Abstracts

SESSION 2 – Fuels and Lubrication, Part 1

Chair: **Kevin Stork, U.S. Department of Energy**

Plasmatron Fuel Reformer Development and Internal Combustion Engine Vehicle Applications

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Onboard generation of hydrogen-rich gas can be used in a number of applications to improve environmental quality and reduce petroleum consumption of internal combustion engine vehicles. Plasmatron fuel reformer technology is being developed at MIT as means of practical on-board production of hydrogen-rich gas from a variety of fuels. The device is based on the use of a special low current, low power volumetric discharge in very rich fuel/air mixtures. Although the process is slightly exothermic, system advantages overwhelm the slight inefficiency of the process. In this paper, recent progress on plasmatron fuel reformer and applications are described.

Diesel reformation: In 2003, a plasmatron fuel reformer was used by ArvinMeritor in a successful test on a bus of a two leg nitrogen oxides (NO_X) trap exhaust aftertreatment system regenerated with hydrogen-rich gas. The input Diesel fuel flow rate to the plasmatron fuel reformer was 0.8 g/s. In 2004 the input fuel flow rate of a Diesel plasmatron fuel reformer at MIT was operated with an increased Diesel fuel flow rate of 2 g/s, corresponding to 80 kW of fuel reformate. This reformer produced about 1.5 $^{l}/s$ of hydrogen without the use of a reforming catalyst for additional hydrogen generation. This type of higher flow rate operation can facilitate quick regeneration of single-leg NO_X trap systems aftertreatment.

Biofuels reformation: Reformation tests of renewable fuels have been carried out. Vegetable oils, including soy and canola oils, have been efficiently reformed, with no soot production at input rates of 0.5 g/s. Ethanol tests have been carried out. Results from both non-catalytic and catalytic (with a catalyst downstream from a homogeneous reforming zone) will be presented. Onboard conversion of biofuels into hydrogen rich gas opens up a range of opportunities for reducing petroleum consumption.

Rapid response: The plasmatron response has been determined using real time gas analysis techniques. For cold start, the response of a plasmatron fuel reformer using homogeneous reforming was faster than that from a plasmatron fuel reformer that included a catalyst. In addition, hydrogen production during warm start has also been studied. This mode of operation could be particularly relevant to some aftertreatment applications, where the hydrogen rich gas needs to be produced in short, frequent pulses.

Regeneration of Diesel Particulate Filters: Concepts have been developed for optimal regeneration of Diesel Particulate Filters, using hydrogen rich gas. The goal is the simplification of the aftertreatment system, the minimization of the fuel penalty, and minimization of fuel reformer system requirements.

Emissions and Operability Results from a Fleet Operating on GTL Fuel and Catalyzed Diesel Particle Filters

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This study examined the emissions and operability from a fleet of Class 6 delivery trucks over a 6-month period. Six vehicles participated in the study; three vehicles were "baseline", operated on CARB specification Diesel and original equipment manufacturer mufflers, and three vehicles were fueled exclusively with gas-to-liquid (GTL) fuel and retrofit with Johnson Matthey CCRT™ filters. Chassis dynamometer emissions were collected at the start and the end of the project.

The filters performed as expected throughout the program, reducing hydrocarbons, carbon monoxide, and particulate matter to below detection limits over both the CSHVR and NYCB cycles. Nitrogen oxides (NO_X) emission reductions were also recorded over these same cycles, with reductions ranging from 8 percent over the CSHVR cycle to 14 percent on the NYCB cycle. NO_X emission reductions were only statistically significant over the low speed NYCB cycle.

The fleet operability was also monitored over the project. The switch to GTL fuel was overnight, with no modifications to the engines or vehicles. Qualitatively, no materials or operability issues have been identified, either with the switch to GTL fuel or the addition of the CCRT filters. A quantitative analysis on the maintenance data is underway. A slight fuel economy penalty was observed with the vehicles operated on GTL fuel and the CCRT filters.

