Highlights from the Coordinating Research Council

22nd Real-World

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For more than two decades, the Coordinating Research Council (CRC) has held an annual vehicle emissions workshop in California. These meetings gather national and international practitioners in the field of vehicle/engine emissions to review and discuss the latest activities in modeling, measurement, and analysis. As in past workshops, the 22nd Real-World Emissions Workshop, held March 25–28, 2012, in San Diego, covered a diverse set of topics, ranging from trends and modeling to measurements and monitoring to inspection and maintenance. The workshop structure consisted of platform sessions, poster sessions, and demonstrations of vehicle emission technology. Highlights of the 2012 workshop sessions are summarized in this article. Full proceedings of the workshop are available through the CRC Web site (www.crcao.org).

Emission Trends in Modeling

Overall declining emissions of oxides of nitrogen (NO_x) from tunnel and remote sensing studies between 1990 and 2010 were presented (see Figure 1). Although declining, emissions of NO_x from diesel were shown to exceed that of gasoline and this was supported by EMFAC2011 modeling. The U.S. Environmental Protection Agency's (EPA) MOVES model estimates for relative vehicle speed and drive cycle effects were generally consistent

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Emissions Workshop

with those observed using a portable emission measurement system (PEMS) across 35 light-duty vehicles. Further evaluations of MOVES emission rate data from several studies showed favorable comparisons with NO_x (see Figure 2 showing comparisons for three cities) and hydrocarbons (HC), with some over-predictions for carbon monoxide (CO).

Air quality model-to-real world monitoring comparisons demonstrated improved performance of MOVES versus the outgoing MOBILE6 emission model. Gathering local data is important for the transition from MOBILE to MOVES. Data collected on one vehicle instrumented with a PEMS system and driven on a test track to mimic the Federal Test Procedure (FTP) and Supplemental Federal Test Procedure (SFTP) certification test cycles were compared to MOVES; discrepancies were noted between model predictions and observed data. Best practices were proposed for performing particulate matter (PM) hot-spot analyses using AERMOD, which is based on a hypothetical road-widening project. Data from studies in Seattle, Los Angeles, Houston, and San Antonio are currently housed in the Transportation Secure Data Center, a repository for studies that instrument vehicles to measure vehicle speed, trip pattern, and global positioning system (GPS) data.

PM Characterization

Linking tailpipe emissions to atmospheric evolution of fine particle emissions from on-road vehicles, by using a purpose-built smog chamber, was discussed. Researchers investigated several different PM issues, including an on-road PM emissions assessment using a 2010-complaint heavy-duty diesel truck crossing the continental United States. Real-world measurements were compared against EPA's 2010 emissions standards, PM mass emitted during not-to-exceed (NTE) events, and proposed

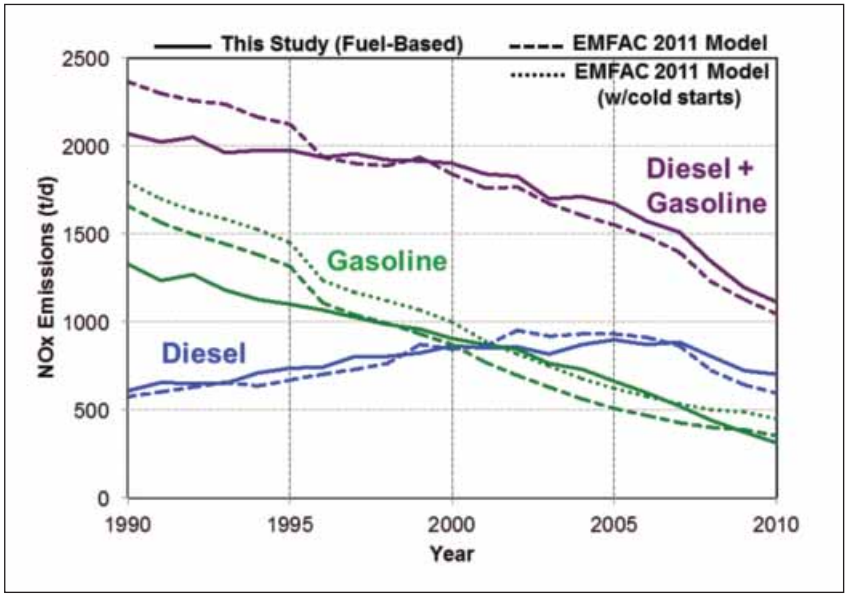

Figure 1. On-road vehicle NO_x emission trends compared to the EMFAC2011 model for diesel and gasoline.

