



Abstracts

Plenary Session – A View from the Bridge

U.S. ENVIRONMENTAL PROTECTION AGENCY HIGHWAY AND NON-ROAD DIESEL STANDARDS UPDATE

William Charmley

U.S. Environmental Protection Agency

ABSTRACT

This presentation will provide an overview of the U.S. Environmental Protection Agency (EPA) highway heavy-duty diesel 2007 program and an update on recent progress, including both light-duty and heavy-duty vehicles. The presentation will also discuss EPA's recent proposal for a new standards

that would dramatically reduce the fuel sulfur levels in off-highway diesel fuel and at the same time require dramatic reductions in particulate matter and oxides of nitrogen from non-road diesel engines used in farm, construction, and industrial equipment.

GLOBAL CLIMATE CHANGE AND THE TRANSPORTATION SECTOR: AN UPDATE ON ISSUES AND MITIGATION OPTIONS

Charlotte A. Geffen and James J. Dooley

Battelle Pacific Northwest National Laboratory

ABSTRACT

It is clear from numerous modeling exercises that addressing the challenges posed by global climate change will eventually require the active participation of all industrial sectors and consumers on the planet. Yet, these and similar modeling exercises indicate that it is the large stationary CO₂ point sources (e.g., refineries and fossil-fired electric powerplants) that are likely to be the first targets for serious CO₂ emissions mitigation. While focusing on large stationary point sources might be a useful starting point, these efforts ultimately must be expanded to include all other sectors of the global economy. Because of its operating characteristics, price structure, dependence on virtually one energy source (oil), and enormous installed infrastructure, the transportation sector will

likely represent a particularly difficult challenge for CO₂ emissions mitigation. Our research shows that climate change induced price signals (i.e., putting a price on carbon that is emitted to the atmosphere) are unlikely to result in fundamental shifts in demand for energy services or to transform the way these services are provided in the transportation sector. We believe that a technological revolution will be necessary to accomplish the significant reduction of greenhouse gas emissions from the transportation sector. This talk will present an update of ongoing research into a variety of technological options that exist for decarbonizing the transportation sector and the various tradeoffs among them.

GLOBAL CLIMATE AND ENERGY PROJECT

Chris F. Edwards

Stanford University

ABSTRACT

Energy is the lifeblood of modern societies. Within 20 years, 7.5 billion humans will occupy this planet, about 25 percent more than do so now. They will want to heat and light their homes, power electrical devices, move from place to place, grow food, and drink clean water. Supplying the energy required to do all this is, by itself, a significant challenge. But that is only part of the challenge. It is now apparent that humans are interacting with the chemistry of the planet on a global scale. The concentration of CO₂ in the atmosphere has increased by a third from its pre-industrial levels. There has been an easily detectable change in the pH of the upper ocean as the CO₂ from the atmosphere dissolves. And, while there is a lively ongoing debate about the magnitude of a global warming response to the presence of greenhouse gases (GHG's) in the atmosphere, there is no question that changes are occurring on a global scale, and there is a significant possibility that the world will need an energy system that adds *much* lower GHG's to the atmosphere in the future. This project aims to make that future possible.

Imagine a global energy system that adds *very* low GHG's to the atmosphere. What would be possible primary sources of energy supply in such a system? How would energy end-users make use of that supply? What technologies and systems would be used in the developing countries in addition to North America and Europe? Would we use wind, solar, nuclear power, hydrogen, fossil fuels, and in what combinations? How would such an energy systems be created? What barriers prevent implementation of such systems today (barriers might

include safety, adverse environmental effects, market acceptance, legal and social environments, and cost, for example)? What technologies will have to be developed to eliminate those barriers? How can the creative talents of the world's great universities be harnessed to invent such a future? Who will train the next generation of scientists and engineers who will make all this possible? Those questions are the reasons for this project.

With the support of visionary, international companies, Stanford University will develop and manage a portfolio of pre-commercial research to provide the basis for the low GHG-emission energy technologies of the future. It is unlikely that any one energy source will be able to meet the full range of future energy needs, and hence it is essential that the exploration of energy futures examines the technology development needed across the full spectrum of energy sources and uses. Guesses made now about which energy technologies will dominate in the future are unlikely to foresee accurately how these complex systems will evolve and how markets will respond to them, and hence investigation of a diversified portfolio of research topics is critical to project success. Research conducted as part of the project will be performed at Stanford and at other universities worldwide. Stanford will draw widely from energy expertise around the world to build the portfolio. Results of the research will be openly available, and any technology patents will be widely licensable. A key objective of this initiative is to encourage future commercial application of the technologies that flow from the research results.

ENERGY INDEPENDENCE FOR NORTH AMERICA: TRANSITION TO THE HYDROGEN ECONOMY

James J. Eberhardt

U.S. Department of Energy

ABSTRACT

A strategy will be presented for achieving energy independence for the United States and North America through a pathway that could ultimately transition the United States and the transportation sector into a hydrogen economy. The U.S. transportation sector, because of the unique mobility requirements of cars and trucks, is almost totally dependent on liquid carbon-based fuels, primarily conventional petroleum-based gasoline and diesel fuel. This has resulted in continued reliance on imported oil, mostly from less politically stable countries. Energy security

concerns have therefore motivated this focus on the hydrogen economy to replace the oil economy. The *National Energy Policy* has included recommendations for the energy independence, not only of the United States, but for the North American continent as well. The President, in his State of the Union address this year, announced the FreedomCAR and Fuel Initiative for achieving energy independence, which would transition the United States and the transportation sector into a hydrogen economy.

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT CLEAN TRANSPORTATION PROGRAMS

Mike Bogdanoff

South Coast Air Quality Management District

ABSTRACT

The South Coast Air Quality Management District (SCAQMD) has a number of programs to facilitate the development and deployment of clean transportation. These program elements arise from the SCAQMD's Air-Quality Management Plan. This plan contains the activities that will be taken by the SCAQMD, the California Air Resources Board, and the U.S. Environmental Protection Agency within their respective jurisdictions to achieve ambient air-quality standards in the South Coast Air Basin.

The SCAQMD has seven fleet rules that require the purchase of low-emission and alternative fuel vehicles. These include government fleets, transit agencies, school districts, and refuse haulers, all with fleets of more than 15 vehicles. State legislation has

also enabled the SCAQMD to provide funding to defray the extra cost of the purchase of low-emission and alter-native-fuel vehicles and engines for these and other fleets. Over \$57 million was disbursed in 2002. There are seven such programs in the basin.

Finally under the SCAQMD's Clean Fuels Program, new alternative-fuel and low-emission technology is being developed and demonstrated. With an annual budget of about \$10 million, there are over 80 contracts in progress at any one time. Currently, the SCAQMD is interested in supporting technologies involving heavy-duty natural gas vehicles, gas-to-liquid fuels, heavy-duty hybrid vehicles, fuel cell technology, and hydrogen production and infrastructure.

GALE BANKS ENGINEERING

**M. Ruth, R. Smith, L. Kocher, K. King, M. Meek, W. Harvey, G. Franks,
J. Mackey, and J. Stang**

Cummins, Inc.

G. Banks, J. Espino, S. Tackett, A. Johnston
Gale Banks Engineering

ABSTRACT

Cummins, Inc., and Gale Banks Engineering have teamed up to build a diesel-powered world record setting vehicle. The objective of the project was to provide a positive showcase to display the virtues of diesel power in a market area where diesel power is not currently available: sport vehicles, mainly trucks. Over a 2-year period, engineers at Gale Banks Engineering, Cummins, Holset, and Robert Bosch worked together to build this showcase. After several hardware exchanges, countless phone calls, and many, many late night thrash sessions, Project Sidewinder hit the road – not the track!

In an unprecedented fashion, the Cummins'-powered, Gale Banks Engineering-built Dodge Dakota made its way to the Bonneville Salt Flats not on a trailer or transporter, but under its own power, pulling a race supply trailer. This amazing vehicle went to the flats in full street-legal dress and capable

of achieving over 21 mpg, with only a tire change. It broke four standing records during the driver's qualifying passes at an average speed over 182 mph. That was just the first day.

For 3 days, like-minded racers watched in awe as a diesel-powered pickup truck that looked a lot like what you would see on the street (complete with trailer hitch, air-conditioning, power windows, and stereo) set record after record. Even more amazing, using diesel fuel that anyone could buy at a corner fuel station, this vehicle would set records at speeds in excess of 222 mph without the signature tunnel of black smoke that was typical of diesels on the Salt. Ultimately, this Gale Banks-engineered Dodge Dakota, powered by a Cummins 5.9L turbo-charged diesel engine, succeeded in setting nine records in only seven passes, including two driver licensing runs.



Abstracts

Session 1 – Emerging Diesel Technologies

REDUCTION OF EMISSIONS FROM A HIGH-SPEED FERRY

Gregory Thompson, Nigel Clark, Mridul Gautam, Donald W. Lyons, Daniel Carder, Byron Rapp, Sam George, Ryan Barnett, and Wesley Riddle

West Virginia University

ABSTRACT

Emissions from marine vessels are being scrutinized as a major contributor to total particulate matter (TPM), SO_x, and NO_x environmental loading. Fuel sulfur control is the key to SO_x reduction. Significant reductions in the emissions from on-road vehicles have been achieved in the last decade, and the emissions from these vehicles will be reduced by another order of magnitude in the next 5 years: these improvements have served to emphasize the need to reduce emissions from other mobile sources, including off-road equipment, locomotives, and marine vessels. Diesel-powered vessels of interest include oceangoing vessels with low- and medium-speed engines, as well as ferries with high-speed engines, as discussed below.

A recent study examined the use of intake water injection (WIS) and ultra-low sulfur diesel (ULSD) to reduce the emissions from a high-speed passenger ferry in southern California. One of the four Detroit Diesel 12V92 two-stroke high-speed engines that power the Waverider (operated by SCX, Inc.) was instrumented to collect intake airflow, fuel flow, shaft torque, and shaft speed. Engine speed and shaft torque were uniquely linked for given vessel draft and prevailing wind and sea conditions. A raw exhaust gas sampling system was utilized to measure

the concentration of NO_x, CO₂, and O₂, and a mini-dilution tunnel sampling a slipstream from the raw exhaust was used to collect TPM on 70-millimeter filters. The emissions data were processed to yield brake-specific mass results. The system that was employed allowed for redundant data to be collected for quality assurance and quality control. To acquire the data, the Waverider was operated at three different speeds in the open sea off Oceanside, California.

Data have shown that the use of ULSD along with water injection could significantly reduce the emissions of NO_x and PM while not affecting fuel consumption or engine performance, compared to the baseline marine diesel. The results showed that a nominal 40-percent reduction in TPM was realized when switching from the marine diesel to the ULSD. A small reduction in NO_x was also shown between the marine fuel and the ULSD. The implementation of the WIS showed that NO_x was reduced significantly by between 11 and 17 percent, depending upon the operating condition. With the WIS, the TPM was reduced by a few percentage points, which was close to the confidence in measurement.

CATERPILLAR INC., HEAVY TRUCK CLEAN DIESEL PROGRAM

David M. Milam

Caterpillar, Inc.

ABSTRACT

The DOE Heavy Truck Clean Diesel (HTCD) program is a 5-year program aimed at demonstrating 50-percent thermal efficiency while complying with the 2007 and 2010 emissions regulations. The development program includes the evaluation of multiple technical solutions and culminates in the demonstration of the emission-compliant engine system in a truck chassis. This demonstration truck

will be used for assessment of drivability, emissions compliance on various driving cycles, noise studies, etc. The other aspect of the demonstration truck is the integration of the various engine subsystems onto the engine and into the truck chassis in a manner that is suitable for multiple original equipment manufacturers.

POWERTRAP ä : ULTRAFINE PARTICULATE MATTER CONTROL WITHOUT PERFORMANCE PENALTIES

Peter Kukla

University of Manchester

ABSTRACT

The PowerTrap™ is a non-exhaust temperature dependent system that cannot become blocked and features a controlled regeneration process independent of the vehicle's drive cycle.

The system has a low direct-current power source requirement available in both 12-volt and 24-volt configurations. The system is fully programmable, fully automated and includes Euro IV requirements of operation verification. The system has gained European component-type approval and has been tested with both on- road and off-road diesel fuel up to 2000 parts per million.

The device is fail-safe: in the event of a device malfunction, it cannot affect the engine's performance. Accumulated mileage testing is in excess of 640,000 miles to date. Vehicles include London-type taxicabs (Euro 1 and 2), emergency service fire engines (Euro 1, 2 and 3), inner city buses, and light-duty locomotives. Independent test results by Shell Global Solutions have consistently demonstrated 85- 99 percent reduction of ultrafines across the 7-35 nanometer size range using a scanning mobility particle sizer with both ultra-low sulfur diesel and off-road high-sulfur fuel.

DEVELOPMENT AND DEPLOYMENT OF ADVANCED EMISSION CONTROLS FOR THE RETROFIT MARKET

Brad Edgar, Marc Rumminger, and Michael Streichsbier

Cleaire Advanced Emission Controls

ABSTRACT

Bringing a diesel retrofit product to market involves two primary phases: development and deployment. Critical product development steps include technology selection, system integration, laboratory and durability testing, and regulatory agency verification work. This initial product development phase is then followed by a deployment phase, which consists of building and managing the infrastructure for installation, distribution, service, sales and warranty support. Building relationships with regulators and air-quality program developers is also a critical aspect of the deployment process. A successful path to market requires close cooperation between developer, distributor, customer, and regulator.

Cleaire Advanced Emission Controls has developed an integrated NO_x and particulate matter (PM) control system called "Longview," which can be applied to a wide variety of engines and applications. In April 2003, Longview became the first broadly applicable, combined NO_x and PM emission control system to be verified by California Air Resources Board. Longview is verified to reduce NO_x by 25 percent and PM by 85 percent. Key elements of Longview include a NO_x reduction

catalyst, a catalyzed diesel particulate filter, a reagent injection system, and a combined controller/datalogger called the "MLC®." Key criteria for the end-user are affordability, minimal impact on vehicle operations, and ready access to qualified service and support facilities. Important features for regulators and grant programs are verifiable emission reductions and cost-effectiveness.

Cleaire is a division of Cummins West, Inc., the exclusive distributor of Cummins Incorporated products in central and northern California. While Cleaire has been focused on the development of the system, it has also worked with its parent to develop the criteria to become an "Authorized Cleaire Distributor." Excellent results in the test cell and proven durability in the field are thereby combined with an organization competent to handle sales, installation and service activities to support the product.

The paper will discuss the basic design features of the Longview system, present laboratory and field test results, and discuss the key process steps required for successful launch and support of retrofit emission control systems.

FUEL ADDITIVE STRATEGIES FOR ENHANCING THE PERFORMANCE OF ENGINES AND ENGINE OILS

C. Yvonne Thiel, Thomas E. Hayden and Benjamin J. Kaufman

Chevron Oronite Technology Center

ABSTRACT

Chevron Oronite is developing and has commercialized fuel additives designed to reach the fuel/lubricant interface at the cylinder wall and impart performance improvements to both the engine and the engine oil. One such product is a gasoline-additive friction modifier that provides an immediate fuel economy benefit due to reduced friction between the piston ring and cylinder wall, a further improvement as it accumulates in the oil, as well as assisting wear protection and improving power output. In addition to these more obvious benefits, equal attention was given to avoiding harm issues such as in fuel handling, intake system deposits, combustion chamber deposits, and negative impacts on the engine oil.

We have designed diesel fuel additives that are intended to work similarly in a variety of diesel engines. The program has provided information about additive characteristics needed to reach the cylinder wall, despite engine design efforts to prevent fuel from doing so. As the candidate additives have reached the wall and sump intact, further work has shown that a functionalized molecule can provide the intended benefit upon reaching the cylinder wall and oil in this manner. We are now in the process of modifying the additive chemistry and getting dose/performance responses in a variety of engines.

TRANSIENT, REAL-TIME, PARTICULATE EMISSION MEASUREMENTS IN DIESEL ENGINES

Sreenath Gupta, Gregory Hillman, and Raj Sekar

Argonne National Laboratory

ABSTRACT

An instrument was developed to measure transient particulate mass emissions from diesel engines. This instrument, while based on laser-induced incandescence, allows measurements at 10 Hz. Using such an instrument, measurements were performed in the exhaust of a 1.7L Mercedes-Benz engine coupled to a low-inertia dynamometer. Comparative measurements performed under engine steady-state conditions show the instrument to agree

within $\pm 12\%$ of measurements with a scanning mobility particle sizer. Moreover, the instrument showed far better time response to a step change in engine operation when compared with a TEOM 1105. Similar measurements performed over an urban driving cycle revealed that the instrument does not yield negative mass concentrations, unlike a typical TEOM.



