Abstracts

Session 4 – Fuels and Lubrication

RENEWABLE DIESEL FUELS: STATUS OF TECHNOLOGY AND R&D NEEDS

Robert McCormick
National Renewable Energy Laboratory

Renewable diesel fuel development has begun to focus on a portfolio of fuels because no single fuel option offers adequate petroleum displacement benefits on its own. In the near term, these options include biodiesel and ethanol-diesel blends. Medium- and longer term options include biomass-derived Fischer-Tropsch (FT) diesel, esters of levulinic acid (produced from cellulosic biomass), and certain other oxygenates. This presentation will review the technical status of these renewable diesel options and their position in the fuels development pathway.

Biodiesel consists of the methyl esters of fatty acids and can be produced from a variety of vegetable oil, animal fat, and waste grease resources. The potential production of biodiesel is from 2 to 6 billion gallons per year in the United States. Biodiesel is a fully commercial fuel based on the development of the ASTM D6751 quality standard and completion of EPA 211b testing requirements. Most engine and fuel injection equipment (FIE) manufacturers believe that use of up to 5-percent blends of biodiesel in petroleum diesel will have no adverse effects and can result in a significant improvement in fuel lubricity. There is little significant change in pollutant emissions at this level. The biodiesel industry supports the use of 20-percent blends, which produces a significant lowering of PM emissions (15-20 percent) relative to conventional diesel. However, there are several technical barriers to the use of 20-percent and higher blend levels. These include the potential for poor oxidative stability, incompatibility with fuel system elastomers and other materials, low-temperature flow properties, and increased NO_x emissions.

Ethanol-diesel blends, or e-diesel, are mixtures of up to 15-percent ethanol in conventional diesel fuel with cosolvent or microemulsifier additives at levels of 0.5-2 percent. E-diesel is an experimental fuel, and most engine and FIE manufacturers are opposed to its use because it exhibits a low flashpoint (13°C), and fuel tank vapor is flammable under most conditions. However, if these safety issues can be overcome, e-diesel offers the potential for significant PM emissions reductions and petroleum displacement. Current U.S. production of fuel ethanol is about 2 billion gallons, and some projections suggest more than 20 billion gallons could be produced at some point in the future.

Longer term, the potential exists to produce on the order of 10 billion gallons of FT diesel via biomass gasification. Biomass FT diesel will be very similar to natural gas- or coal-derived FT diesel. The main technical barrier to this fuel is high cost. A second longer term option is esters of levulinic acid, which is produced via acid hydrolysis of cellulose. Some analyses suggest that levulinic acid could be produced for $0.04-$0.10/lb. The ethyl and methyl esters of this acid exhibit high flashpoint and lubricity. Blends of up to 10 percent in conventional diesel appear to be stable. This potential

renewable blending component is in the initial stages of the fuel development pathway. Potential production capacity is on the order of billions of gallons. Several other oxygenates with potential as fuel-blending components can also be produced from renewable resources and will be briefly discussed.

FUEL REQUIREMENTS FOR HCCI ENGINE OPERATION

Thomas W. Ryan III and Andrew Matheaus
Southwest Research Institute

Researchers at Southwest Research Institute (SwRI) have been working for the past several years on the fundamental and practical aspects of homogeneous charge compression ignition (HCCI) operation of reciprocating engines. Much of the work has focused on the use of diesel fuel. The work at SwRI has, however, demonstrated that there are fundamental limitations on the use of current diesel fuels in HCCI engine. Some of these fundamental limitations were discussed in a paper presented at the THIESEL 2000 Conference.

One of the most difficult aspects of fuel specification for HCCI engines is the characterization of the fuel characteristics that adequately defines the ignition or reactivity of the fuel. The results of the SwRI program are summarized in this paper and used to define the fuel requirements of HCCI engines. A newly defined fuel ignition property for HCCI fuels is introduced, and preliminary constant volume combustion bomb results are presented and discussed.

OPPORTUNITIES FOR THE EARLY PRODUCTION OF FISCHER-TROPSCH DIESEL FUEL IN THE UNITED STATES - - AN OVERVIEW

John Shen and Edward Schmetz
U.S. Department of Energy (Germantown, MD)

Gregory J. Kawalkin, Gary J. Stiegel, John C. Winslow, and Robert M. Kornosky
U.S. Department of Energy National Energy Technology Laboratory (Pittsburgh, PA)

Venkat K. Venkataraman, Joel S. Chaddock, Daniel C. Cicero, Suresh C. Jain, and Jenny B. Tennant
U.S. Department of Energy National Energy Technology Laboratory (Morgantown, WV)

Fischer-Tropsch (F-T) diesel fuels have been of interest to a wide range of industries in recent years because of their desirable attributes, including zero sulfur and aromatics and high cetane number. This paper will discuss the highlights of the industrial projects being co-supported by the Office of Fossil Energy within the U.S. Department of Energy. These projects are to analyze the feasibility of, and to develop the technology for, processes to produce F-T fuels from domestic feedstocks, including natural gas and solid hydrocarbons (coal, petroleum coke, and biomass). F-T fuel production is scheduled to begin in 2003 for natural gas feedstock from two commercial demonstration plants located in Oklahoma. The prospect for commercial production of F-T fuels from solid hydrocarbons will also be discussed.