Source: "Changes in On-Road Diesel Vehicle Emissions in California" by Robert Harley, University of California, Berkeley (CRC Workshop, 2012). Forthcoming paper titled, "Long-Term Trends in Nitrogen Oxide Emissions from Motor Vehicles at National, State, and Air Basin Scales" by McDonald et al. (*Journal of Geophysical Research 2012*), provides more details on the evaluation of mobile source NO_x emission trends.

Euro VI particle number (PN) legislation; research was conducted regarding the reported increase of nuclei-mode particles produced by catalyzed diesel particulate filters (DPF). Presentations discussed solid particle measurement issues, contributions of lubricating oil on PM formation from light-duty gasoline vehicles, and toxicity results of PM emissions from modern heavy- and light-duty vehicles.

A particle-size-distribution study of PM emitted from diesel engines and a diesel burner focused on the impact of particle size on DPF back pressure performance. Data compared PM mass and PN emissions from a heavy-duty diesel vehicle under on-road driving conditions and a standard testing cycle. The effects of using B20 biodiesel fuel on existing fleets across several test cycles were investigated, including fuel economy, regulated emissions, and greenhouse gas emissions. B20 significantly reduced larger diameter PM, but smaller diameter PM remained relatively unchanged compared to ultra-low sulfur diesel (ULSD). Finally, integrated and stand-alone instruments for diesel engine soot emissions measurements were compared to gravimetric filter and photo-acoustic results.

Measurement Methods

Fundamental issues in accuracy and repeatability for measuring mobile source pollutants were investigated. Measurement errors can impact compliance estimations, pollutant effects upon ambient air, and ultimately, influence the development of appropriate methodologies to improve air quality. Presentations included the measurement of transient ammonia (NH_3) emissions from selective catalytic reduction (SCR)-equipped NO_x emission control systems, effects of sampling rates, evaluation of different particle sizers used for PM analysis, evaluation of sampling conditions, and test cycle effects on particulate mass and number emissions. Near infrared tunable diode laser instruments for measuring NH_3 have been developed.

Fast mobility particle sizers (FMPS) concentration and diameter measurements were shown to agree with reference measurements. Faster data acquisition rates are not necessarily better, since the critical improvement in transient response measurement involves getting the sample to the analyzer faster. Enhancing the PM sample conditions and measurements is possible through improved internal air circulation and cooling capabilities. In-use or PEMS instruments are becoming more reliable and consistent as they meet 40 CFR 1065 requirements; however, maintenance of in-use instruments is essential.

Fuel Effects—Compression Ignition

The California Low Carbon Fuel Standard mandates the reduction of the carbon intensity of fuels by 10% by 2020, providing opportunity for the use of biofuels like biodiesel. With the use of lower carbon intensity diesel fuels such as soy and animal-based biodiesel, as well as renewable diesel, testing has occurred to evaluate polycyclic aromatic hydrocarbons (PAHs) emissions and mutagenic activity in both the particle and vapor-phase. The study of a 2007 model-year heavy-duty vehicle equipped with a DPF showed significant reductions in PAH and mutagen emission levels.

Four different transit buses and four fuels were used to improve the understanding of biodiesel on emissions. B20 blended into ULSD certification fuel showed no significant effect on NO_x emissions, while B20 in a low aromatic diesel fuel showed a

3–5% increase in NO_x. Compressed natural gas (CNG) buses showed increased emissions of CO, HC, NO_x, and NH_3 on a mass basis compared to buses running on diesel fuel. Hybrid buses, 2007 to 2009 model-year, showed decreased emissions of CO and HC, but increased NO_x emissions when compared to nonhybrid diesels of the same model years. Claims were made regarding the need to study fuel composition-property relationships to understand the impact of next generation fuel blends in advanced combustion research. Information suggested that the impact of biodiesel blend levels on NO_x emissions varies across driving cycles while no clear trend was found for PM emissions.