Abstracts

Session 2 – Fuels and Lubrication, Part 1

THE NON-PETROLEUM BASED FUEL INITIATIVE

Bruce Bunting and John Storey

Oak Ridge National Laboratory

Wendy Clark

National Renewable Energy Laboratory

Kevin Stork

U.S. Department of Energy

ABSTRACT

The Non-Petroleum Based Fuels Initiative (NPBF) is being undertaken as a multi-year research, development, and testing activity by the Office of FreedomCAR and Vehicle Technologies located in the DOE's Office of Energy Efficiency and Renewable Energy. This activity is being developed in collaboration with industry, academia, and Government agency partners. The primary focus of this activity is to produce data that can help lead decisions relative to fuel options that improve fuel economy, reduce petroleum dependence, and ultimately pave the way to a hydrogen-based transportation system.

The multi-year work plan is being developed with input from fuel, automobile, and engine companies in order to identify which fuel options are the most viable and where gaps in knowledge or technology exist that could be addressed with pre-competitive research. The research plan for this work is being developed through a series of meetings and discussions with all interested parties.

This Diesel Engine Emissions Reduction Conference talk will present the work plan in its current, evolving form in order to help disseminate information and to gather comments and questions relating to this initiative.

APBF-DEC NO_x ADSORBER/DPF PROJECT: PASSENGER CAR PLATFORM

Dean Tomazic and Marek Tatur

FEV Engine Technology, Inc.

Matthew Thornton

National Renewable Energy Laboratory

ABSTRACT

Due to increased fuel costs and a desire to reduce dependence on foreign oil, the diesel engine is becoming a prime candidate for future medium-duty vehicle applications in the United States. The diesel engine exhibits high thermal efficiency and superior durability compared to the gasoline engine. The main obstacle to increased use of diesel engines is the upcoming (extremely stringent) EPA Tier 2 emission standards. To succeed, these vehicles must comply with emission standards while maintaining their excellent fuel economy. The availability of technologies, such as common rail fuel injection systems, low-sulfur diesel fuel, NO_x adsorber catalysts, and diesel particulate filters, allow the development of powertrain systems with the potential to comply with targeted requirements. In support of this, the U.S. Department of Energy (DOE) has undertaken several test projects as part of its Advanced Petroleum Based Fuels - Diesel Emission Control (APBF-DEC) activity. Primary questions

among those addressed by these projects are sulfur tolerance, durability, and performance of the NO_x adsorber/DPF system for varying fuel sulfur levels. The test bed for one project in this activity is an Audi A4 Avant equipped with a 1.9L prototype TDI engine with common rail fuel injection.

While NO_x adsorber catalyst (NAC) systems have demonstrated extremely high levels of NO_x reduction in steady-state laboratory evaluations, the application of NAC systems to actual transient engine applications requires development of an integrated engine-emissions management system. This paper discusses the integrated engine-emissions system management and the development of regeneration control strategies. Performance of fresh and aged systems tested over the FTP-75, HFET, and US06 test cycles will also be summarized, including emissions of regulated and presently unregulated species.

APBF-DEC NO_x ADSORBER/DPF PROJECT: SUV/PICKUP PLATFORM

Cynthia Webb and Phil Weber

Southwest Research Institute

Matthew Thornton

National Renewable Energy Laboratory

ABSTRACT

Due to increased fuel costs and a desire to reduce dependence on foreign oil, the diesel engine is becoming a prime candidate for future medium-duty vehicle applications in the United States. The diesel engine exhibits high thermal efficiency and superior durability compared to the gasoline engine. The main obstacle to increased use of diesel engines is the upcoming (extremely stringent) EPA Tier 2 emission standards. To succeed, these vehicles must comply with emission standards while maintaining their excellent fuel economy. The availability of technologies, such as common rail fuel injection systems, low-sulfur diesel fuel, NO_x adsorber catalysts, and diesel particulate filters, allow the development of powertrain systems with the potential to comply with targeted requirements. In support of this, the U.S. Department of Energy (DOE) has undertaken several test projects as part of its Advanced Petroleum Based Fuels — Diesel Emission Control (APBF-DEC) activity. Primary questions among those addressed by these projects are sulfur tolerance, durability, and performance of the NO_x adsorber/DPF system for varying fuel sulfur levels.

The heavy light-duty (HLDT) and medium-duty passenger vehicles (MDPV) will face the greatest technological challenges in meeting the Tier 2 emissions standards. The test bed for one project in this activity is a 2500 series Chevrolet Silverado equipped with a 6.6L Duramax diesel engine certified for 2002 model year Federal heavy-duty and 2002 model year California medium-duty emission standards.

While NO_x adsorber catalyst (NAC) systems have demonstrated extremely high levels of NO_x reduction in steady-state laboratory evaluations, the application of NAC systems to actual transient engine applications requires development of an integrated engine-emissions management system. This paper discusses the integrated engine-emissions system management and the development of regeneration control strategies. Performance of fresh and aged systems tested over the FTP-75, HFET, and US06 test cycles will also be summarized, including emissions of regulated and presently unregulated species.

**APBF-DEC NO_x ADSORBER/DPF PROJECT: HEAVY-DUTY
LINEHAUL PLATFORM**

Mike May

Ricardo, Inc.

Shawn D. Whitacre

National Renewable Energy Laboratory

ABSTRACT

This presentation outlines the development and integration of an advanced emission control system with a modern heavy-duty diesel engine that is being used for durability testing. The project that is discussed is one of several being conducted under the U.S. Department of Energy's Advanced Petroleum-Based Fuels - Diesel Emission Control (APBF-DEC) activity. This Government/industry collaboration is examining how systems of advanced fuels, engines, and emission control systems can deliver significantly lower emissions while maintaining or improving vehicle fuel economy. A Cummins ISX

EGR engine (15 L), with a secondary fuel injection system to enable NO_x adsorber catalyst regeneration, has been developed for use in a series of durability tests with fuels of different sulfur levels. Development of the strategies for NO_x regeneration and sulfur removal as well as integration of the emission control hardware is discussed. Performance of fresh and aged systems tested over transient and steady-state cycles is summarized, including emissions of regulated and presently unregulated species.

DEMONSTRATION OF THE LOW-EMISSION POTENTIAL FOR UREA SELECTIVE CATALYTIC REDUCTION AND DIESEL PARTICULATE FILTER TECHNOLOGIES

Magdi Khair and Chris Sharp

Southwest Research Institute

Ralph McGill

Oak Ridge National Laboratory

ABSTRACT

The demonstration of the potential for urea selective catalytic reduction (SCR) and diesel particulate filter technologies is one of the major projects in the Advanced Petroleum-Based Fuels – Diesel Emission Control (APBF-DEC) activity. The objective of this project is to integrate several diesel emission control technologies to demonstrate their capability to comply with the 2007 heavy-duty diesel engine standards. Once the engine and control system were developed, several fuels having various sulfur content were evaluated to establish the sensitivity of the control system to sulfur.

The work is being conducted on a Caterpillar C-12 heavy-duty diesel engine. Two different emission control systems, employing urea SCR catalysts and diesel particulate filters, were calibrated and showed the potential for controlling NO_x and particulate matter emissions to levels near the 2007 standards. The project will also examine the long-term durability of the control systems and their interaction with the test fuels. This presentation is a summary of this work, which is still in progress.

THE CHEMICAL STATES AND COMPOUNDS OF LUBE OIL PHOSPHOROUS IN DIESEL EXHAUST

Sam Lewis, Bruce Bunting, and John Storey

Oak Ridge National Laboratory

ABSTRACT

Phosphorous in diesel exhaust is derived from the ZDDP additive in lube oil used for wear control. Phosphorous emitted in the engine exhaust can react with an aftertreatment catalyst and cause loss of performance through masking or chemical reaction. It appears that there is a minimum level of ZDDP needed for engine durability. One of the ways of reducing the effects of the resulting phosphorous on catalysts might be to alter the chemical state of the phosphorous to a less damaging form. And, one of the first requirements of altering the chemical state of

phosphorous is to be able to measure the chemical state and compounds in diesel exhaust. In this preliminary study, the phosphorous compounds in diesel exhaust were measured by a variety of analytical techniques and correlated to such variables as ZDDP concentration in the oil, exhaust temperature, and fuel doping with ZDDP. These analytical techniques will then be applied to lube oil formulation studies and to catalyst durability studies in order to reduce or eliminate phosphorous poisoning in a catalyst.



Abstracts

Session 3 – Fuels and Lubrication, Part 2

EMISSIONS FROM HEAVY-DUTY DIESEL ENGINE WITH EXHAUST GAS RECIRCULATION USING OIL SANDS DERIVED FUELS

Stuart Neill

National Research Council Canada

ABSTRACT

The oil sands deposits in Alberta contain approximately 1.6 trillion barrels of bitumen, a naturally occurring viscous mixture of hydrocarbons. Approximately 20 percent of these bitumen reserves are recoverable with current technology. In 2002, the Canadian oil sands industry produced approximately 800,000 barrels of bitumen and bitumen-derived crude oil per day, and production is expected to increase to almost 2 million barrels per day by 2011. It is estimated that up to 75 percent of the oil sands production in 2011 will be exported to the U.S. market.

The presentation will discuss the unique characteristics and properties of oil sands derived crude, which reflect the bitumen source and the upgrading processes that the bitumen undergoes, as well as the emissions behavior of diesel fuels containing oil sands components.

In a recent study, the exhaust emissions from a single-cylinder version of a heavy-duty diesel engine with exhaust gas recirculation (EGR) were measured using 12 diesel fuels derived from oil sands and conventional sources. Exhaust emissions were measured using the AVL eight-mode steady-state test procedure. Particulate matter (PM) emissions for all test fuels were accurately modeled by a single regression equation with two predictors: fuel total aromatics and sulfur content. Similarly, NO_x emissions were found to depend on fuel total aromatics and density. In summary, the PM and NO_x emissions were significantly affected by key compositional fuel properties, but the crude oil source did not play a role.

DEVELOPMENT AND DEMONSTRATION OF FISCHER-TROPSCH FUELED HEAVY-DUTY VEHICLES WITH CONTROL TECHNOLOGY FOR REDUCED DIESEL EXHAUST EMISSIONS

Brad Adelman and Mike May

Ricardo

Teresa Alleman

National Renewable Energy Laboratory

Adewale Oshinuga

South Coast Air Quality Management District

Bernard Treanton

California Energy Commission

Greg Barton

Automotive Testing Laboratory

Ralph Cherrillo and Ian Virrels

Shell Global Solutions

ABSTRACT

The objectives of this study are to modify two 2002 Model Year Cummins ISM engines (equipped with exhaust gas recirculation [EGR]) to achieve 1.2 g/hp-h NO_x emissions and 0.01 g/hp-h particulate matter (PM) over the heavy-duty Federal Test Procedure (FTP) cycle using Fischer-Tropsch (F-T) fuel, optimized combustion, lean NO_x catalyst (LNC) with secondary injection, and a diesel particulate filter (DPF). After their performance is proven in a test cell, the plan is to install the modified engines and aftertreatment systems in two vehicles and operate the vehicles in a commercial application. The program is sponsored by the South Coast Air Quality Management District, the California Energy Commission, the U.S. Department of Energy, and the National Renewable Energy Laboratory

This presentation covers the first phase of the work — the optimization of the engine and aftertreatment systems to demonstrate the targets in an emissions test cell.

The effect of F-T fuel on the base engine was first evaluated over the heavy-duty diesel FTP cycle. In comparison to a low aromatic California Air

Resources Board ultra-low sulfur diesel fuel, a 4.5-percent decrease in NO_x and a 17.6-percent decrease in PM were measured.

To achieve a major reduction in engine out NO_x emissions, the chosen strategy was to increase the EGR rate and employ an LNC. To tolerate higher EGR rates, the combustion bowl was modified to increase the bowl volume (decreased compression ratio is possible due to the superior ignition qualities of F-T fuel) and air motion. Increased EGR rate and combustion modifications lead to a further 25-percent decrease in NO_x but a 30-percent increase in PM.

An exhaust aftertreatment system consisting of an LNC and catalyzed DPF was then installed. The efficiency of catalyzed aftertreatment is improved with virtually sulfur-free FT fuel. Secondary FT fuel was added to the exhaust to facilitate the LNC performance. The exhaust aftertreatment led to a further 19-percent NO_x reduction and 95-percent PM removal. Composite emissions of 1.168 g/hp-h NO_x and 0.005 g/hp-h PM were achieved over the heavy-duty FTP cycle.

FUEL FORMULATION EFFECTS ON DIESEL FUEL INJECTION, COMBUSTION, EMISSIONS, AND EMISSION CONTROL

André Boehman, Mahabubul Alam, Juhun Song, Ragini Acharya,
Jim Szybist, and Vince Zello

Pennsylvania State University

Kirk Miller

ConocoPhillips

ABSTRACT

This paper describes work under an Ultra Clean Fuels project entitled "Ultra Clean Fuels from Natural Gas," Cooperative Agreement No. DE-FC26-01NT41098. In this study we have examined the incremental benefits of moving from low-sulfur diesel fuel and ultra-low sulfur diesel fuel to an ultra-clean fuel, Fischer-Tropsch diesel fuel produced from natural gas. Blending with biodiesel, B100, was also considered. The impact of fuel formulation on fuel injection timing, bulk modulus of compressibility, in-cylinder combustion

processes, gaseous and particulate emissions, diesel particulate filter regeneration temperature, and urea selective catalytic reduction NO_x control has been examined. The primary test engine is a 5.9L Cummins ISB, which has been instrumented for in-cylinder combustion analysis and in-cylinder visualization with an engine video-scope. A single-cylinder engine has also been used to examine in detail the impacts of fuel formulation on injection timing in a pump-line-nozzle engine in order to assist in the interpretation of results from the ISB engine.

A REVIEW OF VEGETABLE OIL RESEARCH AT PENN STATE

**Kraipat Cheenkachorn, Kimberly Wain, Waleska Castro, Wallace Lloyd,
and Joseph M. Perez**

Pennsylvania State University

ABSTRACT

This presentation will review current projects at Pennsylvania State University on the use of vegetable oils as fuels, hydraulic fluids, and engine oils. Research is being conducted on such alternative fuels as B100, B20, and VPO B20. A hydraulic fluid project to convert farm and construction equipment

on campus will be described as will efforts to develop high- temperature lubricants and next-generation lubricants containing minimal sulfur and phosphorus. Studies of the effect of coatings on friction, wear, and deposits will be discussed.

THE IMPACT OF OIL CONSUMPTION MECHANISMS ON DIESEL EXHAUST PARTICLE-SIZE DISTRIBUTIONS AND DETAILED EXHAUST CHEMICAL COMPOSITION

John Stetter, Nathan Forster, Jaal Ghandhi and David Foster

University of Wisconsin – Madison

ABSTRACT

Detailed exhaust emission data have been taken from a Cummins N-14 single-cylinder research engine in which the oil consumption was varied by different engine modifications. Low-sulfur fuel was used, and oil consumption was varied by modifying the intake valve stem seals, the exhaust valve stem seals, the oil control ring, and combinations of these modifications. Detailed measurements of exhaust gas particle-size distributions and chemical composition were made for the various oil consumption configurations for a range of engine loads and speeds.

The data indicate that the particle-size distribution is impacted by oil consumption of the engine. Furthermore, the nature of the change in

particle-size distribution depends on the mechanism of the oil consumption. For example, the diameter of the maximum particle concentration shifts from being smaller than, to being larger than, the base engine case for different oil consumption modes and different operating conditions.

The particulate mass was measured with TEOM and traditional gravimetric filter methods. Filter data for elemental carbon/organic carbon, sulfates, and trace metals have been taken and are being analyzed. The trace metals in the particulate mass serve as the basis for assessing oil consumption at the different operating conditions. The results of these analyses will be presented.

IMPACT OF THE FUEL-BORNE CATALYST MMT ON DIESEL PARTICULATE FILTERS AND LEAN NO_x TRAP PERFORMANCE

David Human

Ethyl Petroleum Additives

ABSTRACT

This presentation builds on the work summarized by Ethyl at the DEER 2002 Conference by examining the role that MMT can play in catalyzed diesel particulate filter systems and lean NO_x traps (LNT's) using a contemporary Model Year 2002 medium-duty Cummins 5.9L ISB diesel engine. Balance point and filter loading were investigated at a series of engine speed and load combinations, with soot accumulation and balance point being reduced in all

cases. Soot accumulation was affected as MMT lowered the amount of elemental carbon emissions (dry particulate). MMT was also found to protect lean NO_x traps by scavenging the fuel sulfur and engine oil-derived phosphorus and incorporating them into the ash. Improvements in LNT performance and durability were demonstrated using MMT in ultra-low sulfur fuel.



