Abstracts

Session 7 – Emissions-Related Technologies and Regulations

HEAVY DUTY DIESEL EMISSION REGULATIONS AND TECHNOLOGY SOLUTIONS

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Emissions regulations for 2007 and beyond are driving diesel engines to have near-zero emissions. Reaching these goals demands rapid development of many new technologies. Fuel injection systems are progressing to provide high injection pressure and multiple injection capability with complete timing and quantity flexibility. New combustion bowl concepts are evolving to match the injection capability and significantly reduce emissions. Air system design has already evolved to VG, and dual turbochargers in production and assisted turbochargers are considered for the future. Camless valve technology is developing, which will offer command and control of not only the air-fuel ratio but also swirl. New exhaust gas recirculation (EGR) mapping and sourcing strategies are being explored along with a differentiation between internal and external EGR. Aftertreatment technologies, such as particulate filters and NO_x adsorbers, are showing much promise. All these technologies also require their own sophisticated control strategies as well as their integration as a system. The task is quite challenging. However, progress to date is impressive and showing the potential feasibility of being solved.

NO_X ADSORBER REGENERATION IN TRANSIENT CYCLES: PARAMETRIC STUDY

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A 1999 Mercedes A170 CDI has been equipped with prototype NO_x adsorber devices in order to study the impacts of regeneration conditions on the emissions reduction performance of the devices. This study consisted of a number of laboratory experiments utilizing a bottled-gas injection system to periodically provide fuel-rich exhaust conditions for device regeneration. The NO_x adsorbers were evaluated on the LA4 driving cycle using a fixed regeneration schedule. The rich-pulse duration and minimum air/fuel ratio during the rich pulse were varied, and the impacts upon pollutant emission rates were measured. Results are presented for five prototype NO_x adsorbers.

EVALUATION OF PASSIVE AND ACTIVE PARTICULATE FILTERS FOR REMOVAL OF PARTICULATE EMISSIONS FROM DIESEL ENGINES

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As particulate emission standards for diesel engines are tightened, manufacturers and users are looking toward catalytic filters as one means of meeting the new standards. This study evaluated the effect of passive and active catalytic filters on diesel exhaust in terms of particulate matter concentration and size distribution, black carbon (soot) concentration, and particle-bound polycyclic aromatic hydrocarbon concentration. Passive filters were installed on three military diesel buses, and an active filter was installed on two military diesel generators. Particle concentrations were measured before and after installation of the filter and again after several months of operation. Generally, the passive filter removed at least 90 percent of particulate matter mass, black carbon, and particle-bound polycyclic aromatic hydrocarbons, and the removal efficiency did not deteriorate after several months of operation. The limited gas-phase pollutant measurements showed that the filters also reduced total hydrocarbon and carbon monoxide. In addition to evaluating the catalytic filters, the sampling team also compared the results of several real-time particle measurement instruments to traditional filter measurements.

EMISSIONS FROM IDLING TRUCKS FOR EXTENDED TIME PERIODS

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The U.S. Environmental Protection Agency, Oak Ridge National Laboratory, and the U.S. Army Aberdeen Test Center (ATC) collaborated to characterize emissions from heavy trucks idling for extended periods. An environmental chamber at Aberdeen was used to vary the ambient temperature with extremes of 0°F and 90°F while the cab temperature was maintained constant. Emissions sampling and measurement equipment was transported to ATC. Gaseous emissions, including aldehydes plus particulate matter emissions, were recorded for five trucks at three ambient temperatures and two idle speeds. The five trucks covered a range of manufacturers and vintages. A truck auxiliary power unit (APU) was tested and compared to idling the engines for the same duty.

The results show interesting time and temperature dependence of the emissions and fuel use. The APU was found to provide major reductions in NO_x and fuel consumption relative to idling the engine for cab heating/cooling.

