Abstracts

SESSION 12 – Emission Control/PM Reduction

Chair: **Mike Bogdanoff, South Coast Air Quality Management District (SCAQMD)**

Particle Sensor for Diesel Combustion Monitoring

David Kittelson and Hongbin Ma, University of Minnesota
Michael Rhodes and Brian Krafthefer, Honeywell International

The goal of this research program has been to develop a particle sensor for use in Diesel engine applications that is low cost, robust to harsh environments, and manufacturable in high volume. The sensor would be used for engine control applications as opposed to highly accurate laboratory measurements. The current sensor concept is based on image charge monitoring for reasons of probe (electrode) complexity, probe ruggedness, electronics complexity, speed of response, and background effects. The sensor has demonstrated good response with well-defined and reproducible signals and is applicable across multiple engine sizes and types. The sensor response is proportional to the soot or elemental carbon concentration in the exhaust. The time response of the sensor is sufficient to monitor emissions from individual cylinders and its sensitivity is sufficient to detect particle emissions from modern low emission engines such as a Euro IV VW TDI and a Caterpillar C12. The sensor's unique design makes it resistant to carbon fouling. The sensor works best near the exhaust ports because the strength of the signal decreases downstream, although flow through the turbocharger has no significant effect on sensor response. Tests on the VW TDI which was equipped with a catalytic converter showed a 30 percent reduction in sensor response on passing through the catalyst, while tests on the Caterpillar C12 which was equipped with a Diesel particulate filter (DPF) showed nearly 100 percent reduction of the sensor signal (and soot) downstream of the DPF. These results suggest that sensors installed upstream of aftertreatment could be useful for engine control and determination of when filter regeneration is necessary, while sensors downstream of aftertreatment could be useful in on-board diagnostic applications.

Reliability and Design Strength Limit Calculations in DPF's

James E. Webb
Corning Incorporated

Diesel particulate filters, particularly those for heavy duty applications, have stringent requirements for reliability and lifetime. From these requirements, estimates of design strength limits can be calculated. The design strength limits presented here are based on parameters including shape of the strength distribution, DPF size, and time dependent strength or what is commonly known as fatigue behavior in ceramics. Some sample calculations will be presented with typical mechanical properties. However, the main focus will be a normalized strength approach, where the impact of the various inputs on the design strength limits can be compared to each other, similar to a sensitivity analysis. From these design strength limit estimates, implications for confidence intervals and design of test plans will also be discussed.

A New CFD Model for Understanding and Managing Diesel Particulate Filter Regeneration

Z. Jason Hou and Ted Angelo
Donaldson Company, Inc.
PO Box 1299
Minneapolis, MN 55440-1299
952-703-4888
jhou@mail.donaldson.com

One of the key challenges to Diesel Particulate Filter (DPF) technology is regeneration. How well regeneration is understood and managed will have a significant impact on the success of this technology. A good regeneration can be defined as fast, complete, safe, and causing minimal fuel penalty. To achieve this goal, the impact of exhaust gas flow rate, gas temperature, oxygen content, filter material, and soot loading, to name just a few, on regeneration performance must be studied and understood.

DPF regeneration involves a complex variety of physical and chemical processes, encompassing fluid flow, heat transfer, chemical reaction, and catalysis. Modeling can be an effective method to study the complex activities encountered during regeneration. However, most models in the literature are two-dimensional and based on assumptions that the flow field in DPF channels can be treated as such, even though the flow in DPF is fundamentally three-dimensional. There is also a lack of sophistication in the way the filter wall (substrate) and the soot cake layer are modeled.

A new computational fluid dynamics model was developed to predict fluid flow, heat transfer, and soot reaction during DPF regeneration. The underlying physics was solved in one inlet/outlet channel set based on a three-dimensional, unsteady framework. The filter wall and the soot cake layer was modeled as porous media, for which the full Navier-Stokes equation is solved. Specific permeability and thermal properties were assigned for the wall layer and the soot layer, which vary as regeneration proceeds and as a function of temperature. Soot combustion was tracked with a modified Arrhenius equation, which includes the effect of the catalyst applied on the filter.

The model was validated by comparisons with results of DPF heat-up tests and regeneration tests. The validated model was then used to study the effects of exhaust gas flow rate, exhaust gas temperature, oxygen content, filter design, and soot loading on regeneration performance. Spatially and temporally resolved distributions of velocity, temperature, oxygen, reaction rate, and soot layer thickness, etc. will be presented. The model was also used for “what-if” studies, such as the runaway regeneration scenario study. Excellent agreement between measurement and prediction was achieved. The model is being used in the design and development of DPF systems.