Effect of GTL-Diesel Fuels on Emissions and Engine Performance

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In a detailed investigation, the effect of gas-to-liquid (GTL) Diesel fuel blends on emissions and engine performance has been studied. As reference and as a base stock a clean, sulfur-free European Diesel (EU Diesel) fuel was used. Dynamometer tests with a E220 CDI in the NEDC without any changes of the basic EU3 engine calibration revealed that GTL fuels may reduce emissions significantly even in a non-adapted engine. For neat GTL the carbon monoxide and hydrocarbon emissions were reduced by over 90 percent and particulate matter emissions by up to 30 percent. Slight improvements in the percentage range were observed for nitrogen oxides (NO_X) and carbon dioxide emissions. Blending GTL with EU Diesel revealed a strong non-linear characteristic: a 50 percent blend exhibited properties close to those of neat GTL. In order to explore the available potential for further emission reductions, stationary test bed runs were carried out for operating point's characteristic for the NEDC. Based on these data, the range of emission reductions was calculated by a design of experimental approach for a possible new soft-calibration with optimized exhaust gas recirculation rates and injection timings. For neat GTL a conservative prediction projects possible simultaneous reductions of 35 percent both in NO_X and in soot. The non-linear blending characteristic was corroborated for 2 blending ratios: for a 50 and a 20 percent GTL blend in EU Diesel, reductions in NO_X and soot were found to be 86 and 48 percent of the neat values, respectively. The heat release revealed an earlier start of pilot and main combustion for GTL fuels.

Certification of Shell GTL as an Alternative CARB Diesel Formulation

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Hot-start transient emission results were obtained from a 1991 Detroit Diesel Corporation (DDC) Series 60 heavy-duty diesel engine tested per Alternative 3, as specified in the California Air Resources Board (CARB) Procedure for Certification of Emissions Reductions for Alternative Fuels. Two formal testing protocols were conducted using (1) a reference fuel (Fuel R) and Shell gas-to-liquid (GTL) (Fuel C) and (2) a reference fuel (Fuel R) and a blend of 55 percent volume Shell GTL/45 percent volume reference fuel (Fuel C). For both of these testing protocols, the reference fuel (Fuel C) was a CARB ultra low sulfur Diesel (ULSD) obtained from the Shell Martinez Refinery.

Results include emissions of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_X), particulate matter (PM), soluble organic fraction (SOF), SO_4, selected hydrocarbon species, aldehydes, and polynuclear aromatic hydrocarbons. In particular, reductions in NO_X, PM and SOF are substantial.

In addition, a modified testing protocol was conducted with the same reference fuel, Shell GTL, and volumetric blends of 20, 33, 55, and 75 percent Shell GTL in the reference fuel to establish a blend curve to determine emission reductions of HC, CO, NO_X, PM and SOF.

Be Advised: Results of this testing protocol have recently been reported to CARB by the testing laboratory (SwRI). We are actively pursuing formal CARB certification. The focus of this presentation will depend on the status of discussions/negotiations with CARB. In any case, we are prepared to present the emission benefits of the Shell GTL fuel, either neat, or in blends with CARB ULSD.

A Life Cycle Assessment Comparing Select Gas-to-Liquid Fuels with Conventional Fuels in the Transportation Sector

