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Highlights from the Coordinating Research Council 24th Real-World Emissions Workshop in San Diego, CA

For decades, the Coordinating Research Council (CRC) has held an annual vehicle emissions workshop, gathering international practitioners in the field of vehicle/engine emissions to discuss the latest activities in emissions measurement and monitoring, inspection and maintenance, modeling, and vehicle and fuel effects. The most recent, the 24th Real-World Emissions Workshop, was held March 30–April 2, 2014, in San Diego, CA. The workshop consisted of presentations, posters, and equipment demonstrations. Margo Oge, former Director of the Office of Transportation and Air Quality at the U.S. Environmental Protection Agency (EPA), presented the keynote address, describing her role in crafting vehicle emissions policy. Highlights of the 2014 workshop sessions are summarized on the following pages.

Vehicle Emissions Measurement by Remote Sensing

Remote sensing measurements of passenger car emissions in Southern California indicated that due to the decline in new car sales, emissions remained 10–28% higher than expected with fleet average age increase by 1.7 to two years. Remote sensing measurement studies conducted on European cars indicated that diesel cars have higher nitrogen oxides (NO_x) emissions compared to gasoline cars. Comparisons of European diesel cars with U.S. cars found that European diesel cars generally had higher NO_x emissions compared to U.S. gasoline-powered cars (see Figure 1).

An on-road, heavy-duty vehicle monitoring system, where trucks were taken aside and run under a long tent-like fly was used to measure emissions from a large number of trucks at a single location. Emission results from 1,000 trucks collected in two areas in California indicated that model year 2010 and newer truck emissions of particulate matter (PM) and black carbon were three times lower than emissions standards. The top 1% of 2006 to 2009 model year trucks showed elevated PM emissions indicating some form of malfunction.

Vehicle Emissions Measurement in the Laboratory

In-use drive cycles on a chassis dynamometer were used to assess emissions from heavy-duty port trucks in goods movement vocations. Testing found that for port vehicles (near dock, local, and regional), diesel powered trucks with selective catalytic reduction/diesel particulate filter (SCR/DPF) systems showed the lowest NO_x emissions under high-load conditions and relatively high NO_x levels at low-load conditions. Low-temperature NO_x emissions varied between and within manufacturers.

EPA and the Colorado Department of Public Health and Environment (CDPHE) collaborated on a long-term study to develop a large database of emissions measurements from Tier 2 vehicles. Data analyzed over the first two years showed an expected trend in vehicle emissions over time, but it was inconclusive for validating catalyst deterioration as modeled by the Motor Vehicle Emissions Simulator (MOVES) model.

A follow-on study of evaporative emissions leaks provided information on running loss emissions from leaking vehicles over a range of leak sizes. Vehicles were tested using gasoline containing 10% ethanol (E10) with Reid vapor pressure (RVP) of 7 and 10 psi. The data include fuel system pressure and contains information for a variety of purge strategies, as well as trends by RVP, leak diameter, and location.

Finally, VTT Technical Research Centre of Finland used a chassis dynamometer to evaluate emissions and efficiency impacts of cold weather (Nordic) driving conditions. The tests were performed at +23°C (73°F) and -7°C (19°F), using the New European Drive Cycle (NEDC) and two of VTT's own drive cycles. Gasoline vehicles produced lower NO_x, but higher hydrocarbon emissions and fuel consumption under cold driving conditions. Similar trends were observed for gasoline hybrids, but the fuel consumption penalty was smaller. Conversely, diesel vehicles showed higher NO_x and lower fuel consumption under cold driving conditions.

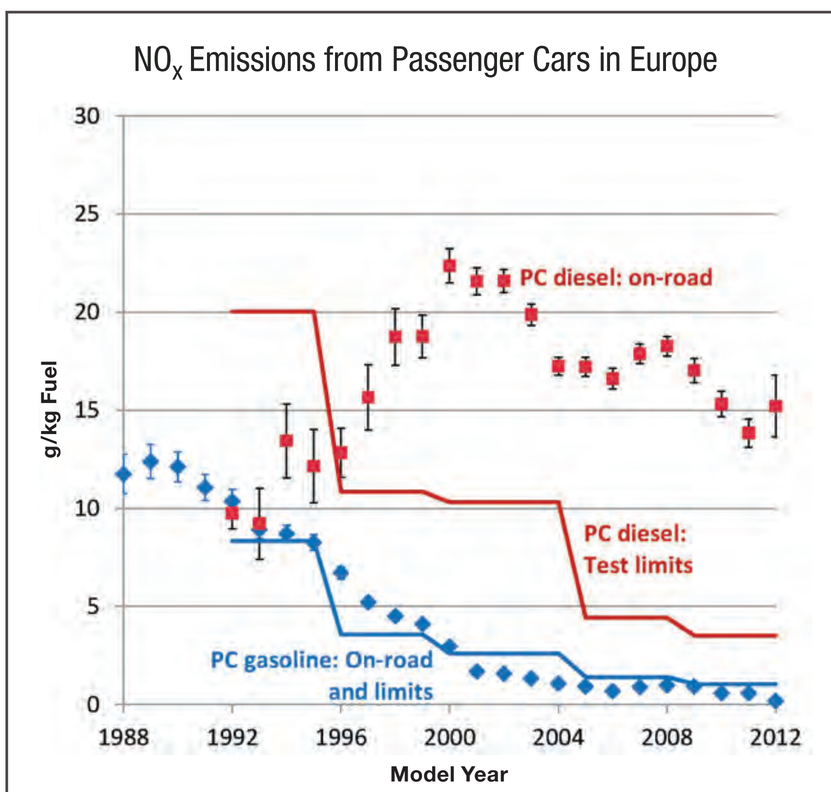

Figure 1. NO_x emissions measurements from European gasoline (blue) and diesel (red) cars.