Fuel Effects—Spark Ignition

Gasoline direct injection (GDI) vehicle research showed decreased benzene, toluene, ethylbenzene, and xylenes (BTEX) emissions when ethanol content increased while emissions increased at colder temperatures (see Figure 3). When engine calibration changed as the ethanol content varied, PM by mass and number was reduced by 30–40%. Researchers demonstrated that by varying fuel quality alone, vehicle PM mass and solid particle number (PN) can show great variation. A durability study reported with high confidence that the

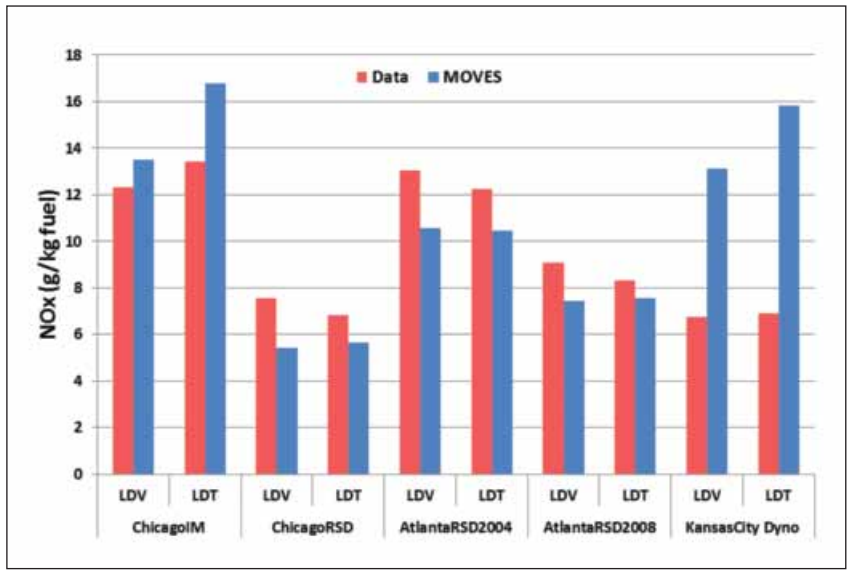

Figure 2. Fleet average NO_x emission rates for MOVES model vs. emissions data collected from light-duty vehicles in Chicago, Atlanta, and Kansas City.

Source: "Evaluation of MOVES using measurements from Dynamometer, RSD, Tunnel, Roadside, and Ambient Air Quality Studies" by John Koupal, U.S. EPA Office of Transportation & Air Quality (CRC Workshop, 2012).

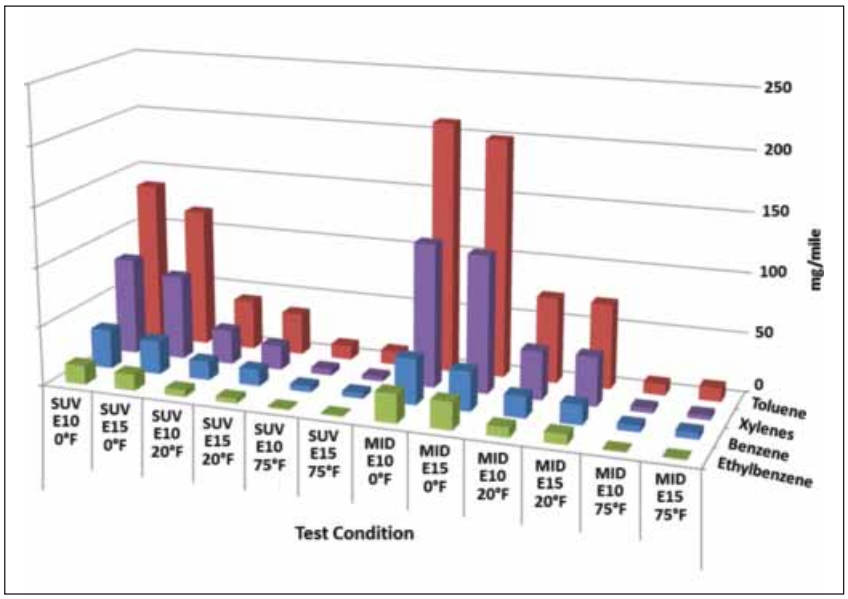

Figure 3. BTEX emissions relative to ethanol content and ambient temperatures evaluated using a small sport utility vehicle (SUV) and mid-size vehicle.

