consumption (to about 200 W), increased flow rate (above 1 g/s of diesel fuel corresponding to approximately 40 kW of chemical energy), soot suppression, and improvements in other operational features.

This technology has been evaluated for use as a regeneration mechanism for NO_x-adsorber aftertreatment systems. At ArvinMeritor, tests were performed on a dual-leg NO_x adsorber system using a Cummins ISC 8.3L diesel engine in a vehicle. A NO_x adsorber system was tested with the plasmatron reformer as a regenerator, and without the reformer (i.e., with straight diesel fuel based regeneration as a baseline case).

The plasmatron reformer was shown to improve NO_x regeneration significantly, compared to the baseline diesel case. The net result was a significant decrease in fuel penalty, roughly 50 percent at moderate catalyst temperatures. This improvement is accompanied by a dramatic drop in slipped hydrocarbon emissions, which decreased by 90 percent or more. Significant advantages are demonstrated across a wide range of engine conditions and temperatures. The study also indicated the potential to regenerate catalytic adsorbers at low temperatures where diesel fuel based regeneration is not effective, such as are typically seen at idle conditions. A vehicle has been equipped for plasmatron reformer exhaust aftertreatment tests.

DIESEL REFORMERS FOR ON-BOARD HYDROGEN APPLICATIONS

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ABSTRACT

Many solutions to meeting the 2007 and 2010 diesel emissions requirements have been suggested. On-board production of hydrogen for in-cylinder combustion and exhaust aftertreatment provides promising opportunities for meeting those requirements. Other benefits may include using syngas to rapidly heat up exhaust after-treatment catalysts during engine startup.

Hydrogen Source's development of a catalytic partial oxidation reformer for generating hydrogen from ultra-low sulfur diesel fuel will be presented. The system can operate on engine exhaust and diesel fuel with no water tank. Test data for hydrogen regeneration of a lean NO_x trap will be presented showing 90 percent NO_x conversion at temperatures as low as 150°C and 100 percent conversion at 300°C. Finally, additional efforts required to fully understand the benefits and commercial challenges of this technology will be discussed.

MEASUREMENT OF IN-USE EMISSIONS FROM HEAVY-DUTY DIESEL VEHICLES: THE STATE-OF-THE-ART

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ABSTRACT

A considerable amount of effort is being devoted toward generating exhaust emissions data from heavy-duty, on-highway diesel engines operating under normal in-use conditions. Engine manufacturers and various regulatory bodies (U.S. Environmental Protection Agency, California Air Resources Board) alike will use this information to ensure that emissions standards are met throughout the useful life of 2007, and later, model year heavy-duty, on-highway diesel engines. Efforts are also being focused on monitoring not-to-exceed emissions compliance. As a result, a fair understanding of in-use and Federal Test Procedures (certification cycle) emission levels from on-highway engines has been afforded. However, there is very sparse information on in-use and steady-state certification cycle emissions from non-road engines. Moreover, the extrapolation of this sparse amount of data to provide estimates of the emissions impact these non-road vehicles have on air quality could lead to large errors (recent work at West Virginia University [WVU] has shown that in-use emissions from non-road engines are severely overestimated by 8-mode steady state certification cycles). An established set of measurement protocols and system design recommendations providing for accurate on-board measurement tools has been the missing link to attaining this information.

In response to such needs, WVU has developed, and continues to evolve, an on-board, in-use emissions measurement system called the Mobile Emissions Measurement System (MEMS) that allows determination of in-use, brake-specific emissions from heavy-duty diesel-powered vehicles. This work is a part of the future trends toward moving out of the certification test cells and into actual in-field emissions measurements. This paper discusses some of the in-use emission results from on-highway engines, marine vessels (from a recently completed study on a high-speed hydrofoil), and non-road engines that were obtained by WVU using the MEMS. Such fieldwork has not only provided WVU with valuable experience related to in-use testing protocols, but also with ideas concerning future on-board emissions measurement system design.

This paper will discuss general in-use test procedures, as well as the essential components of generic, on-board emissions measurement tools. Aspects such as accuracy, precision, “ultra-portability,” and system flexibility will be discussed pertaining to in-use testing of emissions from both on-highway and non-road engines. Advanced concepts, such as fuel-specific emissions, and their impact on design of measurement systems used for compliance and development work are discussed.

DIESEL PARTICULATE FILTER OVERVIEW: MATERIAL, GEOMETRY, AND APPLICATION

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ABSTRACT

This presentation is a review of diesel parti-culate filters (DPF's) from the past to the present. It will cover materials choices, filter geometry, and systems integration needs. Included in the presentation will be a discussion of materials properties and their compatibility with diesel fuel and oil compositional make-up and exhaust use temperature, as well as chemo-thermo-mechanical durability limits of selected supports and catalyst options.