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ConocoPhillips has completed a Life Cycle Assessment (LCA) of its proprietary gas-to-liquid (GTL) technology to convert natural gas to transportation fuels and petrochemical feedstock. GTL is one technological option for monetizing large reserves of natural gas around the world that are "stranded" due to their geographical location. This LCA compares energy efficiencies, greenhouse gas and criteria pollutant emissions among selected transportation fuels produced by GTL with those produced by conventional petroleum refining technologies. This LCA follows ISO 14040 guidelines, including an independent peer review. The Greenhouse Gases Regulated Emissions and Energy in Transportation (GREET) model provides a well-to-wheel comparison of selected fuel/vehicle pathways. One million British thermal units (for energy) and grams of emissions (for greenhouse gases and criteria pollutants, nitrogen oxides, sulfur oxides, particulate matter10, volatile organic compounds, etc.) are normalized against a functional unit chosen for the LCA. This functional unit is *light duty Diesel vehicle miles* driven in the United States. The GREET model was validated and run using efficiencies expected from ConocoPhillips GTL technology. An innovative LCA approach was developed to provide a more equitable life cycle comparison between conventional refining and GTL processes. This approach is referred to as the "Co-Product Function Expansion." GTL fuels compare favorably with Ultra Low Sulfur Diesel (ULSD), being somewhat less energy efficient but having generally lower criteria pollutant emissions. Greenhouse gas emissions for these two fuels are equivalent. The Life Cycle Impact Assessment demonstrated GTL impact indicator values for acidification, eutrophication, photochemical smog, ecotoxicity, human health criteria, human health–cancer, and human health–non-cancer generally trending toward reductions in these parameters when compared to conventionally derived fuels.

Biodiesel Research Update

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Biodiesel quality and stability have been major focus areas for research at the National Renewable Energy Laboratory over the past year. A survey of B100 quality and stability has been conducted, with collection of 27 B100 samples nationwide. Of these samples, 85 percent met the requirements of the B100 quality specification, ASTM D6751. Of the four samples that failed to meet the quality specification, one failed acid value and total glycerine (while meeting the free glycerine requirement), a second failed acid value only, a third failed total glycerine only (while meeting free glycerine), and the fourth failed phosphorus content. The fourth sample appeared to have been contaminated with lube oil because of high phosphorus and high sulfur (83 ppm). These samples were also examined for oxidation stability using several test methods. Using the European stability test (EN 14112), U.S. biodiesels exhibit a typical induction period of 1 hour or less. This is considerably below the European requirement of 6 hours, but it is not clear that this translates into actual stability problems in the field. Work to clarify the mechanism of biodiesel oxidation is ongoing in the summer of 2004 and results of this effort will be described. In a second major focus area; biodiesel produced from several different feedstocks has been tested in two different engines meeting the 2004 heavy-duty emission standards. This work has confirmed the trends observed in older engines: reduced emissions of particulate matter and carbon monoxide with increased emissions of nitrogen oxides. Ongoing studies are examining compatibility with elastomers and impact on fuel pump and injector wear. Additional studies are attempting to quantify the impact of B20 relative to conventional Diesel on vehicle maintenance costs during use by various fleets.

Fuel Impacts on Soot Nanostructure and Reactivity

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Diesel fuel production from alternative or renewable sources such as stranded natural gas, vegetable oils, and animal fats offers the potential of both reducing fossil carbon emissions and producing alternative ultra clean transportation fuels. It is well known that biodiesel, neat or in blends, can provide reductions in particulate matter mass emission through either oxygen content or enhanced air entrainment due to the higher boiling range of biodiesel. Fischer-Tropsch (F-T) Diesel fuel also can provide reductions in PM mass emissions, because F-T Diesel contains no aromatics. However, recent observations have indicated that biodiesel may provide other benefits with regard to particulate emissions. These observations have shown an oxidation reactivity variation with soots derived from different fuels. Identifying the dominant mechanism during oxidation, if any, may have practical implications for reducing the temperature required to regenerate catalyzed Diesel particulate filters. There exists evidence of correlation between reactivity and structure in the case of carbon blacks or coal chars that are synthesized from different hydrocarbons and at different temperature conditions. However, the manner in which crystallinity or pore structure affects soot oxidation rates has not been clarified for Diesel soot whether that soot is derived from conventional or alternative fuel sources.

This paper presents a comparison of soot nanostructures of particulates produced from different fuels in a commercial direct injection Diesel engine by means of high resolution electron microscopy imaging. This nanostructural information such as the graphene layer size and orientation is used to interpret the quantitative reactivity differences measured in an idealized thermo-gravimetric analysis/differential scanning calorimetry oxidation experiment. Together, these results show the potential impact of neat and blended alternative fuels on the low temperature oxidation characteristics of soot.