Abstracts

Session 4 – Waste Heat Utilization

THERMOELECTRICAL ENERGY RECOVERY FROM THE EXHAUST OF A LIGHT TRUCK

Eric Thacher, Brian Helenbrook, Madhav Karri, and Marc Compeau

Clarkson University

Aleksandr Kushch and Norbert Elsner

Hi-Z Technology, Inc.

Mohinder Bhatti and John O'Brien,

Delphi Automotive Systems, Inc.

Francis Stabler

General Motors, Inc.

ABSTRACT

A team formed by Clarkson University is engaged in a project to design, build, test, and develop a plan to commercialize a thermoelectric generator (TEG) for recovering some of the energy in the exhaust from light trucks and passenger cars. The team members are Clarkson University (project management, vehicle inter-face design, system modeling, commercialization plan), Hi-Z Technology, Inc. (TEG design and construction, subcontractor to Clarkson), Delphi Automotive Systems (testing services and engineering consultation), and General Motors, Inc. (test vehicle).

Funds were supplied by a grant from the Transportation Research Program of the New York State Energy Research and Development Authority (Joseph Wagner, Project Manager). Members of the team and the U.S. Department of Energy's Office of FreedomCAR and Vehicle Technologies (John Fairbanks, Project Manager) supplied cost-sharing and in-kind support. General Motors loaned the test truck (a 1999 Sierra) and supplied information about its systems. Delphi Automotive Systems, Inc., supplies engineering consulting services and will furnish 2 weeks of testing time at its Lockport, New York, facility.

The TEG consists of 16 HZ-20 modules connected in series, clamped between the exhaust and coolant heat exchangers and electrically connected to the DC bus through a power-conditioning unit. It will be capable of generating 330 W of electric power when it operates at its design temperature differential. The exhaust from the test truck's 270 hp V8 gasoline engine passes through the two catalytic converters located near the left and right sides of the truck frame and then will be routed through the TEG. To provide for reliable thermoelectric module cooling, the TEG will be integrated into the truck engine cooling system.

This presentation will: (1) show some of the results of initial studies using a model that incorporates the TEG system into the National Renewable Energy Laboratory's ADVISOR vehicle simulation code, (2) discuss the principal conclusions of a market survey done for the project's draft commercialization plan, and (3) summarize the first portion of the Phase 2 work now underway.

SCALE-UP OF Si/Si_{0.8}Ge_{0.2} AND B₄C/B₉C SUPERLATTICES FOR HARVESTING OF WASTE HEAT IN DIESEL ENGINES

P. M. Martin and L. C. Olsen

Pacific Northwest National Laboratory

ABSTRACT

Thermoelectric devices show significant promise for harvesting and recovery of waste heat from diesel engines, exhaust systems, and industrial heat sources. Conversion efficiencies of bulk thermoelectric systems, however, are still too low for economical power conversion in diesel-powered vehicles and heavy vehicles.

Thermoelectric superlattice devices have demonstrated the potential for increased efficiencies and utilization of waste heat. Although reported efficiencies are well above 15 percent, fabrication costs are still too high for use in diesel engine systems. To realize this efficiency goal of ~20% and power generation in the kW-MW range, large quantities of superlattice materials are required. Additionally, if the figure of merit (ZT) of these superlattices can be increased to > 2, even less superlattice material will be required to generate electric power from heat in diesel engines.

We report on development of and recent progress in scale-up of Si/Si_{0.8}Ge_{0.2} and B₄C/B₉C superlattices for thermoelectric applications, and particularly for fabrication of large quantities of these materials. We have scaled up the magnetron sputtering process to produce large quantities of Si/Si_{0.8}Ge_{0.2} and B₄C/B₉C superlattices with high ZT at low cost. Superlattices with up to 1,000 layers were deposited onto substrate areas as large as 0.5 m² by magnetron sputtering.

Initial studies showed that the power factor of these superlattices was high enough to produce a ZT significantly greater than 1. Both p- and n-type superlattices were fabricated to form a complete thermoelectric power-generating device.

ZT measurements will be reported, and based on measured power factor of these materials, should be significantly greater than 1. These results are encouraging for the use of superlattice materials in thermo-electric power generation.

POTENTIAL THERMOELECTRIC APPLICATIONS IN DIESEL VEHICLES

Douglas Crane

BSST, LLC

ABSTRACT

Novel thermodynamic cycles developed by BSST provide improvements by factors of approximately 2 in cooling, heating, and power generation efficiency of solid-state thermo-electric systems. The BSST technology is available now and is currently being evaluated in automotive development programs for important new applications. New thermoelectric materials are likely to become available that further increase performance by a comparable factor. These major advancements should allow the use of thermoelectric systems in new applications that have the prospect of contributing to emissions reduction, fuel economy, and improved user comfort.

Potential applications of thermoelectrics in diesel vehicles are identified and discussed. As a case in point, the history and status of the Climate Controlled Seat (CCS™) system from Amerigon, the parent of BSST, is presented. CCS is the most successful and highest production volume thermoelectric system in vehicles today. As a second example, the results of recent analyses on electric power generation from vehicle waste power are discussed. Conclusions are drawn as to the practicality of waste power generation systems that incorporate BSST's thermodynamic cycle and advanced thermoelectric materials.

RECENT PROGRESS IN THE DEVELOPMENT OF HIGH-EFFICIENCY THERMOELECTRICS

J. C. Bass, N. B. Elsner, and S. Ghamaty

Hi-Z Technology, Inc.

ABSTRACT

This paper will discuss the recent developments of high-efficiency quantum well thermoelectrics at Hi-Z Technology, Inc. The performance of the latest P-type B_4C/B_9C – N-type Si/SiGe couple will be presented as well as data for the new N-type Si/SiC that will replace Si/SiGe and improve couple efficiency.

Preliminary calculations regarding the development of actual quantum well modules will be presented for both power prediction and cooling

applications. These modules can be used in future diesel exhaust energy conversion systems as well as air-conditioning system designs. The design of a family of small quantum well based generator wells being developed for wireless sensor systems will also be presented. These small generators use energy-harvesting techniques to produce power for the system.

Our current efforts to produce quantum well films more rapidly will be discussed.

DESIGN AND DEVELOPMENT OF E-TURBO™ FOR SPORT UTILITY VEHICLE AND LIGHT-TRUCK APPLICATIONS

Craig Balis, Chris Middlemass, and S. M. Shahed

Garrett Engine Boosting Systems

ABSTRACT

The purpose of the project is to develop an electrically assisted turbocharger, e-Turbo™, for application to the sport utility vehicle (SUV) and light truck class of passenger vehicles. Earlier simulation work had shown the benefits of the e-Turbo™ system on increasing low-end torque and improving fuel economy. This paper will present further data to show that advanced turbocharging can enable diesel engine down-sizing of 10-30 percent with 6-17 percent improvement in fuel economy. This is in addition to the fuel economy benefit that a turbocharged diesel engine offers over conventional gasoline engines. In this downsizing scenario, e-Turbo™ is necessary to recover acceptable driving characteristics with downsized diesel engines.

As a first step towards the development of this technology for SUV/light truck sized diesel engines (4-6 L displacement), design concepts and hardware were evaluated for a smaller engine (2 L

displacement). This strategy was chosen to minimize design and development issues and then prove the concept in bench testing and small engine testing. Following small engine success, the concept could be applied to a large V-engine (one on each bank) to prove target performance characteristics. After successful demonstration of concept and performance, large turbomachinery could be designed and built specifically for larger SUV-sized diesel engines. This paper presents the results of development of e-Turbo for a 2 L diesel engine.

A detailed evaluation of motor-generator and turbocharger requirements and designs has been performed, including comparison of different motor-generator technologies and different motor-generator/turbocharger integration schemes. Detailed analysis and bench testing have been performed to confirm basic design concepts and will be used to finalize product design for engine testing.

DIESEL ENGINE WASTE HEAT RECOVERY UTILIZING ELECTRIC TURBOCOMPOUND TECHNOLOGY

Ulrich Hopmann

Caterpillar, Inc.

ABSTRACT

Electric turbocompounding (ETC) is a way to recover exhaust heat energy and return it to the driveline. ETC integrates well into a MorElectric™ Initiative vehicle and allows previously unattainable level of control of the engine air system. The primary goal is a 5percent reduction in fuel consumption and/or emissions.

This presentation will report progress to date on a technology demonstration program. Component design and analysis as well as control system

development will be reviewed. The ETC system requires a completely new control strategy and control system. Two electrical motor/generators, one on the turbo shaft and one on the crankshaft, are part of the ETC system; their design and test results on the dynamometer will be shown. Furthermore, design and performance test results of a newly developed turbocharger will be presented.



Abstracts

Session 5 – Diesel and CNG Bus Emissions

STATE OF THE ART IN DIESEL EMISSION CONTROL

Timothy V. Johnson

Corning, Inc.

ABSTRACT

The entire field of diesel emission control is developing rapidly. In addition to advances in exhaust emission control technology, regulatory proposals are approaching the U.S. 2010 levels in Japan and Europe, and the engines are getting cleaner.

This presentation will bring the audience up to date with the latest published information on the regulations, estimates of engine-out emissions, filter technology, NO_x technology, and integrating it all into viable systems for use in light- and heavy-duty applications.

In summary, it appears that nominally 80-percent filtration efficiency is needed to hit the Japanese 2005 and U.S. 2007 interim heavy-duty diesel regulations, while employing high levels of exhaust gas recirculation (EGR). In Europe, for both Euro 4 in 2005 and Euro 5 in 2008, 70-80 percent selective catalytic reduction (SCR) will be used in fuel-

sensitive applications, while diesel oxidation catalysts (DOC's) and some filters will show up in others. In light-duty, depending on vehicle size and which engine technologies emerge, nominally 50 percent NO_x efficiency will be needed to hit proposed Euro 5 regulation in 2010 and 70-80 percent NO_x efficiency will be needed to hit the Bin 5 U.S. fleet average.

In the filter arena, improvements continue on regeneration strategies and filter performance. For NO_x control, SCR is progressing to commercialization, and the NO_x traps are in a rapid stage of development and improvement, with better materials and strategies for regeneration and desulfation. Integration of NO_x and PM control is entering the heavy-duty vehicle stage with SCR and filter systems on prototype vehicles, and NO_x trap and filter systems showing up on light-duty vehicles and on heavy-duty engine dynamometers.

SUMMARY OF SWEDISH EXPERIENCES ON CNG AND "CLEAN" DIESEL BUSES

Peter Ahlvik

Ecotraffic ERD3 AB

ABSTRACT

In Sweden, emission tests were conducted on compressed natural gas (CNG) and diesel buses in the 1990's as part of several governmental programs in this area. A summary of the evaluation presented at DEER 2001 is provided. In addition, a comparison between the Swedish results and some of the more recent results from the U.S. studies is made.

The analysis of the Swedish results showed considerable improvement on the diesel buses by reformulating the diesel fuel and by fitting after-treatment devices. Particulate filters (DPF's) can reduce particle emissions from diesel buses to a level similar to that of the CNG buses. The NO_x emissions can be reduced by some 50 percent by using retrofit exhaust gas recirculation (EGR) systems, but the level was still higher than for the best CNG buses.

CNG had a positive impact regarding several of the effects investigated, e.g., acidification and local NO₂ emissions. In other cases (e.g., ozone-forming potential), the difference between the best options was small. The cancer risk index is largely dependent on the unit risk factors, but the overall result in this case did not vary much between the sets of risk factors used. Clean diesel fuel with a particulate trap and CNG/biogas were the options with the lowest cancer risk index. The impact on the greenhouse gas emissions was the most significant advantage for the biofuels.

It is interesting to note that there are both similarities and differences between the engine technology used in Sweden and the United States. First, it should be noted that the U.S. buses are relatively new, i.e., Model Year 2002-2001, while the Swed-

ish tests originate from the 1990's. A large proportion of the diesel buses in Sweden use oxidation catalysts, DPFs or EGR in combination with DPF. Practically all CNG buses in Sweden are equipped with oxidation catalysts, whereas until recently, relatively few have been using oxidation catalysts in the United States. However, it is suspected that the first generation of CNG catalysts has poor durability. Closed loop control was not used on the older Swedish CNG buses but was introduced in 2002.

The "best" test results on CNG in Sweden indicated surprisingly low NO_x emissions in comparison to most U.S. results. A more advanced combustion system on the (newer) U.S. diesel engines yielded lower HC emissions and, thus, also less harmful toxic VOCs, e.g., PAH emissions and formaldehyde. The results for twelve tri+ PAH species analyzed in all studies were compared, indicating a great reduction potential for fuel reformulation and catalytic DPFs. The PAH level for CNG without catalyst was significantly higher, but the impact of a catalyst still has to be assessed. An efficient oxidation catalyst is also essential to achieve low levels of formaldehyde for CNG buses. The results on 1,3-butadiene tended to be somewhat inconclusive.

A valid conclusion from all test results is that aftertreatment devices are crucial to achieve low emissions, regardless of fuel used. It is expected that future development on engines and aftertreatment devices will diminish the advantage of the alternative fuels regarding many of the effects on health and environment. On the contrary, the impact on greenhouse gases from some biofuel options will be more pronounced in the future.

**COMPARISON OF EXHAUST EMISSIONS, INCLUDING TOXIC AIR CONTAMINANTS,
FROM SCHOOL BUSES IN COMPRESSED NATURAL GAS, LOW-EMITTING DIESEL, AND
CONVENTIONAL DIESEL ENGINE CONFIGURATIONS**

Warren J. Slodowske, Bill Trestrail, Angelita L. Cook, and William B. Bunn

International Truck and Engine Corporation

Charles A. Lapin

Lapin and Associates

Kenneth J. Wright and Charles R. Clark

ConocoPhillips

ABSTRACT

In the United States, most school buses are powered by diesel engines. Some have advocated replacing diesel school buses with natural gas school buses, but little research has been conducted to understand the emissions from school bus engines. This work provides a detailed characterization of exhaust emissions from school buses using a diesel engine meeting 1998 emission standards, a low-emitting diesel engine with an advanced engine calibration and a catalyzed particulate filter, and a natural gas engine without catalyst. All three bus configurations were tested over the same cycle, test weight, and road load settings. In addition, the quantitative results from this study were used to calculate cancer potency weighted emissions.

Twenty-one of the 41 “toxic air contaminants” (TAC’s) listed by the California Air Resources Board as being present in diesel exhaust were not found in the exhaust of any of the three bus configurations, even though special sampling provisions were utilized to detect low levels of TAC’s. Although there were no significant differences between the low-emitting diesel and the natural gas bus configurations for 14 TAC’s, the low-emitting diesel bus configuration had significantly lower emission levels than the natural gas bus configuration for aldehydes, ketones, and benzene. Overall, the results demonstrate that low-emitting diesel technology had the lowest level of both EPA-regulated emissions and TAC’s.

COMPARISON OF CLEAN DIESEL BUSES TO COMPRESSED NATURAL GAS BUSES

Dana Lowell and William Parsley

MTA New York City Transit

ABSTRACT

Using previously published data on regulated and unregulated emissions, this paper will compare the environmental performance of current-generation transit buses operated on compressed natural gas (CNG) to current-generation transit buses operated on ultra-low sulfur diesel fuel (ULSD) and incorporating diesel particulate filters (DPF). Unregulated emissions evaluated include toxic compounds associated with adverse health effects (PAH, NPAH, benzene) as well as particulate matter (PM) particle count and size distribution.

For all regulated and unregulated emissions except NO_x , both technologies are shown to be comparable, with virtually identical levels of PM emissions, toxic emissions, and particle number emissions. DPF-equipped buses are shown to have lower HC and CO emissions than CNG buses. CNG buses are shown to have NO_x emissions that average 25 percent less than NO_x emissions from DPF-equipped buses, though CNG bus NO_x emissions are shown to be much more variable.

In addition, this paper will compare the capital and operating costs of CNG and DPF-equipped buses. The cost comparison is primarily based on the experience of MTA New York City Transit in operating CNG buses since 1995 and DPF-equipped buses fueled with ULSD since 2001. Published data on the experience of other large transit agencies in operating CNG buses is used to validate the NYCT experience.