Diesel Particulate Filter Technology for Low Temperature and Low NO_X/PM Applications

Sougato Chatterjee, Ray Conway, Satish Viswanathan, Todd Jacobs
Johnson Matthey Catalysts
Environmental Catalysts & Technologies

Diesel Particulate Filter Technology is being widely accepted as a retrofit or first fit technology that can provide significant reductions in hydrocarbon (HC), carbon monoxide (CO) and particulate matter (PM) emissions. Numerous tests and fleet demonstration programs have shown that the technology can be installed and operated for a reasonable cost and that the technology is durable. As a result many legislators are requiring the retrofit of captive Diesel fleets with this technology. Before Diesel particulate filter (DPF) technology can be fit into an application, the vehicle has to be evaluated to ensure that its operating characteristics will allow for the proper operation of a passive device. For the Johnson Matthey CRT® (Continuously Regenerating Technology) to work properly the exhaust temperature profile and the engine out NO_X to PM ratio must be above specific levels. If these criteria are not met, there will be insufficient soot combustion in the filter resulting in high back pressure that will hamper engine operation. In our experience we have found primarily two types of applications that will not work well with the CRT; vehicles with operating cycles that have very low temperature profiles and vehicles with engines that have low NO_X/PM ratios under the real world operating cycle.

This paper will discuss technologies that Johnson Matthey has developed to address applications that have low exhaust temperature profiles, low NO_X/PM ratios, or both. One is a passive system that is a combination oxidation catalyst and catalyzed soot filter and the second is an active system that increases the engine out exhaust temperature by throttling the engine inlet air.

The CCRT® (Catalyzed –CRT) is similar in function to the CRT in that it consists of an oxidation catalyst up stream of a wall flow filter. However, in the CCRT, the wall flow filter has a catalytic coating. Similar to the CRT, nitrogen oxide (NO) is oxidized to nitrogen dioxide (NO_2) in the catalyst section of the CCRT and the NO_2 oxidizes soot trapped in the filter. Within the catalyzed filter of the CCRT, the NO that is formed from the reaction of soot with NO_2, can again be converted to NO_2 and can thus be reutilized for further soot combustion. Because of this mechanism, the CCRT can be used in applications with low NO_X/PM ratios. The additional NO_2 availability also appears to allow the CCRT to operate at a much lower temperature than the standard CRT.

Studies have shown that restriction of the air flow into or out of the engine will increase the exhaust temperature, but careful control is necessary so that such a system will not affect engine power or emissions. The active system developed by Johnson Matthey involves throttling the engine inlet air at the air inlet manifold. The system monitors the engine speed and load and only applies throttling at conditions that have low exhaust temperatures. The maximum amount of throttling that can be applied at each load and speed was determined through an engine mapping process. The maximum amount of throttling that can be applied is limited by the effect on power, inlet manifold temp, increase in exhaust temperature, and engine out emissions. This throttle based active regeneration device can increase the on-road exhaust temperature profile by up to 60°C thus enabling CRT operation in cold exhaust applications.

This presentation will show development test data for both of the above products as well as on-road durability data.

Advanced Ceramic Filter for Diesel Emission Control

Cheng G. Li, Frank Mao, Ravi Ramanathan
Dow Automotive

A new advanced ceramic (ACM) filter for both Diesel particulate matter and exhaust gas emission control has been developed by Dow Chemical Company through a catalyst reaction process. With the ability to modify the filter wall porosity and pore size distribution, the ACM filter provides deep filtration and performance benefits such as little pressure drop, fast regeneration, and multiple emission catalyst function. This technology can also be applied to fine particulate filtration. The testing results from laboratory and an engine dynamometer have demonstrated ACM's advantage as expected and also indicated that there is a high possibility of a 4-way system development by using ACM.

A New Active DPF System for Duty Cycle Vehicles: Durability and Improvements

Jean-Claude Fayard, COMELA
Thierry Seguelong, Aaqius & Aaqius

Diesel urban buses as well as refuse trucks are part of the particulate emission sources that affect the city air quality. So, several Diesel particulate filter (DPF) systems were proposed to reduce such emissions. But the reliability and the durability of the current DPF systems remain an issue, due to the lack of the filter regeneration control during the duty cycles.

To fit particular duty cycle requirements, a new active DPF system was developed with a new regeneration strategy in order to overcome the durability and reliability issues. The DPF system consists of particulate filter units, an oxidation catalyst placed in front of the filters, valves and actuators allowing thermal insulation of the filter units, temperature and pressure sensors, and an electronic control unit to control the positions of the insulation valves.

