Abstracts

SESSION 8 – Diesel Engine Emissions, Parts 1 and 2

Chair: **Roland Gravel, U.S. Department of Energy**

Development of an Active Regeneration Diesel Particulate Filter System

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Due to increasingly strict Diesel engine emission regulations, exhaust aftertreatment devices are widely used to reduce harmful emissions. Particulate matter (PM) emissions have been typically reduced through the use of Diesel particulate filters (DPF). Unless the filter is cleaned, or regenerated, it will eventually fill with soot and become plugged. The two most common forms of regeneration include: 1) passive regeneration where the filter relies on catalytic treatment and sufficient exhaust gas characteristics and 2) active regeneration where controlled heat is added to burn the soot from the filter. In general, the strict requirements for reliable passive filter operation have precluded their use in many applications. Active regeneration is one way to overcome the limitations of passive systems.

A new active filter regeneration system was developed for both retrofit and 2007 original equipment manufacturer aftertreatment applications. The current system is intended for retrofit market release by first quarter 2005. Several active regeneration technologies were evaluated including electric heating, fuel burners, and aerodynamic pulsing. Fuel Injection (FI) based active technology was selected based on preferred regeneration characteristics and less complex system design. General system development and details of key subsystems will be discussed. Extensive lab and field test results will be shown.

Two critical success factors are transient control of fuel injection and a robust regeneration strategy. To allow for use on a wide variety of vehicle applications and duty cycles, a model-based feed-forward adaptive control algorithm was developed. Transient control was refined to ensure rapid regeneration while avoiding thermal degradation of the catalyst system. A regeneration strategy that addresses the issues of fuel penalty and catalyst durability was developed.

To provide for the widest operating range and design flexibility, a unique fuel delivery system has been developed. The effects of the fuel system design parameters such as atomizer design, spray pattern, and fuel/air pressure on regeneration performance will be discussed.

The catalyst system design has significant effect on the operation, efficiency, and durability of the active system. To provide for high hydrocarbon conversion efficiency, low light-off temperature, low tailpipe NO_2/NO_X ratio, and desired durability, a number of catalyst formulations for the Diesel oxidation catalyst (DOC) were evaluated. In addition, the effects of DPF catalyst formulation on regeneration duration and temperature profile were evaluated. Lastly, combinations of the DOC and DPF were evaluated to characterize system-level performance synergies.

Finally, other system parameters including flow distribution, backpressure, outer surface temperature, exhaust leaks, and filter maintenance have been investigated.

Excellent Fuel Efficiency while achieving 2007 Emissions Goals

Chris Nelson
Cummins, Inc.

Since 2001, the Department of Energy has challenged Cummins Inc. to pursue increased levels of Brake Thermal Efficiency amidst the onslaught of ever more stringent emission goals for Heavy-Duty (HD) Trucks. In response to this, Cummins has responded by first achieving 45 percent Brake Thermal Efficiency in January of 2002 while meeting 2002 Legislated Emissions for HD Trucks and then, most recently, by achieving 44 percent Brake Thermal Efficiency in February of 2004 while meeting 2007 Legislated Emissions for HD Trucks. This most recent achievement was accomplished by incorporating advanced, in-cylinder combustion techniques with increased levels of cooled exhaust gas recirculation to reach the very low levels of brake specific nitrogen oxides called for and regenerative particulate filtering to address brake specific Diesel particulate matter goals. Optimized parasitic loads were also studied to benefit the Brake Thermal Efficiency goal. The base engine system was demonstrated to achieve emissions and efficiency performance goals in a calibrated engine test cell. Concurrently, an in-vehicle demonstration was made to prove the realistic feasibility of this technology solution.

Rypos Trap-Field Demonstrations and Recent Developments

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The Rypos Trap is an actively regenerated Diesel exhaust particulate trap in which the filter media and the heating element are one and the same. The filter material is made of sintered metal fibers and has high porosity, high soot holding capacity, and low thermal mass. The trap is self cleaning by an electrical current and very tolerant of fuel sulfur levels. It can be combined with a Diesel oxidation catalyst to further reduce Diesel emissions. The Rypos Trap is currently installed on a prime power generator, accumulating operating hours towards durability testing. Recent developments include scaling up the design to larger applications, such as up to 2 MW electrical generators. The Rypos Trap regenerates during normal operation and does not require being taken off line to regenerate. Fuel penalty for regeneration is about 1 percent. Regeneration is controlled by monitoring back pressure and exhaust temperature. Soot particle reduction is 85-95 percent, depending on design.