The incremental cost (compared to “baseline” diesel) of operating a typical 200-bus depot is shown to be six times higher for CNG buses than for “clean diesel” buses. The contributors to this increased cost for CNG buses are almost equally split between increased capital costs for purchase of buses and installation of fueling infrastructure, and increased operating costs for purchase of fuel, bus maintenance, and fuel station maintenance.

COMPRESSED NATURAL GAS AND DIESEL TRANSIT BUS EMISSIONS IN REVIEW

Alberto Ayala, Norman Kado, Robert Okamoto, Michael Gebel, and Paul Rieger

California Air Resources Board

Reiko Kobayashi and Paul Kuzmicky

University of California, Davis

ABSTRACT

Over the past 3 years, the California Air Resources Board (CARB), in collaboration with the University of California and other entities, has investigated the tailpipe emissions from three different late-model, in-use heavy-duty transit buses in five different configurations. The study has focused on the measurement of regulated emissions (NO_x, HC, CO, total particulate matter [PM]), other gaseous emissions (CO₂, NO₂, CH₄, NMHC), a number of pollutants of toxic risk significance (aromatics, carbonyls, PAH's, elements), composition (elemental and organic carbon), and the physical characterization (size-segregated number count and mass) of the particles in the exhaust aero-

sol. The impact of oxidation catalyst control for both diesel and compressed natural gas (CNG) buses and a passive diesel particulate filter (DPF) were evaluated over multiple driving cycles (idle, 55-mph cruise, CBD, UDDS, NYBC) using a chassis dynamometer. The database of results is large, and some findings have been reported already at various forums including last year's DEER Conference. The goal of this paper is to offer an overview of the lessons learned and attempt to draw overall conclusions and interpretations based on key findings to date. To the extent possible, our results are compared to those from other similar studies.

HEAVY-DUTY VEHICLE IN-USE EMISSION PERFORMANCE

Nils-Olof Nylund, Markku Ikonen, and Juhani Laurikko

VTT Processes

ABSTRACT

Engines for heavy-duty vehicles are emission certified by running engines according to specified load pattern or duty cycle. In the United States, the U.S. Heavy-Duty Transient cycle has been in use already for a number of years, and Europe is, according to the requirements of the Directive 1999/96/EC, gradually switching to transient-type testing.

Evaluating the in-use emission performance of heavy-duty vehicles presents a problem. Taking engines out of vehicles for engine dynamometer testing is difficult and costly. In addition, engine dynamometer testing does not take into account the properties of the vehicle itself (i.e., mass, transmission, etc.). It is also debatable how well the standardized duty cycles reflect real-life driving patterns.

VTT Processes has recently commissioned a new emissions laboratory for heavy-duty vehicles. The facility comprises both engine test stand and a fully transient heavy-duty chassis dynamometer. The roller diameter of the dynamometer is 2.5 m. Regulated emissions are measured using a full-flow CVS system. The heavy-duty vehicle chassis dynamometer measurements (emissions, fuel consumption) have been granted accreditation by the Centre of Metrology and Accreditation (MIKES, Finland).

A national program to generate emissions data on buses has been set up for the years 2002-2004. The target is to generate emission factors for some 50 different buses representing different degree of sophistication (Euro 1 to Euro5/EEV, with and without exhaust gas aftertreatment), different fuel technologies (diesel, natural gas) and different ages (the effect of aging). The work is funded by the Metropolitan Council of Helsinki, Helsinki City Transport, The Ministry of Transport and Communications Finland, and the national gas company Gasum Oy.

The International Association for Natural Gas Vehicles (IANGV) has opted to buy into the project. For IANGV, VTT will deliver comprehensive emissions data (including particle-size distribution and chemical and biological characterization of particles) for up-to-date diesel and natural gas vehicles.

The paper describes the methodology used for the measurements on buses, the test matrix, and some preliminary emissions data on both regulated and unregulated emissions.

COMPARATIVE STUDY ON EXHAUST EMISSIONS FROM DIESEL AND COMPRESSED NATURAL GAS POWERED URBAN BUSES

Patrick Coroller and Gabriel Plassat

ADEME Agence De l'Environnement et de la Maîtrise de l'Energie
Technologies des Transports

Thierry Seguelong, *presenter*

Aaqius & Aaqius

ABSTRACT

A couple of years ago, ADEME engaged in programs dedicated to emissions studies of the exhaust from urban buses. The measures associated with the reduction of atmospheric and noise pollution have particular importance in the sector of urban buses. In many cases, they illustrate the city's environmental image and contribute to reinforcing the attractiveness of public transport. France's fleet in service, presently put at about 14,000 units, consumes about 2 percent of the total energy of city transport. It causes about 2 percent of the HC emissions and from 4 to 6 percent of the NO_x emissions and particles. These vehicles typically have a long life span (about 15 years) and are relatively expensive to buy, about €150,000 per unit.

Several technical solutions were evaluated to quantify, on a real-condition cycle for buses, pollutant emissions and fuel consumption on one hand and reliability and cost in real existing fleets on the other hand.

This paper presents the main preliminary results on exhaust emissions from urban buses for two different cases:

- existing diesel buses, with fuel modifications (diesel with low-sulfur content, diesel with water emulsion, and biodiesel [30 percent oil ester in standard diesel fuel]) and
 - renovated CNG-powered Euro II bus fleet
- over representative driving cycles, set up by ADEME and partners. On these cycles, pollutants (regulated and unregulated) were measured as well as fuel consumption at the beginning of a program and 1 year after to quantify reliability and increase/decrease of pollutant emissions.

At the same time, some aftertreatment technologies were tested under real conditions and in several vehicles. Information such as fuel consumption, lubricant analysis, and problems of the technology were followed during a 1-year program.

On the overall level, it is the combination of various action, pollution reduction, and renewal that will make it possible to meet the technological challenge of reducing emissions and fuel consumption by urban bus networks.

STATE-OF-THE-ART AND FUTURE DEVELOPMENTS IN NATURAL GAS ENGINE TECHNOLOGIES

Mark Dunn

Westport Innovations, Inc.

ABSTRACT

Current, state-of-the-art natural gas engines provide the lowest emissions commercial technology for use in medium- to heavy-duty vehicles. NO_x emission levels are 25-50 percent lower than October 2002 diesel engines, and particulate matter (PM) levels are 90 percent lower than non-filter equipped engines. Yet, in common with diesel engines, natural gas engines are challenged to become even cleaner and more efficient to meet environmental and end-user demands. Cummins Westport is developing two streams of technologies to achieve these goals for medium-heavy and heavy-heavy duty applications.

For medium-heavy duty applications, lowest possible emissions are sought on SI engines without significant increase in complexity and with improvements in efficiency and BMEP. The selected path builds on the capabilities of the Cummins Westport, Inc., Plus technology and recent diesel engine advances in NO_x controls, providing the potential to reduce emissions to 2010 values in an accelerated manner and without the use of selective catalytic reduction (SCR) or LNA technology.

For heavy-heavy duty applications where high torque and fuel economy are of prime concern, the Westport-Cycle™ technology is in field trial. This technology incorporates high-pressure direct injection (HPDI) of natural gas with a diesel pilot ignition source. Both fuels are delivered through a single, dual common rail injector. The operating cycle is entirely unthrottled and maintains the high compress-

ion ratio of a diesel engine. As a result of burning 95 percent natural gas rather than diesel fuel, NO_x emissions are halved, and PM is reduced by around 70 percent. High levels of exhaust gas recirculation (EGR) can be applied while maintaining high combustion efficiency, resulting in extremely low NO_x potential.

Some recent studies have indicated that diesels equipped with diesel particulate filters (DPF) emit fewer nanoparticles than some natural vehicles. It must be understood that the ultra fine particles emitted from SI natural gas engines are generally accepted to consist predominantly of VOC's and that lubricating oil is a major contributor. Fitting an oxidation catalyst to the natural gas engine leads to a reduction in nanoparticle emissions in comparison to engines without aftertreatment.

In 2001, the Cummins Westport Plus technology was introduced with the C Gas Plus engine, a popular choice for transit bus applications. This incorporates drive by wire; fully integrated, closed loop electronic controls; and a standard oxidation catalyst for all applications. The B Gas Plus and the B Propane Plus engines, with application in shuttle and school buses, were launched in 2002 and 2003. The gas-specific oxidation catalyst operates in concert with an optimized ring-pack and liner combination to reduce total particulate mass below 0.01g/bhp-hr, combat ultra fine particles, and control VOC emissions.



Abstracts

Session 6 – Environmentally Concerned Public Sector Organization Panel



Abstracts

Session 7 – Combustion and HCCI Regimes

DIESEL ENGINE ALTERNATIVES

Tom Ryan

Southwest Research Institute

ABSTRACT

There are basically three different modes of combustion possible for use in reciprocating engines. These include: diffusion burning, as occurs in current diesel engines; flame propagation combustion, such as is used in conventional spark ignition engines; and homogeneous combustion, such as is used in the Southwest Research Institute homogenous charge compression ignition (HCCI) engine.

Diesel engines currently offer significant fuel consumption benefits relative to other powerplants for on- and off-road applications; however, costs and efficiency may become problems as the emissions standards become even more stringent.

This presentation presents a discussion of the potentials of HCCI and flame propagation engines as alternatives to the diesel engines. It is suggested that as the emissions standards become more and more stringent, the advantages of the diesel may disappear.

The potential for HCCI is limited by the availability of the appropriate fuel. The potential of flame propagation engines is limited by several factors, including knock, exhaust gas recirculation tolerance, high BMEP operation, and throttling. These limitations are discussed in the context of the potential for improvement of the efficiency of the flame propagation engine.

EXPLORING LOW NO_x AND LOW PARTICULATE MATTER COMBUSTION REGIMES

Robert M. Wagner, Scott Sluder, Sam A. Lewis Sr., John M. Storey

Oak Ridge National Laboratory

ABSTRACT

We are investigating nontraditional combustion regimes for improving engine-system efficiency and reducing the performance requirements of post-combustion emissions controls. Combustion regimes of interest exhibit simultaneous low engine-out NO_x and particulate matter emissions. These regimes are realized through a combination of high EGR rates and/or fuel injection parameters.

In this study, we performed detailed emissions characterization for improved understanding of the combustion process as well as the environmental impact of operating in these regimes. Advanced techniques were applied for speciation of hydrocarbon (HC) emissions and particulate matter (PM).

HC speciation has thus far revealed the presence of many short chain hydrocarbons and partial oxidation products that were not present in the fuel. PM characterization revealed that a significant percentage of the PM in these nontraditional regimes is soluble organic, which may be treated with a simple oxidation catalyst. We are also investigating the possibility of increasing the speed/load envelope of these nontraditional regimes as well as evaluating their applicability to regenerating NO_x adsorbers and diesel particulate filters.

ADVANCED RESEARCH IN DIESEL FUEL SPRAYS USING X-RAYS FROM THE ADVANCED PHOTON SOURCE

Chris Powell

Argonne National Laboratory

ABSTRACT

The distribution and degree of atomization of fuel in the combustion chamber is a primary factor in determining the emissions from diesel engines. A number of diagnostics to study sprays have been developed over the last 20 years that are primarily based on visible light measurement techniques. However, visible light scatters strongly from droplets on the periphery of the spray. This prevents quantitative measurements using these techniques, particularly in the dense near-nozzle region.

For this reason we developed the X-ray technique to study the properties of fuel sprays. X-rays have a very low probability of scattering from droplets in the

spray, which allows them to be used to make quantitative measurements of the fuel distribution. These measurements are particularly effective in the region near the nozzle where other techniques fail.

We will present the results of our work measuring the mass distribution and density of sprays from heavy- and light-duty common rail diesel injectors, as well as our most recent work studying sprays under higher ambient density conditions.

NEW DIESEL COMBUSTION REGIME: PARTICULATE ANALYSIS WITH THE SINGLE-PARTICLE LASER ABLATION TIME-OF-FLIGHT MASS SPECTROMETER

Dan Imre and Alla Zelenyuk/Imre

Pacific Northwest National Laboratory

John Storey, Sean Huff, Dean Edwards, and Sam Lewis

Oak Ridge National Laboratory

Jian Wang, Gunnar Senum, and James Wegrzyn

Brookhaven National Laboratory

ABSTRACT

To meet the new exhaust gas emission laws, most new diesel engines will be using exhaust gas recirculation (EGR). EGR technology has been shown to be very effective means of reducing NO_x emissions; however, typically any change in engine operating parameters to reduce NO_x emissions results in an increase in particulate matter (PM) emissions, which in the case of diesel emissions is of particularly serious concern because of its known carcinogenic effects. Hence, traditionally the point defined as the ultimate EGR limit was delineated by a sudden increase in HC (hydrocarbons) and PM.

Very recently a few studies have suggested that by further increasing EGR, it might be possible to push the engine into a novel low-temperature combustion regime (NLTC) that, unlike the “classic NO_x-PM tradeoff,” simultaneously reduces both PM and NO_x emissions. None of the studies have presented any information about the composition and properties of the particulate mass in this combustion regime.

We will present the results of a recent study investigating this NLTC regime. In this study, diesel exhaust particles generated by the Mercedes A-Class 1.7L diesel engine under the entire range of EGR conditions were sampled and characterized by the Pacific Northwest National Laboratory Single Particle Laser Ablation Time-of-Flight Mass Spectrometer (SPLAT-MS). The instrument’s extremely high sensitivity to small particles made it possible to detect and characterize individual particles down to 50 nm, demonstrating SPLAT-MS’s utility for studying diesel PM emission.

In this study exhaust particle flow was introduced into the SPLAT-MS after dilution by a factor of 100 to 1,000 through an aerodynamic lens inlet. Each individual particle was then aerodynamically sized, and its chemical composition was characterized by using two-step, two-laser laser evaporation followed by ultraviolet ionization. The separation of the process by which ions are formed into two steps -- particle evaporation and ionization -- greatly improves the analytical capability of the SPLAT-MS and makes spectral assignment significantly more tractable.

Particle-size distributions from 3.5 to 500 nm were measured in parallel using Scanning Mobility Particle Sizer (SMPS). In addition, the NTRC group measured gas phase concentrations of NO_x, CO, CO₂, and HC’s; recorded engine performance parameters; collected filter samples for gas chromatograph – mass spectrometer analysis; and measured total aerosol mass with TEOM for all EGR conditions.

Increasing EGR from 0 to 45 percent resulted in an increase (a doubling) in the particle number concentration and a shift in the average particle mobility diameter from 85 nm to 115 nm. At the same time the particle average aerodynamic diameter decreased from 97 to 74 nm, suggesting that increasing EGR from 0 to 45 percent results in a decrease of ~25 percent in particle size.

REAL-TIME SIMULTANEOUS MEASUREMENTS OF SIZE, DENSITY, AND COMPOSITION OF SINGLE ULTRAFINE DIESEL TAILPIPE PARTICLES

Alla Zelenyuk/Imre and Dan Imre

Pacific Northwest National Laboratory

John Storey, Sean Huff, Dean Edwards, and Sam Lewis

Oak Ridge National Laboratory

Jian Wang, Gunnar Senum, and James Wegrzyn

Brookhaven National Laboratory

ABSTRACT

Diesel exhaust particulate has been classified as a carcinogen. To understand its effect on human health, it is important to be able to characterize the composition and size of the emitted particles. We have recently developed a single-particle mass spectrometer for the characterization of size and composition of individual exhaust particles. The instrument was specifically designed to provide high sensitivity for particles in the 150- 50 nm range to cover the bulk of the particle mass that is present in the exhaust. We will present results from a recent deployment of this instrument at the National Transportation Research Center (NTRC) at Oak Ridge National Laboratory.

Our Single Particle Laser Ablation Time-of-Flight Mass Spectrometer (SPLAT-MS) was operated over the period of January 31 through February 13, 2003, and sampled exhaust particles generated by a Mercedes A-Class diesel engine. A total of approximately 0.5 million individual particles were sized and their composition characterized in real-time. The aerodynamic size distribution of the detected particles peaked at 70-100 nm, depending on engine operating conditions. The instrument's extremely high sensitivity to small particles was demonstrated by its ability to detect particles down to 50 nm.

After dilution by a factor of 100 to 1,000, exhaust particles were introduced into the SPLAT-MS through an aerodynamic lens, where each individual particle was sized and its chemical composition was

characterized through a synchronous laser heating for particle evaporation followed by ultraviolet ionization. The separation of the process by which ions are formed into two steps -- particle evaporation and ionization -- greatly improves the analytical capability of the instrument and made spectral assignment significantly more tractable.

Initial studies investigated the effects of different load, revolutions per minute (RPM), and exhaust gas recirculation (EGR) conditions on particle-size distributions and composition. When EGR reached 52 percent, the engine operation became "smokeless," and the number concentration of particles dropped by a factor of 20. Studies of the effects of different loads and RPM on particle size and composition were repeated with the diesel fuel containing 15 percent alcohol.