AN EVALUATION OF SHELL GAS-TO-LIQUIDS DIESEL – THE ENVIRONMENTAL BENEFITS

Richard H. Clark, Jim D. Evans, and Ian G. Virrels
Shell Global Solutions (US) Inc.

The Shell gas-to-liquids (GtL) technology, better known as the Shell Middle Distillate Synthesis (SMDS) process, converts natural gas into diesel or kerosine and speciality products via a modern, improved Fisher-Tropsch synthesis. The diesel cut has very good cetane quality, low density, and virtually no sulphur and aromatics. The environmental credentials of SMDS diesel continue to be evaluated in terms of vehicle and engine exhaust regulated emissions. Other key environmental properties of SMDS diesel, including ecotoxicity, biodegradability, and product sustainability, have also been investigated.

Data from both ecotoxicological screening and biodegradation tests show positive outcomes for both SMDS diesel and certain blend combinations with conventional diesel.

The sustainability of the SMDS process has been studied to encompass all aspects from production to the end use of all products. From the specific viewpoint of diesel usage, test programmes indicate benefits in both mass fuelling and CO_2 emissions when compared with conventional diesel. A proportion of these benefits can be derived in SMDS diesel blends.

DEVELOPMENT OF A DIMETHYL ETHER-FUELED SHUTTLE BUS

Jennifer Stefanik, Elana Chapman, Shirish Bhide, Louis Boehman, Howard Glunt, David Klinikowski, Joseph Perez, and Andre Boehman
Pennsylvania State University

and

Ed Heydorn,
Air Products and Chemicals, Inc.

Dimethyl ether (DME) is a potentially ultra-clean diesel fuel; however, its unique characteristics require special handling and accommodation of its low viscosity and low lubricity. In this project, DME was blended with diesel fuel to provide sufficient viscosity and lubricity to permit operation of a 7.3-liter turbodiesel engine in a campus shuttle bus with minimal modification of the fuel injection system. A pressurized fuel delivery system was added to the existing common rail injection system on the engine, allowing the DME-diesel fuel blend to be circulated through the rail at pressures above 200 psig to keep the DME in the liquid state. Fuel returned from the rail is cooled with heat exchangers and recirculated to the rail using a gear pump. A modified LPG tank (for use on recreational vehicles) stores the DME-diesel fuel blend onboard the shuttle bus, and a small cylinder of helium is used to provide a blanket of inert gas above the fuel mixture to keep the DME in the liquid state and to push the mixture to the fuel rails.

A significant challenge is posed by the rapid increase in DME vapor pressure with increasing fuel temperature. As the fuel mixture passes through the rail, it is heated by the surrounding surfaces in the cylinder head. The target for maximum fuel rail temperature was set at 50°C, which corresponds to a DME vapor pressure of 150 psig. Refueling is accomplished by mixing the diesel fuel and DME onboard the bus, with diesel fuel delivered from the existing diesel tank and DME delivered by 1000-lb cylinders at a small refueling station. The shuttle bus operates on the Faculty/Staff Loop at the University Park campus of the Pennsylvania State University.

INVESTIGATION OF THE EFFECTS OF FUELS AND AFTERTREATMENT DEVICES ON THE EMISSION PROFILES OF TRUCKS AND BUSES

Dave Smith
British Petroleum

A multi-year technology validation program completed in the spring of 2001 evaluated the use of ultra-low sulfur diesel fuels and passive diesel particulate filters (DPF's) in several different diesel fleets operating in Southern California. The fuels used throughout the validation program were ultra-low sulfur diesels, dubbed ECD and ECD-1. These CARB-compliant fuels are produced by ARCO, a BP company, with less than 15-ppm sulfur content. The trucks and buses participating in the study were retrofitted with two types of catalyzed DPF's and operated for over 1 year.

As part of this program, a special study was undertaken to chemically characterize exhaust emissions from a subset of vehicles operated on a multitude of fuels. This select group of vehicles was tested with and without DPF's to obtain detailed emission profiles for a wide range of compounds. The test vehicles included a school bus, two grocery truck tractors, and three transit buses. The fuels used included a representative CARB diesel, ECD, ECD-1, Fischer-Tropsch (F-T) diesel, and motor vehicle-grade compressed natural gas (CNG).