Source: "Light-Duty GDI Vehicle PM and VOC Speciated Emissions at Differing Ambient Temperatures with Ethanol Blend Gasoline" by Thomas Long, U.S. Environmental Protection Agency (CRC Workshop, 2012).

ethanol content (E15/E20) was an influential factor for engine failures found in the study.

Stoichiometric combustion with a three-way catalyst was the most efficient strategy to reduce unregulated emissions from CNG-fueled buses compared to two other exhaust aftertreatment strategies. Introducing an oxidation catalyst was shown to be effective at reducing unregulated emissions, especially formaldehyde, from in-use lean-burn CNG buses. The California Energy Commission and South Coast Air Quality Management District have funded an emissions and performance study to investigate combinations of mixed alcohols.

Off Road and Portable PM Measurement

Measurement of gaseous and PM emissions from various applications, instruments, and approaches for those measurements continue to be an active area of research as evidenced by the material presented. A NO_x control system for marine applications was described. An engine equipped with a catalyzed particulate filter (CPF) and diesel oxidation catalyst (DOC) effectively oxidized nitric oxide (NO) to soluble form while a hydrogen peroxide wet scrubber reduced NO_x; as shown in Figure 4, 60% NO_x absorption was achieved using a hydrogen peroxide solution.

Emissions of NO_2 from DPFs and the transition from steady-state to transient cycle testing for verification of diesel technology inside of the California program were discussed. Second-by-second results from transient operation showed that the nitrogen dioxide (NO_2)/NO_x ratio in post-DPF emissions varies inversely proportional to engine power, likely confirming the well-known temperature dependence of NO oxidation over a catalyzed filter. One particle sensor demonstrated the ability to correlate to particle mass and number emissions inside an error of 38%; this sensor could become a viable option for engine tuning work.

One study identified three main sources of uncertainty in the existing California Transport Refrigeration Unit inventory: emission factors, deterioration rates, and activity rates. Finally, a real-world 2,500-mile coast-to-coast trip made in a transportable laboratory permitted the measurement of emissions, while driving, from a DOC/DPF/SCR-equipped 2011 Class VIII heavy-duty diesel tractor. The study examined engine emissions over a variety of topography and ambient conditions over the entire engine operating envelope, including NTE events. Both NO_x control and DPF regeneration were found to be effective and no NH_3 slip was observed.

Emission Rates and Inventory

Measurements to enhance emission model estimates and their role in mobile source control programs were presented, highlighting the importance of real-world measurements in assessing emissions models and inventory development. Light-duty vehicles were found to have black

carbon underestimated in the emissions model, while remote sensing devices were shown to be capable of detecting high evaporative emissions. Emissions were evaluated from a European vehicle powered by gasoline and natural gas/hydrogen blends. The California emissions model was adapted to the Hong Kong region using specific vehicle mix and measurements. Emission measurements from 2007 and 2010 engines, two decades of transit buses, unregulated diesel engine emissions, and dioxin formation in heavy-duty engines were presented.

Emission Control Measures

Research presented characterized and explored the efficacy of new emissions control technologies introduced into the marketplace to address strict new standards for light-duty, heavy-duty, and off-road applications. The California Advanced Clean Car package adopted in January 2012 requires reductions of NO_x emissions by 75%, of PM emissions from 10 to 1 mg/mi, and of carbon dioxide (CO_2) emissions to a 166 gCO_2e/mi level for light-duty vehicles running nonmethane organic gas (NMOG). Results from remote sensing of light-duty vehicles suggest there are high evaporative emitters in the vehicle fleet that can be identified. One truck test tent concept allows trucks to drive through a tent, while an integrated exhaust emissions sample is collected. A PEMS measurement study showed that DPFs and SCR technologies reduced NO_x emissions by greater than 50% in certain off-road applications; however, real-world NO_x emission can be quite different from chassis dynamometer results. An opposed-piston two-stroke diesel engine was shown to achieve high exhaust temperatures quickly resulting in cold start emissions reductions and improved fuel economy.