Variation of particle composition with injection timing and sequence, the use of oil recirculation, and the presence or absence of a catalytic converter were also investigated. Very preliminary analysis of the data shows that the vast majority of the exhaust particles were composed of soot, which accounted for over 90 percent of all emitted particulates under many operating conditions. Other types of characterized particles include small amounts of oxygenated organics. Engine wear-and-tear particles containing aluminum, aluminum oxide, and iron were observed under extreme operating conditions of high RPM and low load.

DIESEL HCCI DEVELOPMENT AT CATERPILLAR

Kevin P. Duffy

Caterpillar, Inc.

ABSTRACT

Implementation of a practical homogeneous charge compression ignition (HCCI) engine has numerous technical challenges. Among these are proper mixture preparation, controlling combustion phasing and cylinder-pressure rise rates, and expanding the operating range to higher loads and idle/light

loads. Methods to control combustion phasing include inlet manifold temperature and pressure, injection timing, valve timing and fuel properties. Recent progress on part-load HCCI operation using diesel fuel will be given.

MIXED-MODE DIESEL HOMOGENEOUS CHARGE COMPRESSION IGNITION WITH EXTERNAL MIXTURE FORMATION

Shawn Midlam-Mohler, Yann Guezennec, and Giorgio Rizzoni

Ohio State University

Simon Haas and Michael Bargende

University of Stuttgart

ABSTRACT

Diesel homogenous charge direct injection (HCCI) is a combustion technology showing great promise for the reduction of oxides of nitrogen and particulate matter from diesel engines. Our implementation is a mixed-mode concept, which relies on the use of an essentially unmodified common-rail compression ignition direct injection (CIDI) engine, coupled with a highly effective atomizer for external mixture formation. With this concept, the engine can operate in HCCI mode, HCCI/DI mixed mode, or DI mode, depending on the load and with seamless, progressive mode transition.

The external mixture preparation for the HCCI mode offers a number of advantages over techniques that utilize only the DI system to perform HCCI mixture preparation. External mixture formation, with the additional residence time and very active mixing through the intake stroke, allows for better HCCI operation due to the very effective mixing and charge homogeneity when compared DI HCCI. The traditional problems of external mixture formation (wall wetting, poor cold start, etc) are largely remedied by a novel fuel atomizer with its ultra-fine atomization. Furthermore, when used in a mixed combustion

mode or in pure DI mode at higher loads, the DI injectors can be optimized strictly for DI operation with respect to number, orientation, or size of injector holes.

This mixed-mode operation has been demonstrated on a single-cylinder engine (one-quarter of a recent production 2L engine) in collaboration between Ohio State University and the University of Stuttgart, Germany. The concept has demonstrated extremely low levels of nitrogen oxides (below 10 ppm) and pure HCCI operation up to an IMEP of 4.7 bars. Operation at various conditions (engine speeds, loads, boost pressures, intake temperature, exhaust gas recirculation rates from 0 to 60 percent, etc.) have shown that this technique enables HCCI operation over a wide range of engine conditions with relative insensitivity of the combustion process to operating conditions. This is probably due to the high level of charge homogeneity achieved by this technique. Furthermore, the transition from HCCI to mixed HCCI/DI to DI combustion mode is seamless, significantly enabling the controllability of such a combustion system over the entire engine operating map.

DETAILED MODELING OF HOMOGENEOUS CHARGE COMPRESSION IGNITION AND PRE-MIXED CHARGE COMPRESSION IGNITION COMBUSTION AND MULTI-CYLINDER HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINE CONTROL

Salvador Aceves, Daniel Flowers, Joel Martinez-Frias, Francisco Espinosa-Loza,
and Robert Dibble

Lawrence Livermore National Laboratory

ABSTRACT

This work supports the need to develop a new combustion concept that allows both high efficiency and low emissions for transportation applications. Our work on homogeneous charge compression ignition (HCCI) combustion is a synergistic combination of analysis and experimental work.

On analysis, we have developed advanced methodologies that combine chemical kinetics with fluid mechanics to analyze HCCI engines with accuracy never before achievable for other types of engines. These analysis tools have also been used to guide the experimental effort.

On experimental work we have a multi-cylinder Volkswagen TDI engine that allows us to work on balancing combustion between cylinders. This is a crucial problem with HCCI combustion that has so far precluded commercialization of these engines.

Previously, our analysis capabilities applied only to perfectly homogenized air-fuel mixtures. We have recently extended our methodologies to include mixing between zones. We have used this model to demonstrate that mixing between zones is responsible for

most of the production of carbon monoxide in an HCCI engine. In addition to being an important enhancement to our HCCI engine analysis tools, this new model can be used as a framework to analyze engine operating conditions where the charge is not perfectly homogeneous (i.e., PCCI combustion).

We are also developing methodologies for controlling and balancing combustion in a multi-cylinder HCCI engine. We are using an exhaust throttle as a low-cost surrogate for variable valve timing. Our results for using an exhaust throttle in an HCCI engine show some unexpected results. Throttling the exhaust typically advances combustion in a single-cylinder engine, due to the effect of hot combustion gases on HCCI combustion. However, in a multi-cylinder engine, throttling the exhaust of a cylinder *delays* combustion in this cylinder and *advances* combustion in other cylinders. This is due to flow interactions between cylinders, as the exhaust throttle in a cylinder diverts the flow of the fresh charge to the other cylinders. Characterizing these effects is extremely important in obtaining satisfactory combustion in a multi-cylinder HCCI engine.

OVERVIEW OF DETAILED CHEMICAL SPECIATION AND PARTICLE SIZING FOR DIESEL EXHAUST, BOTH REAL-TIME AND FILTER-BASED MEASUREMENT

Choi-Bum Kweon, Shusuke Okada, David E. Foster, Martin M. Shafer,
Charles G. Christensen, and James J. Schauer

University of Wisconsin

Deborah S. Gross

Carleton College

ABSTRACT

EPA ambient air-quality measurement protocols have been incorporated into the exhaust measurement system of a research single-cylinder diesel engine. To allow more detailed assessment of the individual chemical components of the diesel particulate matter (PM), the exhaust dilution system includes a residence-time chamber (RTC) to allow for residence times of 30-60 seconds in the second stage of dilution before sampling. Measurements have been performed using the more normal approach of catching the particulate matter on filters and then analyzing the filters, and also using an aerosol time-of-flight mass spectrometer (ATOF-MS), which is capable of analyzing individual particles for size and composition at a rate of up to 150 particles per minute for a particle-size range from 0.15 to 5 micrometers. Additional data on particle size were obtained using a scanning mobility particle sizer (SMPS).

Samples have been collected on a range of different filters where mass loading, elemental and organic carbon (EC/OC), trace metals, sulfate ions (SO_4), volatile organic compounds, and semi-volatile organic compounds have been evaluated. Using the SMPS, particle-size distributions have been measured for the different operating conditions and for different exhaust gas residence times in the RTC.

This paper gives an overview of the results obtained with the different measurement techniques for the range of engine operating conditions covered by the CARB 8 mode test. Results show that the chemical composition and size distribution of the particulate matter are highly dependent on the engine operating conditions. There is a dramatic shift in the ratio of elemental to organic carbon and in the sulfate ions (SO_4) when the engine is traversed across a load and speed range. Similarly, there is a shift in the particle-size range for which there is virtually no impact on the mass loading, and the nano-particle-size distribution, at a fixed dilution ratio and temperature, is a function of the time spent in the RTC. Trace metal concentrations in the particulate vary significantly with load and speed and are treated as indicative of oil consumption.

Results of the filter-based measurements are being compared to those obtained using the ATOF-MS, which has been widely used to study atmospheric aerosols but has only seen limited use for assessing internal combustion engine exhaust emissions. Using the ATOF-MS to make fundamental measurements of chemical composition and particle size in engine exhaust has the potential to offer unique insights into the impact of changes in engine operating conditions on the resultant changes in the exhaust characteristics.

NON-SOOTING, LOW-FLAME TEMPERATURE, AND MIXING-CONTROLLED DIRECT INJECTION DIESEL COMBUSTION

Lyle M. Pickett and Dennis L. Siebers

Sandia National Laboratories

ABSTRACT

Methods of producing non-sooting, low-flame temperature diesel combustion were investigated in an optically accessible, quiescent constant-volume combustion vessel under mixing-controlled diesel combustion conditions. Combustion and soot processes of single, isolated fuel jets were studied after auto-ignition, transient premixed combustion, and while the injector was fully open (i.e., during the mixing-controlled phase of heat release for diesel combustion).

The investigation showed that small injector tip orifices could be used to produce non-sooting, low-flame temperature combustion in two different ways. First, using a 50-micron injector tip and ambient oxygen concentrations as low as 10 percent (simulating the use of extensive exhaust gas recirculation), a fuel jet was non-sooting at typical diesel ambient temperatures (1000 K). Second, using the same injector tip at a reduced ambient gas temperature (850 K), but with 21-percent oxygen, it was shown that non-sooting, mixing-controlled combustion occurred at the lift-off length in a fuel-air mixture with a cross-sectional average equivalence ratio of approximately 0.6—suggesting that the quasi-steady combustion was fuel lean and thereby avoided the formation of a diffusion flame.

The adiabatic flame temperature with reduced ambient oxygen concentration or fuel-lean combustion was approximately 2000 K, compared to typical diesel flame temperatures that exceed 2600 K. The 50-micron injector tip results above were obtained using a #2 diesel fuel. However, using an oxygenated fuel (20 weight percent), the investigation showed that the same low-temperature combustion, either with reduced ambient oxygen concentration or fuel-lean combustion, was realized with a 100-micron injector tip.

Although these single, isolated jets do not have jet-jet interactions that would occur in realistic engines, the results are useful for understanding limiting-case behavior of single-jet mixing and combustion during an injection event. The non-sooting and low-flame temperature, mixing-controlled combustion realized using small orifice tips suggests that the use of small orifices offers the potential for a simultaneous soot and NO_x reduction in an engine, much like diesel homogeneous charge compression ignition combustion.

SHELL GAS -TO-LIQUIDS IN THE CONTEXT OF A FUTURE FUEL STRATEGY – TECHNICAL MARKETING ASPECTS

Ralph A. Cherrillo, Richard H. Clark, and Ian G. Virrels

Shell Global Solutions (U.S.), Inc.

Roger Davies

Shell Gas and Power

ABSTRACT

Liquid fuels refined from crude oil are likely to continue to dominate the transportation fuels market for the next 20 years. However, fuel properties and specifications will not stand still, with change driven by sustainability challenges of:

- Security and diversification of energy supply
- Reduced greenhouse gas emissions
- Reduced local pollutant emissions
- Affordability, availability, and customer acceptance.

In the long term, hydrogen produced from renewable sources is seen by many as the ultimate solution, combining both local and global environmental advantages. However, in the personal mobility domain, there is still a long way to go on the path to commercialization of hydrogen and fuel cells.

In the interim period, alternative fuels – such as biofuels, liquefied natural gas, compressed natural gas, and gas to liquids (GTL) fuels -- will play, in

varying degrees, an increasingly important role in meeting mobility needs. Some may grow beyond niche positions depending on Government transport fuel policy.

GTL fuel offers strategic diversification of energy supply, since it is derived from natural gas, and can provide a bridge to future fuels and technologies. Its compatibility with the existing diesel infrastructure in combination with significant local pollutant emissions benefits (both as pure, 100-percent GTL and as a blend with conventional diesel) results in a more cost effective solution in reducing emissions than other alternative fuels.

This paper discusses various market development activities associated with GTL fuel and how these are often directly related to the technical attributes of the fuel. For example, the ability of GTL fuels to deliver emissions benefits when blended with conventional diesel, has recently allowed the formulation of fuels with reduced black smoke emissions in Thailand and Greece.

EFFECTS OF FUEL TYPE AND ENGINE SPEED ON REQUIRED INTAKE TEMPERATURE AND COMPLETENESS OF COMBUSTION IN A HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINE

Magnus Sjöberg and John E. Dec

Sandia National Laboratories

ABSTRACT

Homogeneous charge compression ignition (HCCI) engines have shown potential for both high efficiency and low emissions of NO_x and particulates. However, as the fuel/air-equivalence ratio is reduced for decreasing engine loads, CO and hydrocarbon (HC) emissions become excessive.

In a previous study, the sources of emissions at low loads were investigated using iso-octane as the fuel. It was found that the peak combustion temperature had a strong influence on the completeness of the bulk-gas combustion reactions, particularly the CO-to-CO₂ reactions. In the engine, this peak temperature is reached by a combination of intake temperature, compression, and combustion heating. However, the intake temperature required to maintain combustion phasing near top dead center (TDC) varies with both the fuel type and engine speed. Therefore, it can be anticipated that the fuel/air-equivalence ratio for onset of incomplete bulk-gas reactions is dependent on both the autoignition characteristics of the fuel and the engine speed.

To gain a better understanding of how the onset of incomplete bulk-gas combustion changes with fuel type and engine speed, a parametric study of HCCI combustion and emissions has been conducted. Four fuels with different ignition characteristics were investigated, including: a research-grade gasoline, pure iso-octane, and two mixtures of the primary reference fuels (*n*-heptane and iso-octane) with octane numbers of 80 and 60. The experiments were conducted at naturally aspirated conditions in a single-cylinder engine (0.98 liters/cylinder) fitted with a custom HCCI piston that minimizes crevice volume. For

each fuel, data were acquired at four engine speeds (600, 1200, 1800, and 2400 revolutions per minute), and the fuel loading was varied from near the knocking limit to loads at or below idle (based on typical diesel-engine fueling) at each speed. Cylinder pressure and exhaust-gas data (CO₂, O₂, CO, HC, NO_x, and smoke) were acquired for each condition.

The results show that there is a strong coupling between the ignition quality of the fuel and the intake temperature required to phase combustion at TDC. The intake temperature, in turn, directly affects the completeness of combustion for a given engine speed and fueling rate. The effect of engine speed depends on the ignition characteristics of the fuel. For fuels with little cool-flame activity (i.e., gasoline and pure iso-octane), the equivalence ratio for the onset of incomplete bulk-gas reactions is independent of engine speed. This occurs because the increased compression temperatures required to maintain combustion phasing as the engine speed is increased also increase the rate of CO-to-CO₂ conversion, balancing the shorter time available to complete combustion. However, for fuels with a significant fraction of *n*-heptane (i.e., significant cool-flame chemistry), the onset of incomplete bulk-gas combustion depends strongly on engine speed, with a shift to higher equivalence ratios at lower speeds. This is due to the strong time dependence of the cool-flame chemistry, which necessitates lower intake temperatures at lower engine speeds to maintain combustion phasing. This leads to lower combustion temperatures and a commensurate rise in CO-emissions unless the fueling is increased.



Abstracts

Session 8 – Diesel Engine Development and Durability

STATE-OF-THE-ART AND EMERGING TRUCK ENGINE TECHNOLOGIES FOR OPTIMIZED PERFORMANCE, EMISSIONS, AND LIFE-CYCLE COSTING

Michael Schittler

DaimlerChrysler AG

ABSTRACT

The challenge for truck engine product engineering is and will be not only to fulfill increasingly stringent emission requirements, but also to maintain or improve the engine's economical viability as the powerplant that is the backbone of our economy. As emission limit values are to be reduced in big steps, continuous improvement is not enough but technological quantum leaps are necessary. In the past, the introduction and refinement of electronic control of all major engine functions have been such a quantum leap required to make full use of parameter optimization.

The next big step forward will be exhaust after-treatment, which is successfully established since many years on Otto-cycle engines. The introduction of exhaust aftertreatment especially for diesel engines for commercial vehicles is a much more demanding task, but the limit values to be met starting in the 2005-2007 timeframe in Europe, the U.S.A., and Japan require this step and the engine industry is able to implement the new technology if all stakeholders support the necessary decisions.

One decision has already been taken: the reduction of sulfur in diesel fuel. This is comparable to the elimination of lead in gasoline as a prerequisite for the three-way catalyst. Now we have the chance to optimize ecology and economy of the diesel engine simultaneously by taking the decision to provide an additional infrastructure for a NO_x reduction agent needed for the introduction of the selective catalytic reduction technology, which is already implemented in electric power generation. This requires some effort, but the costs are significantly below the gains in fuel efficiency in comparison to other technologies. After long discussions, this decision has been taken in Europe and is supported by all truck and engine manufacturers. The necessary logistic support will be in place when it will be needed in 2005.