SIZE-RESOLVED CHEMICAL COMPOSITION OF AEROSOL VIA SINGLE-PARTICLE, REAL-TIME MASS SPECTROMETRY

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We will present results from measurements of single-particle size and chemical composition using the Brookhaven National Laboratory (BNL) Single Particle Mass Spectrometer (SPMS). We will also demonstrate our data analysis and visualization tools that provide an interactive interface between the user and the statistical analysis package.

SPMS is the ideal tool to address the combustion engine industry needs to characterize particulate emissions. It provides real-time detailed accounting of particle composition and size as a function of time and distance from the point of emission, making it possible to derive correlations between engine and fuel performance and aerosol properties.

The compositions of exhaust aerosol tend to be complex, containing inorganic compounds, elemental carbon, and a large number of organic compounds, many of which are semi-volatile. SPMS can readily distinguish between the three classes and quantify their presence.

Single-particle instruments use an ultraviolet laser to vaporize individual particles and produce ions for time-of-flight mass analysis. The vaporization ionization process, also known as ablation, is highly nonlinear and nonspecific. Organic compounds tend to be the most sensitive to the ablation process, producing a high degree of fragmentation that can vary drastically from one particle to the next. To resolve this problem, we at BNL have recently developed an experimental approach, in which particle evaporation is separated from ionization, thereby eliminating the inconsistent spectra and the nonlinear response. Moreover, we are in the process of introducing modifications that are designed to make possible a molecular-level analysis of the highly complex organic fraction.

DEVELOPMENT OF A SUB-GRID MODEL OF A DIESEL PARTICULATE FILTER

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The U.S. Environmental Protection Agency's (EPA) 2007 heavy- duty diesel engine exhaust emissions standards mandate a 90-percent reduction in particulate matter over current levels. The majority opinion in the diesel industry is that these standards are, by implication, mandating exhaust particulate filtration for diesel engines. Currently there is no commercially viable filtration technology that can be universally applied to all on-highway heavy-duty diesel engines. Several key technical hurdles that must be overcome in order for diesel particulate filters to become practical include: filter plugging, thermal failures, size, cost, filtration performance, and durability.

The resolution of these issues requires a detailed systems-level understanding. This includes the diesel engine's characteristics and the application duty cycle in order to understand the temperature of exhaust gas and its constituents. It also includes a characterization of installation requirements and the individual aftertreatment-device performance to understand filtration effectiveness, durability, and fuel-economy impacts.

In order for the diesel industry to meet the quickly approaching EPA regulations, the industry requires modeling capabilities. These models can be used to optimize the engine-control strategies in order to help determine the physical dimensions of the catalyst system and to simulate numerous real-world applications, which are prohibitively expensive to test in the field. Regardless of the specific question being answered, a critical key component of these models is the representation of the soot oxidation rate. This term directly influences most of the macroscopic phenomena of interest, including filtration efficiency, heat transfer, back pressure, and substrate geometries.

One key technical challenge relates to the fact that particulate filter soot regeneration remains a poorly understood and inadequately characterized phenomenon. Current sub-grid models use gross simplifications to represent the carbonaceous soot oxidation rates. All phenomena that occur on the finest length scales (approximately less than 100 microns) are typically lumped together into a single Arhenius-type equation with curve-fitted, pre-exponential and activation energy terms. Furthermore, intrinsic soot cake properties, such as packing density, permeability, and heat transfer coefficients, are poorly understood. Improvements in these sub-grid model formulations will improve the ability of engineers to model the filter on a device scale and lead to better systems optimization capabilities and improved design tools.

This paper will report on improved sub-grid representations of the local oxidation reactions by employing detailed sub-grid modeling techniques. These techniques involve the use of a lattice Boltzman modeling approach coupled with validation via both

in-situ and ex-situ experiments. This approach resolves length scales, which are orders of magnitude below those typical of a standard computational fluid dynamics (CFD) representation of an aftertreatment device. This improved resolution allows for the characterization of functionality not previously employed in the CFD analysis. Sub-grid modeling results will be presented describing the interactions of the soot-cake layer evolution with the substrate structure and catalyst materials.