Results from the program provided vehicle emission profiles for nitrogen oxides (NO_x), carbon monoxide (CO), total particulate matter (TPM), PM_{10}, $PM_{2.5}$, particulate-bound elements, inorganic ions, and elemental /organic carbon. Also provided are data for gas phase volatile organic compounds (VOC's), poly aromatic hydrocarbons (PAH), nitro-PAH's, and carbonyl compounds. All emission results are presented relative to the average CARB diesel fuel to highlight emission reduction potentials. In addition to results for the various compound classes, specific detailed chemical data will be presented for highly reactive or toxic compounds. These include compounds such as ethene, benzene, toluene, xylene, formaldehyde, and acetaldehyde.

The results will illustrate the impact of the fuel and hardware combinations on exhaust emissions and will compare emission profiles for controlled diesel vehicles vs. those fueled by CNG.

FUEL ADDITIVES FOR IMPROVED PERFORMANCE OF DIESEL AFTERTREATMENT SYSTEMS

David Human
Ethyl Corporation

In response to increasingly stringent diesel engine emissions standards, the industry has accelerated its investigation of technologies that can significantly lower NO_x and particulate matter emissions from diesel engines and exhaust. At the 2001 DEER conference a paper was presented on the use of a fuel-borne additive's ability to improve catalyst durability by scavenging sulfur and phosphorous from the exhaust stream before they had the opportunity to react with catalytic surfaces in lean No_x traps. Work has continued on the use of fuel-borne additives to not only protect NO_x traps but also to improve the efficiency of soot oxidation in particulate control devices. While being able to scavenge sulfur and phosphorus, this additive technology has also been found to significantly effect the conditions for particulate trap regeneration. This presentation will show the benefit of a fuel-borne catalyst on lowering the balance point temperature and exhaust back pressure in particulate traps.

STATUS OF APBF-DEC NO_X ADSORBER / DPF PROJECTS

Brian West
Oak Ridge National Laboratory

and

Matthew Thornton and Shawn Whitacre
National Renewable Energy Laboratory

The Advanced Petroleum-Based Fuels – Diesel Emission Control Activity (APBF-DEC) is a Government/Industry collaborative research study aimed at identifying optimal combinations of fuels, lubricants, diesel engines, and emission control systems to meet projected emission standards through 2010. The research projects are co-funded and supported with in-kind contributions from the U.S. Department of Energy and other Government agencies, engine and vehicle manufacturers, catalyst manufacturers, energy and additive companies, and these industries' respective trade associations. Five separate projects involving light- and heavy-duty engine platforms are being conducted to measure the effects of fuel and lubricant composition on engine-out and tailpipe emissions. Three of these five projects are focused on emissions control systems using NO_x adsorber catalysts in combination with diesel particle filters. Ricardo, Inc., is using a heavy-duty line-haul engine, Southwest Research Institute is conducting a pickup truck/sport utility vehicle project, and FEV is performing a passenger car study. The effects of fuel properties on system performance and unregulated emissions will be investigated, generating comprehensive data on these technologies for the U.S. Environmental Protection Agency's biennial technology assessments. The presentation will provide an overview and current status of the three projects.

THE IMPACT OF LUBRICANT FORMULATION ON EMISSIONS FROM A MEDIUM-DUTY DIESEL ENGINE

Shawn D. Whitacre
National Renewable Energy Laboratory

Increasingly stringent engine emission standards are driving the need for advanced technologies that control nitrogen oxides (NO_x) and particulate matter (PM). To enable the efficient and durable application of these new technologies, a growing body of evidence suggests that diesel fuel quality improvements, specifically reductions in fuel sulfur content, are necessary. Recognizing that this may not be enough, additional research is underway to further examine if new lubricants will also be required in catalyst-equipped engines.

This presentation summarizes the results of the first in a multi-phase research agenda to quantify the effects of lubricant composition on the performance and durability of advanced diesel emission control systems. This first phase examines engine-out (i.e., catalyst-in) emissions from a 1999 International T444E (7.3L, V8) base engine that has been equipped with exhaust gas recirculation (EGR) and closed crankcase ventilation (CCV) systems.

Twelve additive technologies spanning a range of key properties were blended in up to four separate basestocks. Engine emissions, using each of the finished lubricants, were evaluated over a modal steady-state operating cycle. In addition to measuring gaseous emissions, PM was collected in three separate sample trains and analyzed for mass, soluble organic fraction, sulfates, nitrates, metal content, and polycyclic aromatic hydrocarbons.

These results form the basis of follow-on work that is studying how these lubricant-derived emission components impact diesel emission control system performance. This work is being conducted within the U.S. Department of Energy's Advanced Petroleum Based Fuels – Diesel Emission Control Activity, a Government/Industry collaborative research program to study advanced fuel- efficient systems for diesel emission control.