For the United States, the decision has to be taken this year in order to have the infrastructure available in 2007. It will enable the global engine industry to focus their R & D budgets on one direction not only for 2007 but for the years beyond 2010 with the best benefit for the environment, the customers, and the industry.

RECENT DEVELOPMENTS IN BMW'S DIESEL ENGINE TECHNOLOGY

Fritz Steinparzer

Bayerische Motoren Werke AG

ABSTRACT

In Europe, diesel engines have begun to play a very significant role in the luxury segment of the automotive market. By reengineering the 6 and 8 cylinder engines for the new 7 Series, BMW again succeeded in significantly improving the customer-relevant product characteristics. The advanced engine technology used has also laid the foundation for meeting the more stringent emission requirements of the future.

Improved combustion processes, highly flexible injection systems, and high-performance exhaust aftertreatment are key elements in further reducing emissions. In order to allow manufactures to make a long term commitment to this technology for this market, there must be a holistic approach when considering the environmental benefits of diesel engines vis-à-vis their overall contribution to energy independence and maintaining individual mobility.

DEVELOPMENT OF SIMULTANEOUS REDUCTION SYSTEM FOR NO_x AND PARTICULATE MATTER FROM A DIESEL ENGINE

Tetsu Watanabe

Toyota Motor Corporation

ABSTRACT

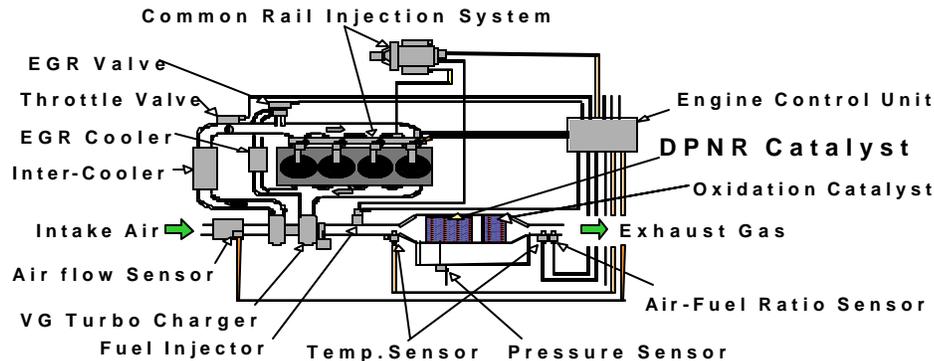
Toyota has developed a simultaneous reduction system for NO_x and particulate matter from a diesel engine (DPNR - Diesel Particulate and NO_x Reduction system) and tested it for various applications. We have verified that the DPNR has a high potential for realizing clean diesel engine use for various market segments, such as passenger vehicles in the European market and light-duty trucks in the Japanese market.

The key technologies of the system incorporate the following: the DPNR catalyst; common rail fuel injection system to control catalyst bed temperature and air fuel ratio; an electrically controlled exhaust gas recirculation (EGR) system; and exhaust port-or-pipe injector in order to supply rich gas to the DPNR catalyst for NO_x reduction and sulfur discharging.

For the European market, Toyota has carried out a field trial project in which 60 vehicles with the DPNR system installed in 2L TDI have been tested in order to verify its operation and confirm the reliability of the system. In applying the DPNR to light-duty

trucks, we have developed the DPNR for 2-ton payload trucks for the Japanese market. In this application, deterioration of the NO_x storage catalyst was a critical issue because of its long traveling distance. For this issue, we conducted extended durability tests on an engine test bed, using 40-ppm and 7-ppm sulfur content diesel fuel. As a result, the Japanese U-LEV (75-percent reduced emission level from Japanese new short-term regulation in Japan D-13 mode) emissions standard could be achieved when using fuel with sulfur content of 7 ppm even after 1,000,000 km.

When considering applications for the U.S. market, in addition to improving the DPNR performance, the quality and specification of diesel in the market are very important in order to meet severe emission targets (i.e., Tier 2 bin 5). That is, the cetane level and aromatics content need to be at least equivalent to the level required in the European and Japanese fuel standards.



PERFORMANCE AND DURABILITY OF PSA PEUGEOT CITROËN'S DIESEL PARTICULATE FILTER SYSTEM ON TAXIS FLEET IN PARIS AREA

Patrick Coroller and Gabriel Plassat

ADEME Agence De l'Environnement et de la Maîtrise de l'Energie
Technologies des Transports

Thierry Seguelong, *presenter*

Aaqius & Aaqius

ABSTRACT

The use of diesel engines has strongly increased during the last years and now represents 40 percent of the sales in Europe and up to 50 percent of the number of cars in circulation from some countries. This success is linked not only to the economical aspect of the use of such vehicles, but also to the recent technological improvements of these engines. The new technical solutions (high-pressure direct injection, turbocharger, etc.) have indeed allowed the increase of these engine performances while decreasing their fuel consumption, pollutant emissions, and noise level.

From an environment point of view, diesel engines are nevertheless penalized by their particulates and NO_x emissions. The study and the treatment of the particulates, highly criticized for their potential impact on health, are the subject of numerous works of characterizations and developments.

PSA Peugeot Citroën has recently (2000) launched its diesel particulate filter (DPF) technology in several types of vehicles (500,000 vehicles with DPF have been sold today). In order to evaluate the durability of this technology over a long period of time, a study program has been set up by ADEME (French Environmental Agency), IFP Powertrain, PSA Peugeot Citroën, and Taxis G7 (a Parisian taxi company).

The objective is to study the evolution of five taxis and their aftertreatment-system performance over 80,000 km in hard urban-driving conditions, which correspond to the recommended mileage before the first DPF maintenance, as well over 120,000 km, after the DPF maintenance and re-manufacturing. More specifically, the following evaluations are being performed at regular intervals (around 20,000 km): regulated gaseous pollutant emissions on NEDC cycle, particulate emissions, and unregulated pollutant emissions. The results obtained until now have not shown any degradation of the DPF efficiency (more than 90 percent).

This paper presents the methodology set up, and the explanation of the first results obtained. Indeed, a more specific study has shown that most of the aerosols, measured with a scanning mobility particle sizer are composed of liquid fractions, mainly sulfates due to the sulfur coming from the fuel but also from the lubricant. The impact of sulfates stored on the catalyst surface during low-temperature running phases and removed during high-temperature running phases has been also outlined.

COMBINATION OF DIESEL FUEL SYSTEM ARCHITECTURES AND CERIA-BASED FUEL-BORNE CATALYSTS FOR IMPROVEMENT AND SIMPLIFICATION OF THE DIESEL PARTICULATE FILTER SYSTEM IN SERIAL APPLICATIONS

Michael D. Civiello

RHODIA Electronics & Catalysis Inc.

Paul Wouters

INERGY Automotive Systems Research

ABSTRACT

Diesel vehicles have an increasing market share in Europe. To further increase their environmental friendliness, control of particulate emissions is a key topic. Ceria-based fuel-borne catalysts have proven their efficiency to optimize the diesel particulate filter (DPF) efficiency and durability: since the market introduction of the DPF system in serial applications in May 2000 by PSA Peugeot Citroën, more than 500,000 vehicles have been DPF-equipped. Tracking the serial production current situation, several themes for improvement have been identified, including system simplification to limit its total cost as well as an optimized maintenance. The paper presents those upgrades that will be proposed in serial applications, in the near future.

Catalytic activity of ceria-based fuel-borne catalysts has been chemically tuned to meet the 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, based on the use of the iron-doped ceria nanoparticles as active catalytic ingredient.

In parallel, dosing strategies of ceria-based fuel-borne catalyst are being developed to match with the proposed evolution in the fuel-borne catalyst for serial applications. New designs of the automatic on-board dosing system are being developed to ensure the global accuracy in the diesel fuel treatment and to limit the maintenance operation for fuel-borne catalyst tank refilling.

Improvement and simplification of the DPF system for serial applications are based on the adaptation and the optimization of several functionalities of the global system. The next step of the "fit for life" target goes necessarily by co-developments between the various functionalities of global DPF system.

DIESEL PARTICULATE FILTER: A SUCCESS FOR FAURECIA EXHAUST SYSTEMS

Robert Parmann

Faurecia Exhaust Systems

ABSTRACT

The presentation is based on more than 3 years experience in mass production of diesel particulate filters (DPF's) for passenger cars in Europe. Faurecia, the technology leader in diesel, has produced over 400,000 DPF's to date – around 70 percent of the present market.

We have developed a number of in-house tests and a wealth of expertise. The function of the DPF system on vehicles is explained, with a focus on the use of the Rhodia's Eolys™ fuel-borne catalyst for DPF regeneration. Several design factors are dis-

cussed: substrate and thermal conditions, different operating conditions of the system, linked to the driving profile, and their effect on function and durability. Measurement of thermal stresses on the substrate will be presented along with a method for filter sizing.

Service interval strategies related to filter size and regeneration system are discussed. As a full-system supplier, Faurecia provides a remanufacturing service, and the filter cleaning process used today in Europe is described.

CUMMINS/DOE LIGHT TRUCK DIESEL ENGINE PROGRESS REPORT – 2003

John Stang, David Koeberlein, and Michael Ruth

Cummins, Inc.

ABSTRACT

Cummins has studied requirements of the light-truck automotive market in the United States and believes the proposed V-family of engines meets those needs. Design and development of the V-family engine system with DOE's partnership continues. The engine system is a difficult one since the combined requirements of a very fuel-efficient commercial diesel and the performance and sociability requirements of a gasoline engine are needed.

Results show that full EPA Tier 2 Bin 5 emission results are achieved, while also meeting the fuel-economy targets established by DOE. Various results of ongoing system development are shown including air-handling system, noise, and overall vehicle performance. General aftertreatment system design and direction are discussed.

ADVANCED DIESEL ENGINE AND AFTERTREATMENT TECHNOLOGY DEVELOPMENT FOR TIER 2 EMISSIONS

R. Aneja, B. Bolton, B. Oladipo, Z. Pavlova-MacKinnon, and A. Radwan

Detroit Diesel Corporation

ABSTRACT

Advanced diesel engine and aftertreatment technologies have been developed for multiple engine and vehicle platforms. Tier 2 (2007 and beyond) emissions levels have been demonstrated for a light-truck vehicle over a FTP 75 test cycle on a vehicle chassis dynamometer. These low-emissions levels are obtained while retaining the fuel-economy advantage characteristic of diesel engines.

The performance and emissions results were achieved by integrating advanced combustion strategies (CLEAN Combustion[®]) with prototype after-

treatment systems. CLEAN Combustion[®] allows partial control of exhaust species for aftertreatment integration in addition to simultaneous NO_x and particulate matter reduction. Analytical tools enabled the engine and aftertreatment subsystems development and system integration. The experimental technology development methodology utilized a range of facilities to streamline development of the eventual solution, including utilization of steady-state and transient dynamometer test-beds to simulate chassis dynamometer test cycles.

THE DEVELOPMENT AND ON-ROAD PERFORMANCE AND DURABILITY OF THE FOUR-WAY EMISSION CONTROL SCRT™ SYSTEM

B.J. Cooper, A.C. McDonald, and A.P. Walker

Johnson Matthey

Mario Sanchez

Cummins, Inc.

ABSTRACT

The progressive tightening of the heavy-duty diesel emissions legislation worldwide necessitates the development of pollution control systems capable of enabling engines to meet the incoming legislative requirements. It is clear that to maximize the benefit to the environment, as well as to meet the very stringent future standards (especially the U.S. 2010 limits), systems capable of high simultaneous conversions of all four major pollutants -- carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate matter (PM) -- are required.

Very high conversions of CO, HC, and PM are achieved using catalyst-based diesel particulate filter (DPF) systems, such as the Continuously Regenerating Technology, (CTR®) system. High NO_x conversions can be obtained using selective catalytic reduction (SCR) systems, in which ammonia (generated from urea) is used to selectively reduce the NO_x. This paper summarizes the key steps in the development of the four-way SCRT™ system, which comprises the CRT system followed by an SCR system. Engine bench results obtained during the development of this system are presented and discussed.

However, the key to real-world emissions benefit is the actual on-road performance of such systems. It is well established that the CRT system provides very high and durable conversions of CO, HC, and PM so the focus of this current work was to demonstrate the NO_x conversion capability and durability of the SCRT™ system.

The SCRT™ unit was installed on a long-haul truck powered by a 15L Cummins engine. On-road NO_x emissions performance was measured using NO_x sensors located upstream and downstream of the SCRT™ unit. Over an 850-km evaluation route, the average on-road NO_x conversion obtained was up to 82 percent, even when the urea injection quantity was set to give a maximum NO_x conversion of around 85 percent. The durability of the system has also been assessed. Over the course of 150,000 km, no reduction in the NO_x conversion efficiency of the system was observed.

The results presented in this paper demonstrate that the SCRT™ system provides very high on-road NO_x conversion and that the system has excellent durability within real-world applications.

VARIABLE CHARGE MOTION FOR 2007- 2010 DIESEL ENGINES

Josef Maier

AVL Powertrain Engineering, Inc.

ABSTRACT

The use of direct-injection diesel engines in U.S. heavy-duty pickup truck applications is becoming increasingly popular, with over 250,000 produced in 2002. The high torque density and greatly improved fuel consumption offer distinct advantages to the end user.

The 2007 and 2010 emissions legislation will present another set of technical and product-cost challenges to this type of powertrain. The introduction of efficient aftertreatment systems is mandatory for the success of these engines, but optimization of engine-out emissions is also a critical element.

Much has been written about the improvements in modern fuel systems, which offer great flexibility for the direct introduction of fuel into the cylinder. This paper presents complementary technologies that allow improved air/fuel mixing processes by the additional flexibility of variable in-cylinder charge motion. This approach is particularly applicable to pickup truck engines, which require high BMEP levels across a wide engine speed range to offer the driveability demanded by the consumer.

Design solutions for 2-valve and 4-valve engines are presented along with the potential emissions and fuel consumption benefits.

DIESEL EXHAUST EMISSIONS CONTROL FOR LIGHT-DUTY VEHICLES

R. Mital, J. Li, S. Popuri, S. C. Huang, B. J. Stroia, and Yul Tarr

Cummins, Inc.

Kenneth Howden

U.S. Department of Energy

ABSTRACT

Results of diesel exhaust aftertreatment testing and analysis being conducted at Cummins, Inc., under the FreedomCAR program are presented. Various NO_x adsorber aftertreatment configurations were tested both in steady state and in transient in an effort to reduce the size and cost of the system while minimizing the fuel economy penalty. Both systems, discrete (adsorber and catalyzed particulate filter) and 4-way (NO_x, HC, CO and particulate matter [PM]), were tested.

After various iterations of the catalyst formulation, regeneration strategy, catalyst configurations etc., the aftertreatment components were integrated and optimized for the light-duty application. The optimized exhaust aftertreatment system was first tested under steady-state conditions in the test cell to evaluate performance and optimize regeneration strategy. The system was then tested in the transient test cell

and on the chassis dynamometer. Emission results for FTP-75, US06, HWFET, and UDDS cycles were obtained at different test weights.

Encouraging reduction in both NO_x and PM emissions was observed for all test cycles. Even though the engine-out emissions were high for the aggressive US06 cycle, the system-out results were low, meeting the SFTP Tier II targets. Durability testing was conducted for both the discrete and the 4-way system, the results of which are presented in the paper.

A transient adsorber-modeling tool has been developed to predict and further assist in improving system performance. Results for various other issues including low-temperature light-off, engine-managed regeneration, exhaust sulfur management, system integration, and design trade-off, are also presented and discussed.

ANALYTICAL TOOL DEVELOPMENT FOR AFTERTREATMENT SUB-SYSTEMS INTEGRATION

B. Bolton, A. Fan, K. Goney, Z. Pavlova-MacKinnon, K. Sisken, and H. Zhang

Detroit Diesel Corporation

ABSTRACT

The stringent emissions standards of 2007 and beyond require complex engine, aftertreatment, and vehicle systems with a high degree of subsystem interaction and flexible control solution. This necessitates a system-based approach to technology development, in addition to individual subsystem 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 this lead to efficient utilization of available experimental resources.

A suite of analytical models has been developed to represent particulate matter and NO_x aftertreatment subsystems. 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 toolbox for complete engine, aftertreatment, and vehicle subsystems development and system integration applications. However, the fidelity of aftertreatment models and application going forward is limited by the lack of fundamental kinetic data.