Inspection and Maintenance

New-vehicle emissions standards have become more stringent and the durability of those vehicles has become longer in both time (number of years) and total mileage. Fleet emissions have become increasingly skewed, with a smaller fraction of vehicles contributing to the total. 1996 model-year and newer vehicles include a standardized data port in association with second generation on-board diagnostics (OBD II) systems that checks for defects under all operating modes. Analysis of historical remote sensing device (RSD) data showed little difference in the distribution of high-emitting vehicles between inspection and maintenance (I/M) and non-I/M areas. Enforcement of I/M programs is important to maintain its effectiveness. Improper and fraudulent testing can be significant, with some estimates that up to 20% of I/M certificates are counterfeit or improperly issued. Enforcement measures can include assessment of I/M emissions and OBD II databases for inconsistencies, conducting covert operations on vehicle emissions inspection stations, and prosecuting offenders for counterfeit inspection certificates.

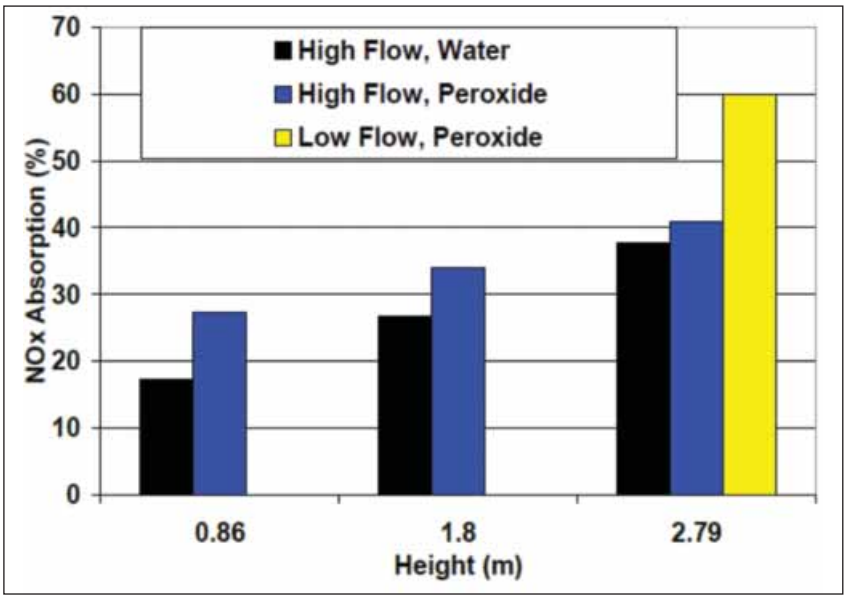

Figure 4. NO_x absorption conversion efficiency as a function of the scrubber height.

Source: "Diesel Marine Engines Emissions Reduction: A Combined, Onboard NOx Oxidation, Absorption and Reduction System" by Nigel Clark, West Virginia University (CRC Workshop, 2012).

RSD can be incorporated into I/M programs in two ways: to identify and exempt clean vehicles from periodic inspection, and to identify the highest emitting vehicles for scrappage and repair programs. One European view of I/M program design and operation was offered where in Germany, a back-up tailpipe test is conducted if all of the OBD II "readiness" codes have not been set. Since light-duty diesels represent a significant fraction of the fleet in Europe, concerns were expressed regarding the ability of OBD II systems to capture all defects related to the DPF. New measurement technology needs (beyond opacity meters) was expressed especially as PM certification standards become more stringent.

Next Workshop

The 23rd Real-World Emissions Workshop is scheduled for April 7–10, 2013, in San Diego, CA. **em**