Transient Simulation of a 2007 Prototype Heavy-Duty Engine

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Caterpillar ACERT™ (Advanced Combustion Emission Reduction) technology is a unique systems approach to delivering an engine with low emissions and excellent customer value. Simulation played a critical part in the identification and development of the ACERT technology solution. The order of magnitude reduction in emissions required by future regulations requires even more emphasis on simulation for performance, emissions, and controls development. To support this need, a detailed transient simulation model of a prototype 2007 heavy-duty Diesel engine and aftertreatment system has been built in the Caterpillar Dynasty simulation software. The details in the engine model have a one-to-one correspondence to the real engine and the model is hardware and software reconfigurable like the real engine to match different application needs. Results from a transient emissions test cell model containing the engine system are compared to measured data. Results are also shown for the engine system in a detailed on-highway truck model.

Aftertreatment Modeling Status, Future Potential and Application Issues

Brian Bolton, Detroit Diesel Corp

The presentation will cover the status of aftertreatment model performance. The stringent emissions standards of 2007 and beyond require complex engine, aftertreatment and vehicle systems with a high degree of sub-system interaction and flexible control solutions. This necessitates a system-based approach to technology development, in addition to individual sub-system optimization. Analytical tools can provide an effective means to evaluate and develop such complex technology interaction as well as understand phenomena that are either too expensive or impossible to study with conventional experimental means. The analytical effort can also guide experimental development and thus lead to efficient utilization of available experimental resources.

A suite of analytical models has been developed to represent particulate matter and nitrogen oxides aftertreatment sub-systems. These models range from computationally inexpensive zero dimensional models for real-time control applications to computational fluid dynamics (CFD) based multi-dimensional models with detailed temporal and spatial resolution. Such models in conjunction with well established engine modeling tools such as engine cycle simulation, engine controls modeling, CFD models of non-combusting and combusting flow and vehicle models provide a comprehensive analytical tool-box for complete engine, aftertreatment and vehicle sub-systems development and system integration applications. However, the fidelity of aftertreatment models and application going forward is limited by several factors, including for example the lack of fundamental kinetic data.

Advanced Diesel Common Rail Injection System for Future Emission Legislation

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Future emission legislation will define a challenging goal for Diesel engines and an intense competition with alternative concepts e.g. advanced gasoline engines. Lowest emissions with the highest engine performance, namely high specific power output, gasoline like noise levels, benchmarking low fuel consumption, and attractive costs are defining the goals of future development activities. The key for success will be a highly sophisticated Fuel Injection System which supports all of these goals.

To cover all segments of Diesel market demands BOSCH started two parallel development paths; an evolutionary way based on the piezo-inline injectors and a revolutionary way to define the requirements for future injection systems regarding mixture preparation, maximum injection pressure, rate shaping capability, and multiple injections. Based on studies with state-of-the-art piezo systems and several versatile prototype injection systems a comprehensive engine investigation was accomplished to determine the optimum system configuration for the above mentioned Diesel engine goals.

Applying the criteria function performance, manufacturing robustness, durability over lifetime, and costs, the number of technical solutions has been reduced down to four concepts which were selected for the future product development process.

With all four concepts, the “Piezo Vario Coaxial Nozzle Injector”, “Hydraulically Amplified Diesel Injector”, both stages of the “Piezo-Inline Injectors” (Vario Coaxial Nozzle and 2000bar injector), and the “Hydraulically Amplified Diesel Injector” BOSCH will support the engine manufacturers to achieve challenging future emission goals in a wide spectrum of engine applications for cars and trucks. To maintaining the highest fuel metering accuracy, intelligent closed loop functions will drive the hydraulic system. In addition for the “Piezo Vario Coaxial Nozzle Injector”, and “Hydraulically Amplified Diesel Injector” concepts, the innovative high pressure platform, the so-called CP4, will be introduced in regard to the hydraulic system.