Abstracts

Session 9 – Environmental Science and Health Impacts

THE WEEKEND OZONE EFFECT - THE WEEKLY AMBIENT EMISSIONS CONTROL EXPERIMENT

Douglas R. Lawson

National Renewable Energy Laboratory

**Charles L. Blanchard and
Shelley J. Tanenbaum**

Envair

Tami H. Funk and Lyle R. Chinkin

Sonoma Technology, Inc.

**Eric Fujita, Barbara Zielinska, John Sagebiel,
John Bowen, William Stockwell,
and Mark McDaniel**

Desert Research Institute

Greg Yarwood and Till E. Stoeckenius

ENVIRON

Jeremy G. Heiken

Air Improvement Resource, Inc.

Alan M. Dunker

General Motors Research & Development
Center

ABSTRACT

Since the mid-1970s, ozone concentrations in California's South Coast Air Basin (SoCAB) have been higher on weekends than on weekdays. Despite significantly lower ozone precursor levels on weekends, 20 of all 78 southern California sites show statistically significant higher mean ozone levels on Sundays than on weekdays ($p < 0.01$); 49 of the remaining 50 sites show no significant differences between mean weekday and Sunday peak ozone levels. The weekend effect has generated strong interest because of its implications for development of air-quality control strategies.

To investigate the possible causes of higher weekend ozone compared to weekday ozone in the SoCAB, the National Renewable Energy Laboratory (NREL), with support from DOE's Office of FreedomCAR and Vehicle Technologies, and the Coordinating Research Council (CRC) sponsored a multi-phase effort beginning in 1999 to collect and analyze weekday and weekend air-quality, emissions, and meteorological data to formulate hypotheses likely to explain the causes of elevated weekend ozone in the SoCAB.

As part of the field study, on-road mobile source emissions activity data were collected in close proximity to each ambient air-quality monitoring site.

These emissions-activity data include daily diurnal vehicle count figures for selected surface streets and Caltrans Weigh-in-Motion data collected on major freeways. Surveys also were conducted to acquire data about business and residential activities on weekdays and weekends.

The ambient air-quality field program was conducted during September and October 2000. Measurements were used to attribute weekday/weekend changes in the temporal and spatial patterns of volatile organic compounds (VOC's) and NO_x concentrations to major sources of ozone precursor emissions. While exhaust emissions from on-road gasoline and diesel vehicles are the primary sources of interest, detailed speciation of VOC's also allowed for attribution of other sources of volatile organic compounds.

Air-quality simulation modeling explained the observed weekend ozone effect very well. Changes to the mass of motor vehicle emissions were the main contributor to ozone differences rather than changes to the timing of motor vehicle emissions. Ozone increases on weekends are caused by lower NO_x emissions because ozone formation is strongly VOC-limited throughout most of the Los Angeles area. Carryover of precursors and/or ozone is not an important factor in explaining the relationships between emission changes and ozone effects.

GASOLINE VEHICLE EXHAUST PARTICLE SAMPLING STUDY

David Kittelson, Winthrop Watts, and Jason Johnson

University of Minnesota

ABSTRACT

The University of Minnesota collaborated with the Paul Scherrer Institute, the University of Wisconsin (UWI), and Ricardo, Inc., to physically and chemically characterize the exhaust plume from recruited gasoline spark ignition (SI) vehicles. The project, supported by DOE's Office of FreedomCAR and Vehicle Technologies, had four primary objectives:

- Measure representative particle-size distributions from on-road SI vehicles and distinguish between SI and diesel emissions.
- Compare the information obtained from on-road tests to a small subset of light-duty gasoline vehicles tested on a chassis dynamometer under steady-state cruise conditions and using the Unified Cycle at both room temperature and 0°C.
- Characterize bulk and size-segregated chemical composition of the particulate matter (PM) emitted in the exhaust from the gasoline vehicles.
- If results from objectives 1 and 2 do not agree with regard to PM-size distribution, utilize the latest information on particle formation and dilution to explain the differences.

Particle number concentrations and size distributions are strongly influenced by dilution and sampling conditions. Laboratory methods were evaluated to dilute SI exhaust in a way that would produce size distributions that were similar to those measured dur-

ing experiments. Size fractionated samples were collected for chemical analysis using a nanomicroorifice uniform deposit impactor (nano-MOUDI). In addition, bulk samples using Teflon and quartz fiber filters followed by polyurethane foam were collected and analyzed by the UWI researchers.

Data were also collected during cold, cold start idle tests, laboratory tests to determine the impact of lube oil consumption on particulate matter emissions and during an on-road study to compare weekday with weekend air quality around the Twin Cities area. This portion of the study resulted in the development of a method to apportion the diesel and SI contribution to on-road aerosol.

A mixture of low-, mid-, and high-mileage vehicles was recruited for testing during the study. Under steady highway cruise conditions, a significant particle signature above background was not measured, but during hard accelerations number weighted size distributions for the test fleet were similar to modern heavy-duty diesel vehicles. Number emissions were much higher at high speed and during cold starts, and fuel-specific number emissions range from 10^{12} to 3×10^{16} particles/kg fuel. A simple relationship between number and mass emissions was not observed. Other results will be discussed.

DOE'S GASOLINE/DIESEL PARTICULATE MATTER (PM) SPLIT STUDY – CHARACTERIZATIONS OF THE VARIATIONS IN CHEMICAL COMPOSITION OF PM_{2.5} IN THE SOUTH COAST AIR BASIN

Eric M. Fujita, David E. Campbell, William P. Arnott, Barbara Zielinska, and Judith C. Chow

Desert Research Institute

Douglas R. Lawson

National Renewable Energy Laboratory

ABSTRACT

DOE's Gasoline/Diesel Particulate Matter (PM) Split Study is being conducted to quantify the relative contributions of tailpipe emissions from gasoline-powered motor vehicles and diesel-powered motor vehicles to the ambient concentrations of fine particulate matter (PM_{2.5}) in the urbanized region of Southern California using an organic compound-based chemical mass balance model (CMB). This study involves several groups working cooperatively on sample collection and quality assurance aspects of the study, but working independently, at least initially, on chemical analysis and data analysis. Groups participating in the study include California's Bureau of Automotive Repair, the South Coast Air Quality Management District, the U.S. Environmental Protection Agency, Ralph's Groceries, the Clean Air Vehicle Technology Center, the West Virginia University, the University of Wisconsin at Madison (UWM), and the Desert Research Institute (DRI).

Source testing of 59 light-duty vehicles (including 2 diesel vehicles) was completed in June 2001; ambient measurements were performed in July; and the testing of 34 heavy-duty vehicles was completed in September. DRI used sample collection and chemical analysis methods consistent with those employed during the Northern Front Range Air Quality Study. Parallel samples were collected by UWM using methods consistent with previous PM studies in Los Angeles. This paper describes the variations in the chemical composition of the ambient samples collected by DRI.

Twenty-four hour samples were collected on Teflon and quartz filters and Teflon-impregnated glass fiber (TIGF) filters followed by polyurethane foam

(PUF) plugs and XAD-4 resin cartridges for 28 consecutive days at air-monitoring stations in downtown Los Angeles and Azusa. Teflon filters were analyzed for gravimetric mass, elements, and ions, and quartz filters were analyzed for organic and elemental carbon by thermal optical reflectance (TOR) and thermal optical transmittance (TOT) using both MPROVE and NIOSH protocols. The TIGF/PUF/XAD samples were combined and extracted together by day of the week, and analyzed for polycyclic aromatic hydrocarbons, hopanes, steranes, alkanes, methoxyphenols, lactones, sterols, and polar organic compounds.

A third set of ambient samples was collected from a mobile sampling van at several regionally representative sites and at locations with expected higher proportions of PM emissions from diesel trucks (e.g., Terminal Island, truck stop, highway truck routes) and from gasoline vehicles (e.g., congested freeways during commuter rush hours, surface streets during weekends, and a parking lot at major sporting events). Black carbon and total PM were monitored continuously by photoacoustic and DustTrak instruments. As a prelude to the CMB analysis, we examined the variations in relative abundances of key marker compounds in the source-dominated ambient samples relative to corresponding variations in the samples from regional air-quality monitoring sites by day of the week. This work was supported by the DOE's Office of FreedomCAR and Vehicle Technologies through the National Renewable Energy Laboratory.

RELATIONSHIP BETWEEN COMPOSITION AND TOXICITY OF ENGINE EMISSION SAMPLES

**Joe Mauderly, JeanClare Seagrave, and Jake
McDonald**

Lovelace Respiratory Research Institute

Ingvar Eide

Statoil

Barbara Zielinska

Desert Research Institute

Kevin Whitney

Southwest Research Institute

Doug Lawson

National Renewable Energy Laboratory

ABSTRACT

Differences in the lung toxicity and bacterial mutagenicity of samples from gasoline and diesel vehicle emissions were reported previously and have been published (Seagrave *et al.*, *Toxicological Sciences* 70:212-226, 2002). Although the toxicity rankings provided important information, the ultimate goal was to determine the physical-chemical species responsible for the differences. The relationships between sample composition and toxicity have now been analyzed.

Filter and semi-volatile organic compound (SVOC) samples were collected from normal and high-emitter gasoline and diesel vehicles operated on chassis dynamometers on the Unified Driving Cycle. Seven vehicle-operating temperature conditions were tested. The composition of extracted filter and SVOC material was measured in detail. The filter and SVOC fractions were combined in their original mass collection ratios, and the toxicity of the seven

samples was compared by instillation into rat lungs followed by measures of inflammation and tissue damage and by the Ames bacterial mutagenicity test. There was good coherence among multiple measured variables in ranking the samples and demonstrating a five-fold range in toxicity.

The relationship between chemical composition and toxicity was analyzed by principal component analysis (PCA) and projection to latent surfaces (PLS, also known as partial least squares). The stepwise PCA-PLS analysis revealed the chemical constituents co-varying most strongly with toxicity and gave predictions of relative toxicity with good accuracy. The results, which will be described in detail, suggest that selected, but not all, nitro-aromatic compounds most strongly influenced mutagenicity, and that organic compounds, especially particle-associated organics, most strongly influenced the lung inflammatory response.

THE EFFECT OF CHANGES IN DIESEL EXHAUST COMPOSITION AND AFTERTREATMENT TECHNOLOGY ON LUNG INFLAMMATION AND RESISTANCE TO VIRAL INFECTION

Jacob D. McDonald, Kevin S. Harrod, Matthew D. Reed, JeanClare S. Seagrave,
and Joe L. Mauderly

Lovelace Respiratory Research Institute

ABSTRACT

Diesel engine exhaust changes in composition with modification of engine operation/configuration, including the addition of emission reduction technologies, such as low-sulfur fuel and catalyzed ceramic traps. While previous studies have shown that diesel exhaust can cause inflammation in rodents and humans and decreased resistance to respiratory infection in mice (Harrod et al., *Am. J. Resp. Cell Mol. Biol.*, vol. 28, pp. 451-463), there is little information on the impact of changes in exhaust composition (resulting from change in engine operation) and aftertreatment technology on these effects.

To address this, identical inflammation and respiratory infection assessments were conducted after exposure of mice to diesel exhaust gener-

ated from a single-cylinder diesel engine generator under three steady-state operating conditions: 1) high-load operation, #2 certified fuel, diluted to 200 $\mu\text{g}/\text{m}^3$ particulate matter (PM), 2) low-load operation, #2 certified fuel, diluted to 200 $\mu\text{g}/\text{m}^3$ PM, and 3) high-load operation with ultra-low sulfur fuel and catalyzed ceramic trap, with same dilution rate as condition 1.

Changing the operation (load) of the engine resulted in a twofold change in particle organic content and a fourfold difference in particle size. Comparative results of the compositions of these three exposure atmospheres and the biological effects will be discussed.

IN VITRO GENOTOXICITY OF PARTICULATE AND SEMI-VOLATILE ORGANIC COMPOUND EXHAUST MATERIALS FROM A SET OF GASOLINE AND A SET OF DIESEL ENGINE VEHICLES OPERATED AT 30⁰F

M. Ensell, M. Keane, T. Ong, and W. Wallace

Centers for Disease Control and Prevention

ABSTRACT

Extracts of engine exhaust particulate material (PM) or of exhaust semi-volatile organic compound material (SVOC) pooled from a set of gasoline engine automobiles or from a set of diesel engine autos or light trucks, all operated at 30⁰ F, were assayed *in vitro* for three measures of genotoxic activity. Materials supplied by the U.S. Department of Energy from modern vehicles operated on the Unified Driving Cycle for light-duty vehicles were acetone extracted and re-suspended into TWEEN-80.

Both diesel and gasoline vehicle PM extracts were significantly active for the induction of gene mutation at dose concentrations from 5 to 120 microgram extract/ml, and both displayed a positive dose-response in the *Salmonella typhimurium* histidine reversion micro-suspension assay with tester strains YG1024 and YG1029, with and without S9 microsomal activation of samples. The diesel vehicle PM extract was about twice as active as the gasoline vehicle PM extract on a mass basis.

Chinese hamster lung fibroblasts (V79 cells) were assayed for chromosome damage and for DNA damage at doses from 50 to 125 microgram extract/ml. For chromosome damage determined by the micronucleus induction assay, the maximum activity expressed by gasoline vehicle PM extract was about three times that of the maximum diesel vehicle PM extract. For DNA damage measured by the single cell gel-electrophoresis (comet) assay, the gasoline vehicle PM extract was significantly active at all but the lowest dose. The diesel vehicle PM extract did not express significant activity at any of the doses.

In general, the SVOC extracts were severalfold less active than their PM extract counterparts in all assays. Results are compared with those of a National Institute of Standards and Technology Standard Reference Material diesel exhaust particulate sample, and with those of a similar study of these gasoline and diesel vehicles operated at 70⁰F.

COMPARISON OF DIRECT EXPOSURE OF HUMAN LUNG CELLS TO MODERN ENGINE EXHAUST PARTICLES

John Storey, Meng-Dawn Cheng, and Boyd Malone

Oak Ridge National Laboratory

Jean-Clare Seagraves

Lovelace Respiratory Research Institute

ABSTRACT

Cultured human lung cells have been exposed in situ to dilute exhaust from two different vehicles, a gasoline spark-ignited vehicle equipped with a three-way catalyst and a light-duty diesel equipped with a catalyzed diesel particulate filter. Both of these vehicles have extremely low particulate mass emissions, on the order of 5 mg/mile. Particle size and number concentrations are monitored by a scanning mobility particle sizer.

As in previous reports to DEER, the cells are grown in transwell membranes, and dilute exhaust is pumped through the chamber, allowing exhaust nanoparticles to interact individually with the cells. Measurements of cell inflammatory response, including interleukin-8 production and LDH, are reported for time-resolved exposures up to 6.5 hours in duration. A cold start is included in each test sequence.

AN ENGINE EXHAUST PARTICLE SIZER FOR TRANSIENT EMISSION PARTICLE MEASUREMENTS

Tim Johnson, Rob Caldow, and Arndt Pöcher

TSI Incorporated

Aadu Mirme

University of Tartu

David Kittelson

University of Minnesota

ABSTRACT

The measurement of particle emissions from vehicles has been a compromise based on which parameters were most important for the particular measurement. There has been increased interest in obtaining size-distribution data during transient engine operation where total number concentrations can change dramatically. For measuring submicrometer particle sizes, currently the most common technique, scanning mobility particle sizer (SMPS), relies on electrical mobility. The SMPS gives high size resolution but requires an aerosol to be stable with time to make a particle-size distribution measurement.

This paper describes a new instrument, the engine exhaust particle sizer (EEPS), which has high time resolution, uses electrical mobility for classifying the

particles, and was designed specifically for measuring engine exhaust. The measurement is based on the particles' electrical mobility similar to what is used in the SMPS system.

Particles entering the instrument are charged to a known charge level. The particles then are repelled outward by the voltage from a central column. When the particles reach an outer cylindrical (a column of rings), they create a current on one of the rings that is measured by an electrometer. The electrometer currents are measured multiple times per second to give high time resolution.



Abstracts

Session 10 – Urea, NO_x Adsorber, and Non-Thermal Plasma NO_x Reduction

SELECTIVE CATALYTIC REDUCTION SYSTEMS FOR HEAVY-DUTY TRUCKS: PROGRESS TOWARDS MEETING EURO 4 EMISSION STANDARDS IN 2005

Georg Huethwohl

PUREM Abgassysteme GmbH & Co. KG

ABSTRACT

Emissions of diesel engines contain some components that support the generation of smog and are classified as hazardous. Exhaust gas aftertreatment is a powerful tool to reduce NO_x and particulate emissions.