The principle strategy is based on an adjustable volume of filtration in combination with the global thermal management allowing the filters to regenerate in all driving conditions. Furthermore, in order to fully control the filters regeneration, an additional heat injection strategy is needed. Diesel fuel injected over the oxidation catalyst, heats up the filters individually depending on the position of the insulation valves.

The DPF System was evaluated by the ADEME (French Agency for Environment and Energy Management) on refuse truck (EURO2) applications for more than 12 months, using standard European Diesel fuel (350ppm of Sulphur). The DPF system demonstrated high efficiency and durability and reduced particulates by more than 89 percent (in mass per kilometre) over the duty driving cycle reference. This result confirms the previous evaluations carried out on EURO½ urban buses and EURO3 original equipment manufacturer refuse trucks.

In parallel, in order to extend the field of applications, further improvements have been developed, using a fuel-borne catalyst (FBC) to control the filters regeneration and limit the maintenance. The experiments have demonstrated the positive effects of FBC in the trap loading as well as the filter regeneration. In addition, the combination of the basic process and the FBC leads to a limitation in FBC dosing rate. Details of experiments and results will be presented in the paper.

DPF Systems Comparison – Fuel Borne Catalyst or Catalyzed Particulate Filter for Diesel Passenger Cars

J. Michelin, S. Schürholz, A. Lang, and F. Terres
Tenneco Automotive

The German Automobile industry has announced to fit at least a part of their Diesel models with particulate filters by the beginning of this year (2004). In contrast to the PSA concept, which is dependent on fuel additives to support the regeneration, most of the German car manufacturers want to launch a system that operates without additives. The innovative system they rely on needs a catalyzed soot filter.

The content of this presentation is the technical comparison of both concepts with regard to exhaust backpressure, regeneration behavior, packaging and related issues, fuel consumption, and operating cost. In this comparison the fuel borne catalyst has clear technical advantages. A severe disadvantage is the additional ash from the fuel-bourne catalyst clogging the filter leading to an increased maintenance schedule. This issue can be solved using a bigger filter or using new filter geometry.

Using P-CAT, a calculation tool developed by Tenneco Automotive, it is possible to show that the back pressure targets for 250,000 km (useful life) set by the car manufacturers can be met with both systems. On one hand, the fuel additives have been optimized, which permitted a reduction in the dosage and thereby reduced ash production. On the other hand, a new generation of filters has been developed with optimized ash storage capacity.

Improvement and Simplification of DPF System Using a Ceria-based Fuel-borne Catalyst for Diesel Particulate Filter Regeneration in Serial Applications

Pierre Macaudiere
Rhodia Electronics & Catalysis

Since the market introduction of the Diesel Particulate Filter (DPF) system in serial applications in May 2000, more than 500,000 vehicles have been DPF-equipped. Tracking the current situation, several themes for improvement have been identified, including system simplification to limit its total cost as well as proposition to optimize maintenance. The paper presents those upgrades that will be proposed in serial applications.

Based on DPF regeneration assisted by engine management systems in combination with the use of a Ceria-based fuel-borne catalyst, the first improvement is to limit the ash build up phenomenon of fuel-borne catalyst and then to limit the DPF clogging effect.

In the first stage, catalytic activity of Ceria-based fuel-borne catalyst has been improved, by introducing Iron as a catalytic promoter. Targeting the “fit for life” DPF application (and thus "zero maintenance" on the DPF), it is necessary to find a compromise between the catalytic activity (reduction in the temperature of soot burn-off and kinetics of DPF regeneration), the temperature peak generated during the DPF regeneration (exotherms of regeneration), and the density of the inorganic ash arising from the fuel-borne catalyst (ash build-up speed). A good compromise is proposed in this way, based on the use of the Iron-doped Ceria nanoparticules as the active catalytic ingredient.

In parallel, a dosing strategy of a fuel-borne catalyst is being developed to match with the proposed evolution in the Ceria-based fuel-borne catalyst for serial applications. New designs of the automatic on-board dosing system have been developed to ensure the global accuracy in the Diesel fuel treatment. On the other hand, the maintenance operation for fuel-borne catalyst tank refilling is integrated in the design of the dosing systems, which is adapted to the platform of the vehicle and the car makers’ specifications. In the paper, the following approaches are developed, and the data obtained on a demonstrator are proposed.

Retrofit Program on EURO 1 and EURO 2 Bus Fleet in La Rochelle using a Ceria Based Fuel Borne Catalyst for Diesel Particulate Filter Regeneration - Status after one Year Experience.