Performance and Durability Evaluation of an Integrated NO_X Adsorber Aftertreatment Subsystem

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In order to assess the capability of an integrated nitrogen oxides (NO_X) and particulate matter (PM) aftertreatment system to meet expected 2007 emission levels, several durability tests were conducted. These durability tests included: (1) a 500 hour accelerated test focusing on thermal deactivation, (2) a 500 hour accelerated test focusing on both thermal deactivation and sulfur poisoning, (3) a 1250 non-accelerated test focusing on thermal deactivation and sulfur poisoning, and (4) a vehicle test to assess the cold-operation capability of the aftertreatment system. First, the main catalyst deactivation factors for integrated NO_X and PM aftertreatment systems were described. Then each durability test scope and procedure was described. Results for each durability test for NO_X, PM and other conversion functions were presented. The results included steady state NO_X conversion, NO_X capacity, sulfur capacity, NO_X conversion over transient cycle, and PM regeneration. Based on the results, several improvements to the architecture of the integrated aftertreatment system were suggested to improve overall performance.

Long-Term Aging of NO_X Sensors in Heavy-Duty Engine Exhaust

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The Advanced Petroleum Based Fuels – Diesel Emissions Control (APBF-DEC) program has sponsored an ongoing project at Southwest Research Institute to assess the low emissions potential of an emission control system consisting of urea selective catalytic reduction (SCR), exhaust gas recirculation, and diesel particulate filters. This project includes an aging phase in which the emission control systems are exposed to exhaust from a heavy-duty engine operating over a cycle for a total of 6,000 hours. During this phase of the work, 25 nitrogen oxides (NO_X) sensors, generously supplied by NGK, are also being exposed to the engine exhaust for the 6,000 hours. The sensors are located in three different locations along the exhaust stream – two locations upstream of the SCR catalyst and one after the cleanup catalyst at the end of the system. Sensors of two different NO_X ranges are included – 1-1500 ppm and 0-500 ppm.

Performance of the sensors is being monitored continuously along with the emission control systems' performance. This paper summarizes the NO_X sensors' performance for the first 2,000 hours of the aging test. The analysis of data examines how well the NO_X sensors correlate with the NO_X analyzer data, whether there are systematic changes in sensor performance, how often the sensors need recalibrations, and what might be their expected life.

NO_X Sensor and NO_X Removal Technologies at Ceramatec, Inc.

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Ceramatec, Inc. is developing a nitrogen oxides (NO_X) sensor and NO_X removal technologies. The sensor work is funded by the Environmental Protection Agency (EPA) and the NO_X removal work is internally funded.

In the EPA funded program, Ceramatec has demonstrated a mixed potential type sensor system which offers the advantages of high-temperature operation and very good sensitivity to low NO_X concentrations due to the logarithmic response to NO_X concentration. Previously, mixed-potential type NO_X sensor technologies have been limited by problems of cross sensitivity with other gas constituents commonly found in diesel exhaust, as well as an inability to provide a meaningful signal in varying NO/NO_2 mixtures. A novel proprietary catalyst system developed at Ceramatec has overcome many of the problems previously associated with such NO_X sensors. Sensors have been fabricated and tested that have the following characteristics: (1) Operation temperature of 500-600°C; (2) excellent sensitivity in NO_X levels of 1-1200 ppm; (3) response times as fast as 1-3 seconds; (4) insensitivity to various NO/NO_2 ratios in the exhaust stream; (5) very low cross-sensitivity to carbon monoxide, carbon dioxide, water, and low levels of sulfur dioxide; (6) ability to operate in oxygen-containing environments with no requirement for a pumping cell. The primary application targeted for the new sensor technology is heavy-duty diesel trucks. Other potential applications include advanced turbines, light-duty trucks, automobiles, heavy farm and construction machinery, off-road vehicles, and power generation as well as applications that utilize natural gas as the combustion fuel.

Through internally funded work, Ceramatec has developed a proprietary ceramic catalyst system, with no noble metal content, that can oxidize >85% of nitric oxide (NO) to nitrogen dioxide (NO_2) at 275°C. In combination with a conventional NO_2 adsorber, which intrinsically is a very poor absorber of NO, it has been demonstrated that the catalyst can remove greater than 95% of NO from a gas mixture. Ceramatec is actively seeking partners to develop this technology for engine emissions reduction systems.