NO_x emissions can be reduced by selective catalytic reduction (SCR) technology. A reduction agent has to be injected into the exhaust upstream of a catalyst. On the catalyst, the NO_x is reduced to N_2 and H_2O . This catalytic process was developed in Japan about 30 years ago to reduce the NO_x emission of coal-fired powerplants. The first reduction agent used was NH_3 .

SCR technology was used with diesel engines starting in the mid-1980's. The first applications were stationary operating generator sets. In 1991 a joint development between DaimlerChrysler, MAN, IVECO, and Siemens was started to use SCR technology for the reduction of NO_x in heavy-duty trucks. Several fleet tests demonstrated the durability of the systems. Today, SCR technology is the most promising technology to fulfil the new European Regulations EURO 4 and EURO 5 being effective in October 2005 and October 2008. The efficient NO_x reduction of the catalyst allows an engine calibration for low fuel consumption. Daim-

lerChrysler decided to use the SCR technology on every heavy-duty truck and bus in Europe, and many other truck manufacturers will introduce SCR technology to fulfil the 2005 emission regulation.

The truck manufacturers in Europe agreed to use aqueous solution of urea as the reducing agent. The product is called "AdBlue," which is a non-toxic, non-smelling liquid. The consumption is about 5 percent of the diesel fuel consumption to reduce the NO_x emissions. A small AdBlue tank has to be installed on the vehicle. With an electronically controlled dosing system, the AdBlue is injected into the exhaust. The dosing system is simple and durable. It has proven its durability during winter and summer testing as well as in fleet tests.

The infrastructure for AdBlue is under evaluation in Europe by urea producers and mineral oil companies to be readily available in time. Urea is one of the most common chemical products in the world, and its production and the distribution are very much known. However, a pure grade is needed for automotive application and requires special attention.

UREA SELECTIVE CATALYTIC REDUCTION AND DIESEL PARTICULATE FILTER SYSTEM FOR DIESEL LIGHT-DUTY TRUCK/SPORT UTILITY VEHICLE MEETING TIER II BIN 5

Robert Hammerle and Christine Lambert

Ford Research & Advanced Engineering

Mike Noorman

ExxonMobil Research & Engineering

ABSTRACT

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 in Europe they currently offer up to 50-percent better volumetric fuel economy and up to 25-percent lower CO₂ emissions than comparable gasoline vehicles. We are using selective catalytic reduction (SCR) with 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 on a light-duty truck/sport utility vehicle application. We are using very low sulfur diesel fuel (~15 ppm) to enable low PM emissions, reducing the fuel economy penalty due to the emission control system, and improving 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 second year of the program, we switched from an ultra low sulfur Swedish-style fuel to a low sulfur fuel developed by ExxonMobil that has properties reflective of those projected for 2007 U.S. diesel fuel. Recalibration of the engine was necessary to compensate for increases in NO_x and hydrocarbon emissions. We continued to separately improve the durability of both the urea SCR and DPF systems. We also have been improving exhaust gas NO_x and ammonia sensors for more accurate control of reductant injection and on-board diagnostics. Finally, we worked with nozzle and dispenser manufacturers to develop durable hardware for delivery of diesel fuel and aqueous urea simultaneously to the vehicle.

**ENSURING THE OVERALL SUPPLY OF UREA IN NORTH AMERICA
AND THE RELIABILITY OF THE UREA-DOSING UNITS FOR
SELECTIVE CATALYTIC REDUCTION SYSTEMS**

Glenn Barton

Hilite International

Barry Lonsdale

Terra International

ABSTRACT

Urea is the proven ingredient in the post-combustion treatment of diesel engine exhaust gas for NO_x reduction. This paper will discuss the status of urea-dosing units and developments in sensors to insure urea is available and being delivered in the appropriate dose to the post-treatment region and verify that the post-combustion treatment process is effective.

The paper will also address the urea supply infrastructure in North America and how it will insure the proper urea is available for all diesel engine treatment systems, stationary and on-road nationwide.

SELECTIVE REDUCTION OF NO_x IN OXYGEN-RICH ENVIRONMENTS WITH PLASMA-ASSISTED CATALYSIS: CATALYST DEVELOPMENT AND MECHANISTIC STUDIES

C. H. F. Peden, S. E. Barlow, J. H. Kwak, J. Szanyi, and R.G. Tonkyn

Pacific Northwest National Laboratory

M. L. Balmer-Millar and A. G. Panov

Caterpillar, Inc.

J. W. Hoard

Ford Research Laboratory

S. J. Schmieg

General Motors R&D

ABSTRACT

The control of NO_x (NO and NO₂) emissions from so-called 'lean-burn' vehicle engines remains a challenge. In recent years, there have been a number of reports that show that a plasma device combined with a catalyst can reduce as high as 90 percent or more of NO_x in simulated diesel and other 'lean-burn' exhaust.

Non-thermal plasma (NTP)-catalysis treatment of a gas stream consists of the sequential (or possibly simultaneous) action of NTP and heterogeneous catalysis. The most common reported strategy for lean NO_x treatment is to separate the plasma from the catalyst, as it is difficult to create robust plasma inside a catalyst bed. In the case of propylene-containing simulated diesel exhaust, the beneficial role of a plasma treatment is now thought to be due to oxidation of NO to NO₂ and the formation of partially oxidized hydrocarbons that are more active for the catalytic reduction of NO₂ than propylene. For plasma-assisted catalysis, both zeolite- and alumina-based materials have shown high activity, albeit in somewhat different temperature ranges, when preceded by an NTP reactor.

This presentation will describe our research efforts aimed at optimizing the catalyst materials for NTP-catalysis devices based, in part, on our continu-

ing studies of the NTP- and catalytic-reaction mechanisms. Various alkali- and alkaline earth-cation-exchanged Y zeolites have been prepared and their material properties characterized. They have been tested as catalytic materials for NO_x reduction in laboratory NTP-catalysis reactors. Interestingly, NO₂ formed in the plasma, and not subsequently removed over these catalysts, will back-convert to NO, albeit to varying extents depending upon the nature of the cation.

Besides this comparative reactivity, we will also discuss selected synthesis strategies for enhancing the performance of these zeolite-based catalyst materials. A particularly important result from our mechanistic studies is the observation that aldehydes, formed during the plasma treatment of simulated diesel exhaust, are the important species for the reduction of NO_x to N₂. Indeed, acetaldehyde has been found to be especially effective in the *thermal* reduction of both NO and NO₂ over Ba- and Na-zeolite-Y catalysts.

Finally, we will discuss experiments aimed at understanding and controlling deactivation of these zeolite-based catalysts due to 'coking.' We believe that this catalyst deactivation mechanism explains a loss of catalyst efficiency with time that is observed in engine dynamometer tests.

HEAVY-DUTY NO_x EMISSIONS CONTROL: REFORMER-ASSISTED VS. PLASMA-FACILITATED LEAN NO_x CATALYSIS

Christopher L. Aardahl

Pacific Northwest National Laboratory

Paul W. Park

Caterpillar, Inc.

ABSTRACT

Recent efforts in plasma-facilitated lean NO_x catalysis and thermal lean NO_x catalysis have shown that hydrocarbon speciation has a dramatic impact on catalyst performance. In particular, use of oxygenated hydrocarbons as reducing agents results in better NO_x efficiency than typical fuel hydrocarbons. In a cooperative research and development agreement between

Pacific Northwest National Laboratory and Caterpillar, Inc., reformation of non-oxygenated hydrocarbons to oxygen-containing molecules is being examined as a way to enhance performance in lean NO_x catalyst systems. Recent results for reformer-assisted catalysis are compared to results using traditional plasma-catalysis.

DYNAMOMETER EVALUATION OF PLASMA-CATALYST SYSTEM FOR DIESEL NO_x REDUCTION

John Hoard

Ford Motor Company

Dave Brooks

DaimlerChrysler

Steve Schmieg

General Motors R&D

**Charles H. F. Peden, Steve Barlow, and Russ
Tonkyn**

Pacific Northwest National Laboratory

ABSTRACT

A three-stage plasma-catalyst system was developed and tested on an engine dynamometer. Previous laboratory testing suggested high NO_x efficiency could be obtained. With hexene reductant added to the exhaust, we observed over 90-percent NO_x reduction. However, with diesel or Fischer-Tropsch reductant, the catalyst efficiency rapidly dropped off. Heating the catalyst in air removed brown deposit from the surface and restored conversion efficiency.

Following the engine tests, the used catalysts were evaluated. BET surface area decreased, and temperature-programmed desorption revealed significant storage. This storage appears to be partly un-

burned diesel fuel that can be removed by heating to around 250-300°C, and partly hydrocarbons bonded to the surface that remain in place until 450-500°C.

Laboratory testing with propene reductant demonstrated that the catalyst regains efficiency slowly even when operating temperature does not exceed 300°C. This suggests that control strategies may be able to regenerate the catalyst by occasional moderate heating.

NOXTECH'S PLASMA-ASSISTED CATALYST SYSTEM DEVELOPMENT AND DEMONSTRATION

Ralph Slone, Victor Puchkarev, and Jeff Marguglio

Noxtech, Inc.

ABSTRACT

The non-thermal plasma-assisted catalyst (NTPAC) technology being developed at Noxtech, Inc., continues to focus on achieving the 2007 and beyond emissions standards for heavy-duty vehicles. Noxtech's NTPAC technology utilizes an efficient non-thermal plasma reactor with a solid-state pulsed power supply to efficiently convert NO to NO₂ in the presence of a suitable hydrocarbon generated on-board from diesel fuel. NO₂ is then converted to N₂ in the presence of a sulfur-tolerant catalyst that contains no precious metals.

Noxtech has made significant 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 generator using diesel fuel as a source of reductant.

Noxtech's emphasis for its 2003 program has been to improve and enhance the performance, reliability, and commercial capability of its NTPAC system. It is working with a commercial partner to reduce the size and cost and improve the efficiency of the pulser for its plasma reactor. Noxtech has also redesigned and improved its diesel fuel converter to produce effective hydrocarbons to act as a catalyst and reductant for the NTPAC system. Several new catalysts have been formulated and evaluated to enhance performance (surface efficiency/availability and selectivity) as well as to improve durability and operating temperature range. The goal is to produce a system that is commercially capable in the near future.

Noxtech has conducted a demonstration of its NTPAC system at a third-party test site for assessment by Government and private industry representatives. The result of this test will be presented at the DEER 2003 Conference.

NO_x ADSORBER REGENERATION PHENOMENA IN HEAVY-DUTY APPLICATIONS

Brian West, John Thomas, Mike Kass, John Storey, and Sam Lewis

Oak Ridge National Laboratory

ABSTRACT

Hydrocarbon species are being measured with a gas chromatograph/mass spectrometer and Fourier transform infrared at NO_x adsorber inlet and outlet locations in the exhaust system of a heavy-duty diesel engine. The engine is equipped with electronic throttle and exhaust gas recirculation, in-pipe fuel injection, and various diesel oxidation catalysts upstream of a catalyzed diesel particle filter (CDPF) and a high-temperature NO_x adsorber catalyst. Raw diesel

fuel injected into the exhaust system is readily cracked into lighter compounds over catalysts, and the NO_x adsorber more readily utilizes certain compounds during regeneration. Augmenting the CDPF with oxidation catalysts produces preferred species such that comparable NO_x reduction can be achieved with less supplemental fuel.

COMPARISON OF 4-WAY NO_x ADSORBER CATALYST PERFORMANCE ON FIBROUS AND CONVENTIONAL SUBSTRATES

Neil Currier, Matthew Henrichsen, Bill Epling, and Jim Lucas

Cummins, Inc.

ABSTRACT

Performance of a 4-way NO_x adsorber is dependent on a number of non-operating factors. These include catalyst composition, monolith cell size, monolith aspect ratio, substrate thermal properties, substrate material, and substrate wall morphology. The relative significance of these factors was scouted by

comparing a standard cordierite monolith to a fibrous monolith. Flexibility in the choice of catalyst loading and differences in heat distribution were found to play a significant role in determining NO_x performance of these devices.

MEASUREMENT AND CHARACTERIZATION OF NO_x ADSORBER REGENERATION AND DESULFATION

Shean Huff, Stuart Daw, John Storey, Brian West, Bill Partridge,
Sam Lewis, Dean Edwards, Katey Lenox, and Jae-Soon Choi

Oak Ridge National Laboratory

ABSTRACT

Experiments at Oak Ridge National Laboratory are being conducted to characterize NO_x adsorber catalysts. Full-size samples are being evaluated on a diesel engine stand with full-pass control of electronic throttle and exhaust gas recirculation (EGR), wastegate, number and timing of fuel injection events, etc. Bench-scale work with powders, wafers, and small monolith cores is being conducted in parallel to the engine work.

The presentation will describe recent measurements of hydrogen and other species inside catalyst channels and in the bulk exhaust using spatially resolved, capillary-inlet mass spectrometry (SpaciMS). Gas chromatography is being used in conjunction with SpaciMS to fully characterize the exhaust hydrocarbons and other species that are formed in-cylinder for various regeneration strategies and the usage of various compounds through the oxidation and NO_x adsorber catalysts downstream.

NO_x ADSORBER CATALYST DURABILITY: LIGHT - AND HEAVY-DUTY PERSPECTIVES

Jim Parks, Bill Epling, Greg Campbell, Michele Sanders, and Aaron Watson

EmeraChem

ABSTRACT

NO_x adsorber catalysts can reduce NO_x from diesel engines by over 90 percent, but to be commercially viable, NO_x adsorbers must demonstrate compliance-range durability. Sulfur masking has traditionally limited NO_x adsorber durability, but sulfur management by a combination of catalyst desulfation and fuel-sulfur reduction is an effective method of controlling degradation from sulfur masking.

Since the control of sulfur masking has been demonstrated, thermal degradation is expected to be the primary degradation mechanism. Thermal degra-

ation rates will greatly depend on the operation temperatures of the catalyst, and the desulfation process typically results in the highest and most severe temperature exposure. A NO_x adsorber catalyst aging experiment testing repetitive thermal exposure during the desulfation process will be presented. Results will be used to predict catalyst lifetime and compare to compliance mileage requirements. Issues relating to the different requirements for light- and heavy-duty applications will be discussed.

COMPLEMENTARY EXPERIMENTAL TOOLS FOR UNDERSTANDING DIESEL PARTICULATE FILTER BEHAVIOR

Aleksey Yezerets, Neal Currier, Arvind Suresh, and William Epling

Cummins, Inc.

ABSTRACT

During the last 3 years, a set of unique laboratory techniques was developed at Cummins to investigate various aspects of diesel particulate filter (DPF) loading and regeneration processes. A novel rapid protocol for measuring particulate matter oxidation rates under various conditions has been developed using a micro-reactor system. Also, a unique system was

designed, which allows us to load soot-filter cores in a diesel exhaust and subsequently study their regeneration and back-pressure behavior under well-controlled conditions in a pilot reactor. The results obtained with these techniques show good correlation with the on-engine testing.



Abstracts

Session 11 – Aftertreatment

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

R. Dalla Betta, J. Cizeron, D. Sheridan, and T. Davis

Catalytica Energy Systems, Inc.

ABSTRACT

NO_x adsorber or NO_x trap systems must be regenerated frequently to convert the adsorbed NO_x to N₂ 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 H₂, 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

Christopher L. Marshall, Michael K. Neylon, Mario J. Castagnola, and A. Jeremy Kropf

Argonne National Laboratory

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 C₃H₆, 2% O₂, 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 as 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

Dennis L. Endicott, Paul Park, Steve Faulkner, and M. Lou Balmer-Millar

Caterpillar Inc.

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

Mike Kass, John Thomas, and Bruce Bunting

Oak Ridge National Laboratory

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

Leslie Bromberg

Massachusetts Institute of Technology

Sam Crane

ArvinMeritor

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-enhanced 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 corre-

sponding 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

Mark Mauss

Hydrogen Source

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

**Mridul Gautam, Greg Thompson, Nigel Clark, Dan Carder, Scott Wayne,
Wes Riddle, and Don Lyons**

West Virginia University

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

Martin J. Murtagh and David L. Hickman

Corning, Inc.

ABSTRACT

This presentation is a review of diesel particulate 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 com-

patibility 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

G.A. Merkel, T. Tao, W.A. Cutler

Corning, Inc.

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

**R. McAdams, R. Morgan, J. Shawcross, P.
Beech, D. Weeks, R. Gillespie,
C. Guy, S. Jones, and T. Liddell**

Accentus plc

Lt. Cdr. D. Hughes

U.K. Ministry of Defence

J. Oesterle

J. Eberspächer GmbH & Co. KG

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 1/10th 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 1/10th scale system.

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

Daniel J. Gore

U.S. Maritime Administration

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 renowned 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.