NEW CORDIERITE DIESEL PARTICULATE FILTERS FOR CATALYZED AND NON-CATALYZED HEAVY-DUTY APPLICATIONS

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ABSTRACT

Ceramic wall-flow diesel particulate filters (DPF's) are presently being explored for the collection and combustion of carbonaceous soot in heavy-duty vehicle applications. To minimize reduction in vehicle power, it is important for the DPF to have a low pressure drop. The pressure drop of a DPF is known to increase with the accumulation of soot. Furthermore, depending upon the type of engine and the strategy employed to initiate regeneration of the filter, DPF's may be catalyzed to reduce emissions of NO_x, CO, and HC, as well as to lower the temperature required for regeneration. The presence of a catalyst within, or on top of, the filter wall can further contribute to an increase in pressure drop of the filter. To minimize the pressure drop for catalyzed and non-catalyzed filters, it is necessary to optimize the pore microstructure of the ceramic walls as well as the external dimensions and cell geometry of the filter.

Cordierite DPF's provide an economical approach to diesel emission control. However, further reduction in the pressure drop of catalyzed and non-catalyzed cordierite filters is desirable. In an effort to develop new cordierite filters that possess lower pressure drop while maintaining high filtration efficiency and strength, cordierite ceramics have been fabricated spanning an extended range in porosity, pore-size distribution, and pore connectivity. Pressure drops of the clean and soot-loaded filters before and after catalyst impregnation have been measured over a series of flow rates for a wide range of pore microstructures. Analysis of the results has provided explicit equations relating the pressure drop versus soot- loading behavior to the porosity and pore-size distribution of the ceramic wall, and has increased the fundamental understanding of the relationship between filter permeability and pore microstructure.

Optimum values for the percent porosity, median-pore diameter, and breadth of the pore- size distribution for minimizing pressure drop have been identified. These results have been applied to the development of several new, high-porosity, cordierite diesel particulate filters that possess a unique combination of high filtration efficiency, high strength, and very low clean and soot-loaded pressure drop in both the catalyzed and non-catalyzed states. By controlling the microstructure, the impact of the catalyst on pressure drop has been minimized. Soot-loaded pressure drops of these new filters in their catalyzed state are less than 50 percent of other catalyzed commercial filters with the same cell geometry.

NON-THERMAL PLASMA BASED TECHNOLOGIES FOR THE AFTERTREATMENT OF AUTOMOTIVE EXHAUST PARTICULATES AND MARINE DIESEL EXHAUST NO_X

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ABSTRACT

The trend in environmental legislation is such that primary engine modifications will not be sufficient to meet all future emissions requirements, and exhaust aftertreatment technologies will need to be employed. One potential solution that is well placed to meet those requirements is non-thermal plasma technology. This paper will describe our work with some of our partners in the development of a plasma-based diesel particulate filter (DPF) and plasma-assisted catalytic reduction for NO_x removal.

Accentus and Eberspächer have been working to develop non-thermal plasma regenerated DPF technology for diesel passenger car applications. The results from the evaluation of a prototype system on a 3.0L diesel engine with Euro IV engine management will be presented. During the evaluation, filtration efficiencies between 95 and 100 percent were recorded with plasma regeneration demonstrated at powers down to 600 W at a range of exhaust gas temperatures. The evaluation also demonstrates the possibility for a flexible control strategy, which could be based around either continuous or intermittent regeneration.

The U.K. Ministry of Defence (Navy) is evaluating the feasibility of exhaust control technologies suitable for the reduction of NO_x emissions from diesel engines. The plasma - assisted catalysis approach can offer a number of potential advantages over the use of selective catalytic reduction in a warship application, such as low-load performance and the removal of the need for a urea-based reductant. A development program is underway to produce a plasma-assisted catalytic reduction system for NO_x removal. This program has been based on understanding the process at the laboratory scale and then undertaking the design, build, and testing of a system to treat $1/10^{th}$ the flow from a 1.4 MW marine diesel engine. The overall strategy for the program will be described together with results from the programme to date, including the initial testing of the $1/10^{th}$ scale system.

RECENT DIESEL EMISSION MITIGATION ACTIVITIES OF THE U.S. MARITIME ADMINISTRATION ENERGY TECHNOLOGIES PROGRAM

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ABSTRACT

The Santa Barbara County (California) Air Pollution Control District is forecasting that NO_x pollutants generated by coastal ships are on the way to eclipsing all land-based county sources. The Port of New York and New Jersey is developing an innovative strategy whereby emissions reduced from the renown Staten Island ferries could be used to legally offset other sources within the harbor. What technologies can be applied to vessels (which are often foreign owned) to reduce criteria pollutants? What marine unique challenges will have to be accommodated by an emissions-measurement protocol to support the concept of "offsetting" and other technology incentive programs?

At the DEER 2002 Conference, the author gave a presentation providing an overview of the Maritime Administration (MARAD) Energy Technologies Program. The presentation highlighted air-pollution mitigation pressures currently being applied to diesel engines in the maritime industry and program steps taken to address these pressures. This year's presentation will provide an update of the program and respond to the above questions by examining four subject areas:

- Brief review of program, goals, progress, and new regulations.
- Emissions measurement and performance results from ultra-low sulfur diesel fuel and inlet air humidification technology tests aboard a San Diego based ferry.
- Discussion of marine unique emission measurement challenges presented by ships and the maritime environment.
- Developments in a large vessel engine retrofit technology demonstration project.