NATURAL OILS – THE NEXT GENERATION OF DIESEL ENGINE LUBRICANTS?

Joe Perez
Pennsylvania State University

and

Shawn Whitacre
National Renewable Energy Laboratory

This presentation focuses on the next generation of diesel engine lubricants. It reviews current lubricant technology, including both petroleum and renewable lubricants. Current technology suggests that diesel engines will require aftertreatment systems to meet the stringent 2007 emission regulations. To meet current regulations, API CI-4 was developed to handle anticipated severe oil conditions, such as increased soot, acids, and higher temperatures resulting from the use of cooled exhaust gas recirculation.

The next generation of diesel engine lubricants faces an even more severe challenge. Changes in lubricant additive packages will be the biggest challenge faced by lubricant manufacturers in the last two decades. Poisoning or plugging of emission control system components by ash, sulfur, and other metals may require elimination or significant reduction of currently preferred additives, such as zinc dithiophosphate. Similar problems exist for passenger car motor oils. Most of the effective antiwear and EP lubricating additives contain either sulfur, phosphorus, chlorine, or combinations.

The question is whether natural renewable oils can be utilized to make the quantum leap transition to the next generation of diesel engine and passenger car engines. The weaknesses of vegetable oils are well known and include poor thermal and oxidative stability and undesirable low-temperature properties. Significant progress is being made in each of these areas. Chemical and genetic modification can be used to change the chemical structure of these oils and thereby improve their oxidative stability. Alkylation and other syntheses are used to modify the low-temperature properties and also to improve thermal and oxidative stability. However, this costly processing makes the oils more similar in price to synthetic esters and hydrocarbons.

One issue is whether there are enough vegetable oils to go around. Competition exists from the demand for food products, hydraulic fluids, and biodiesel fuels. Another issue is whether variations in composition of the oils can be controlled and acceptable specifications developed. Although a number of companies are manufacturing and supplying environmentally friendly lubricants, most of the applications are niche markets or hydraulic oils. This still leaves their unproven performance as engine oils as an issue. This presentation discusses these issues and the technical hurdles yet to be tackled. A research plan to accelerate the use of these natural oils is reviewed.

HYDROGEN AS A CANDIDATE FUEL FOR TRUCKS

Jay Keller
Sandia National Laboratories (Livermore, California)

This presentation discusses the motivation and opportunities for hydrogen use as a fuel for light- and heavy-duty trucks. The production application of fuel cells is now recognized to be decades away. Moreover, it is not clear that the application of fuel cell technologies will ever meet the constraints of the trucking industry. I will discuss the applicability of hydrogen-fueled internal combustion engines as they exists today and as they might develop in the near future to meet the needs of the trucking industry. This discussion will highlight those trucking applications where I believe hydrogen as a fuel may work well and those where it will not work.

CONCENTRATIONS AND SIZE DISTRIBUTIONS OF PARTICULATE MATTER EMISSIONS FROM CATALYZED TRAP-EQUIPPED HEAVY-DUTY DIESEL VEHICLES OPERATING ON ULTRA-LOW SULFUR EC-D FUEL

Mridul Gautam, Sandeep Mehta, Dan Carder, Nigel Clark, and Don Lyons
West Virginia University

Miriam Lev-On and Chuck LeTavec
British Petroleum

Keith Vertin and Teresa Alleman
National Renewable Energy Laboratory

This paper will present particulate matter (PM) concentration and size distribution results from heavy-duty vehicles equipped with catalyzed filters and operating on EC-Diesel (ECD), produced by BP-ARCO. The test vehicles were also operated on EC-D 1 (with and without catalyzed traps), CARB diesel, and natural gas. These vehicles had undergone a year-long investigation in Southern California.
EC-D fuel, produced by BP/ARCO, has less than 15 ppm sulfur.

As part of this comprehensive program, concentrations and size distributions of the PM emissions were measured to determine the effect of catalyzed filters on the number count of PM emissions. It was observed that an order of magnitude reduction of total PM mass emissions with the EC-D fueled vehicles equipped with traps over CARB-certified diesel-fueled vehicles (without any exhaust aftertreatment systems) was accompanied by drastic reductions in concentrations of particulate matter emissions.

The natural gas-fueled vehicles also showed very low concentrations of particulate matter compared to the Cummins L10G vehicles that were tested in Dallas in 1999 by West Virginia University. Nanoparticle emissions from natural gas-fueled heavy-duty vehicles are linked to lube oil control and very likely to the age of the vehicles.

Measurement of PM concentrations and size distributions from the filter-equipped vehicles and natural gas-fueled vehicles is rather challenging. A dedicated mini-dilution system with an accurate dilution ratio control scheme was employed to measure PM-size distributions. Utmost care was taken to ensure that particle losses in the sampling system were minimal.