Laurent Rocher
Rhodia

Diesel emission control is becoming a priority particularly in urban areas and specific efforts are made to reduce emissions from urban buses. In September 2003 the CDA La Rochelle has started a voluntary retrofit program to equip their EURO 1 & 2 urban bus fleet. The selected technology was the combination of a Silicon Carbide Diesel Particulate filter and a Ceria based fuel borne catalyst used to ensure a fast and complete Diesel particulate filter (DPF) regeneration. This paper describes the preliminary technical assessment phase which was done to implement the system followed by the extension of the equipment to the whole bus fleet.

In the first phase a preliminary study was carried out on a EURO 2 Diesel engine bench test to check the regeneration behavior and thus the efficiency of the DPF technology. In the second phase the system was fitted on 4 buses and has proven its efficiency after 4 months of field evaluation even with fuel containing 250 ppm sulfur. In parallel a stationary automatic dosing system was used to add the ceria based fuel borne catalyst to the fuel by a co-filling process.

After this field evaluation, the CDA La Rochelle decided to extend the DPF system to the whole EURO 1 and EURO 2 bus fleet. Different parameters were measured (back pressure, exhaust temperature and efficiency of DPF regeneration). A specific maintenance procedure was also set up and the filter could be washed successfully by using a mobile DPF washing machine.

The paper relates more than 10 months of a large scale experience showing the reliability of a diesel emission control technology based on a Particulate Filter and a ceria based fuel borne catalyst. Details of experiments, results, and approaches will be described in the paper.

Diesel Particulate Filters Market Introduction in Europe: Review and Status

Thierry Seguelong
Aaqius & Aaqius

The challenge for Diesel particulate filters (DPF) in serial applications is real, multiple, and complex. Taking into account different and sometimes conflicting aspects such as: **technical** (DPF efficiency, reliability, durability, and compatibility with engine performance); **economical** (system cost compatibility and maintenance); **environmental** (regulated and non-regulated emissions, such as nitrogen dioxide, ozone, furans, dioxins, and solid particulate); **geographical** (flexibility regarding Diesel fuel qualities and sulfur content); and finally, **customer acceptance** (extra cost, vehicle drivability, acoustic performance and maintenance constraints).

Since May 2000, PSA Peugeot Citroën has marketed the "FAP™" DPF System as a world first. It is based on the sequential DPF regeneration that uses a specific engine management, a silicon carbide-based DPF, pressure and temperature sensors, adapted DPF canning, the Eolys™ Ceria-based fuel-borne catalyst, and an automatic on-board dosing system. Since its market introduction, more than 1million vehicles have been sold over Europe, without recall or failure, and with constant improvement in the global DPF System approach.

With EURO IV deadline approaching, European car manufacturers have accelerated their development effort and the Diesel Particulate Filter was the most presented emission control technology during the 2003 edition of the prestigious Frankfurt Auto Show. The principle of a Diesel soot filter was largely announced and appears to have gained automotive industry acceptance as the preferred technology for Diesel particulate emission control. This move from industry is also a response to the current pressure of environmental organizations and public opinion in some countries. As main conclusions on the Frankfurt Auto Show, it can be said:

- The important number of announcements confirms that DPF is now accepted by the Automotive Industry.
- Uncertainties remain as to when significant series introduction will truly begin.
- Maturity of the different technological options is diverse and work remains to be done.

The paper will present the present situation and the main issues to address such as the global cost function and evolution, the maintenance and recycling, and the compatibility in the next challenge of particulate matter, nitrogen oxides, and carbon dioxide standards.

Soot Nanostructure: Definition, Quantification and Implications

Dr. Randy L. Vander Wal and Aaron J. Tomasek
The NCMR c/o the NASA-Glen Research Center

Soot is ordinarily considered as a carbonaceous material with environmental and health consequences highly dependent upon particle size. Though to-date unexplored, the nanostructure of the soot, i.e. the degree of atomic level order in carbon lamella comprising the soot primary particle can have profound consequences for soot reactivity and associated environmental and health effects. The talk will define soon nanostructure, describe its quantification by image analysis of high resolution transmission electron microscopy images and illustrate its impact on oxidation rate.

Differences in soot nanostructure based upon formation and growth conditions will be presented first. Fuel structure effects can be masked or accentuated depending upon both temperature and rate of increase. Low temperature yields different results depending upon the rate of increase. A rapid increase as realized by a high flow rate, emphasizes pyrolysis kinetics that favor polyaromatic hydrocarbons (PAHs) with 5-membered rings leading to soots with many shells capsules; a highly curved nanostructure. Slower rates result in a different pyrolysis chemistry leading to graphitic soot, as characterized y long graphite segments, oriented parallel to each other. Reflecting high thermodynamic stability, PAHs may resist decomposition and yield a less graphitic soon nanostructure using either a fast or slow temperature increase. In contrast, ethanol produces a highly curved nanostructure using wither temperature increase rate.