Alternate Fuels-DME Rheology and Materials Studies

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Dimethyl ether (DME) is a significant alternate fuel candidate for Diesel engines. It is environmentally benign and significantly reduces particulate emissions. However, DME is a gas at room temperature and requires modification of the system to maintain the fuel in the liquid state. Earlier studies at Penn State resulted in a 6-week test in a campus vehicle. The system was pressurized and maintained an approximate 1:5 ratio of DME to Diesel fuel.

Laboratory tests indicated that ideally a 1:4 ratio reduces particulate emissions by 25 percent or better. This study evaluated several properties of DME including viscosity, materials compatibility, and wear. One of the drawbacks of using DME is that its viscosity is an order of magnitude lower than the ASTM specification required for Diesel fuel. This paper reports on the development of a pressurized viscometer and a series of additives evaluated to increase the viscosity to achieve minimum requirements. Only three formulations of some two dozen formulations evaluated met this requirement at 25 percent DME in other fuels. The campus vehicle test also indicated the potential for material problems. Several seal materials were evaluated and the test results indicate most common seal materials are not adequate for extended use with DME. Wear of blends of DME in alternate and low sulfur fuels were evaluated in a modified Cameron Plint. As expected, the wear increased with increased DME concentration but was lower than some of the additive formulations. Although DME is a beneficial way to reduce engine out emissions, significant research is required to resolve material and rheological issues.

EVALUATING EXHAUST EMISSION PERFORMANCE OF URBAN BUSES USING TRANSIENT HEAVY-DUTY CHASSIS DYNAMOMETER

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Abstract
Engines for heavy-duty vehicles are emission certified by running standalone engines according to a specified load pattern. In the US, the US 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. It is also debatable, how well the standardized duty cycles reflect real-life driving patterns.

Testing a complete bus on a chassis dynamometer by driving representative urban bus cycles, like Braunschweig or Orange County Bus cycles will give results that represent accurately the desired real-life operation. In chassis dynamometer testing, all important vehicle-specific properties, for example weight of the vehicle, driving resistances and the performance of the whole power line have been taken into account.

VTT Processes has recently commissioned a new emission laboratory for heavy-duty vehicles. The facility comprises both an engine test stand and a fully transient heavy-duty chassis dynamometer. The roller diameter of the dynamometer is 2.5 meters. Regulated emissions are measured by using a full-flow CVS system.

A national program to generate emission data on buses has been set up for the years 2002-2004. Emission factors will be generated for about 35 different buses representing different degree of sophistication (Euro1 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, the gas company Gasum Oy and Swedish Road Administration (SRA).

The International Association for Natural Gas Vehicles (IANGV) has opted to buy into the project. For IANGV, VTT will deliver comprehensive emission data (including particle size distribution and chemical and biological characterization of particles) for diesel and natural gas vehicles. The main objective for the IANGV addition is to generate comprehensive emission data for the newest available diesel and natural gas vehicles.

Based on measurements, both NO_x and PM emissions have clear downward trend along with newer Euro emission standards. CRTs reduce particles effectively even on older Euro2 buses with high mileage. On other

hand, the CRTs seem to be vulnerable to poor maintenance or other failures. CNG buses have always extremely low particulate emissions and the NO_x follows generally the Euro levels hand by hand with diesels.

From the group of three different Euro5/EEV CNG buses, tested for the IANGV addition, the stoichiometric bus got the lowest NO_x and CO2 values. Engines operating on the lean burn principle seem to suffer from unfavorable interrelation of NO_x and CO2. Overall results for newer CNG buses were excellent, no signs of high aldehyde content, high number of small particulates or any other disadvantageous results were recorded.

Practically all CNG buses in Europe are catalyst equipped, which makes a difference between these results and the results of many North American studies.

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