To quantify these differences in nanostructure, a lattice fringe analysis program has been developed to quantify the data conveyed by HRTEM images. By providing a direct measure if the molecular level of graphitic structure, it is expected that its application could provide predictive capabilities for carbon reactivity, particularly towards oxidation. The robustness of this program is demonstrated by using a series of carbon blacks possessing different levels of graphitic structure, prepared at different heat treatment temperatures. Its credibility is benchmarked against a traditional measure if graphitic structure as provided by Roman analysis. Lattice fringe length is found to be monotonic with the level of graphitic structure as provided by the ration of the integrated intensities of the G/D spectral peaks in the Raman spectra. Reciprocally, for production purposes, the G/D band intensity ratio can serve as a direct measure of the lattice fringe reactivity.

We further explore the relationship between soot nanostructure and reactivity towards oxidation by measuring the oxidation rates of laboratory synthesized soots with Ò modelÓ identity. Structural variations in the graphene layer plane dimensions necessarily alter the ratio of basal plane versus edge site carbon atoms. A corresponding variation on the overall reactivity, reflecting an average of the different relativities associated with these specific atomic sites arises. This variation is illustrated here between a disordered soot derived from benzene and a graphitic soot derived from acetylene. Their oxidation rates differ by nearly 5-fold. Curvature of layer planes, as observed for an ethanol derived soot, is found to substantially increase oxidative reactivity. Relative to fringe length as a manifestation of graphitic structure, curvature more effectively increases reactivity towards oxidation. Larger variations in oxidation behavior may be expected, depending upon the soot synthesis conditions. Other physical properties may similarly be affected. Related implications due to differences in nanostructure will be discussed.

Emission Control Systems and Components for Retrofit, and First-Fit Applications

Bradley L. Edgar, Ph.D.
Cleaire Advanced Emission Control

Cleaire has developed a set of core components that serve as "building blocks" of integrated emission control systems for retrofit and first fit applications. The key components include the following: a modular "gasketless" packaging design, a hydrocarbon dosing system, a control module with datalogging and I/O capability, an active lean NO_X (HC-SCR) catalyst, and a catalyzed silicon carbide particulate filter. These components can be assembled in total as an integrated "turnkey" system for retrofit applications, or can be used individually to support optimized catalyst/engine platforms for First-Fit applications.

An example of an integrated "turnkey" system is Cleaire's Longview; the first CARB verified NO_X and PM control system for retrofit applications. The system, called Longview, is verified to reduce NO_X by 25% and PM by 85% on the majority of heavy-duty diesels built between 1994 and 2002. To date, over 500 systems have been installed in a variety of applications. As a result, these systems and components have logged millions of miles and thousands of hours of "real world" experience, which has proved their durability and robustness.

This presentation will discuss the design, testing, and application of these systems and components.

Catalyzed Particulate Filter: Development and Application for Diesel Engine Emission Control

Yinyan Huang, Zhongyuan Dang, Yongtaek ChoiAmiram Bar-Ilan
Süd-Chemie Prototech, Inc.

A catalyzed Diesel particulate filter (CDPF) was developed with the use of Corning cordierite wall flow filter substrate. A new precious metal/base metal catalyst on high surface area support was developed. The deposition of catalyst/washcoat leads to negligible back pressure increase to blank filter substrate. Lab bench testing shows that the CDPF is very active for the oxidation of carbon monoxide (CO) and hydrocarbon (HC). Supporting the catalyst on high surface area material enhances the activity for CO, HC oxidation. The catalyst also shows high thermal stability.

The CDPF was tested on 8HP LPA2 stationary Diesel engine at 1800 rpm with the use of federal Diesel fuel. The balance point temperature of the CPDF is 350°C. As the CDPF was tested on Caterpillar C12 Diesel engine with ultra low sulfur Diesel fuel, high removal efficiency of CO, HC and PM was achieved. The measure balance point temperature is 300°C.

Full verification of the CDPF for back-up generators (BUG) at Ce-Cert is in progress. Under ISO8178 five model test cycles with the use of regular CARB fuel resulted in the CDPF having a high removal efficiency of CO (99%), THC (86%) and PM (90%) for Caterpillar 3406 Diesel Genset.