Vehicle Emissions Measurement by PEMS

Real-world emissions were measured using portable emissions monitoring systems (PEMS) for both light- and heavy-duty vehicles. Comparisons were made to emission standards and laboratory methods. Refuse trucks with unique duty cycles needed better representation in laboratory testing. SCR in refuse truck applications achieved sufficient operating temperatures, but there may be other still unknown challenges in achieving low NO_x. A hydraulic hybrid system was able to double refuse truck fuel economy.

In Europe, PEMS measurements showed that light-duty diesel emits considerably higher NO_x on road than expected, while underestimating PM emissions in Hong Kong. Real-world fuel economy in 100 tested light-duty vehicles agreed, on average, with vehicle fuel economy estimated by EPA methods. The effect on carbon dioxide (CO_2) emissions of providing real-time information to the driver about speed versus speed limit was evaluated and found to be quite small. Initial testing suggests that diffusion charger-based PEMS devices may hold promise for the 2017 European particle number (PN) requirement.

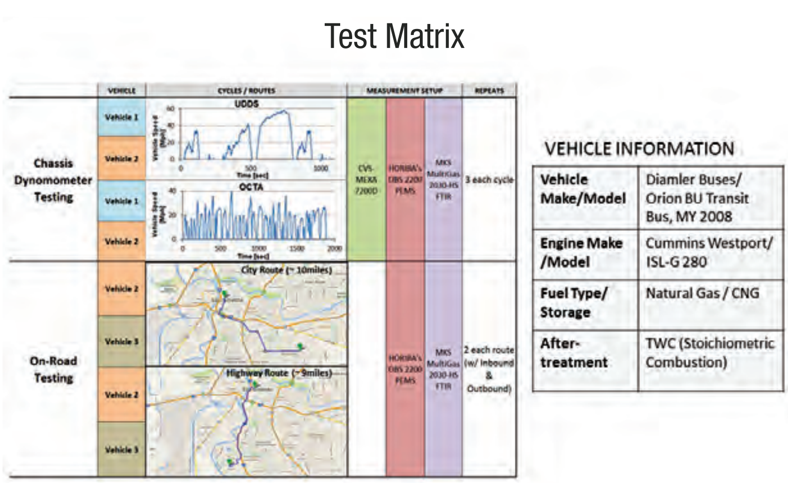

Figure 2. Test matrix for studies comparing FTIR and PEMS instruments.

Figure 3. The ExhaustTrak venturi system for emissions measurement.

Emissions Measurement Methods Development

This session included presentations on instruments used in vehicle emission testing, such as a spectrometer, a cascade laser, and cooled Fourier transform infrared (FTIR) for nitrous oxide (N_2O) measurements. Five N_2O analyzers were evaluated using exhaust samples generated by light-duty vehicles on a chassis dynamometer.

At this time, FTIR-based instruments are not an approved method to quantify regulated pollutants. FTIR was evaluated as an alternative to PEMS instruments. Comparative studies demonstrated FTIR capabilities against constant volume sampler (CVS) measurements while engine certification test compared the total hydrocarbon flame ionization detector (THC FID) difference method and the FTIR direct measurement method (see Figure 2).

Finally, the session discussed using raw (undiluted) measurements to certify engines below 560kW for PM emissions, providing a potential option in lieu of CVS systems, although significant challenges remain. The ExhaustTrak venturi system was described as a method for simplifying and improving emissions measurement by eliminating complicated post-test chemical balance analysis (see Figure 3).

Off-Road Vehicle Emissions

Real-world emissions from a bulldozer and excavator equipped with hybrid powertrains were compared to similar machines using conventional diesel engines to promote deployment of commercialized hybrid construction equipment (see Figure 4). First-generation hybrids showed possible fuel consumption savings, but with increased NO_x and PM emissions.

Advanced engine and exhaust aftertreatment technologies and alternative fuels (i.e., fatty acid methyl ester biodiesel fuels) helped the mining industry reduce exposure of underground workers to gases and aerosols emitted by diesel-powered equipment and comply with regulations. Biodiesel

Figure 4. A track excavator outfitted for emissions measurement.

also showed a significant emission reduction benefit over ultra-low sulfur diesel fuel in locomotive and marine applications.

Particulate Matter Emissions Measurement

Light-duty Tier III emissions regulations at 3 mg/mi (2017) and future 1 mg/mi (2025+) levels drove research on gravimetric PM techniques to increase PM mass on the filter. Dilution factor, filter face velocity, combining filters over the federal test procedure (FTP), and filter handling were investigated. A denuder made of alumina/zeolite catalyst on a cordierite honeycomb substrate was used to remove PM artifact from the PM filter material and has shown nearly 100% soot penetration and greater than 94% removal of gas phase sulfuric acid and hydrocarbons. Studies showed that not all combustion soot is black carbon and care should be taken when interpreting real-time PM based on optical absorption measurements.

The European PN emissions measurement method requires hot dilution and high temperature vaporization of non-solid components of PM. A Condensation Particle Counter (CPC) operated under ambient conditions provided PN count, while a high temperature CPC allowed PN measurement under "raw" conditions without dilution and the use of a vaporizer. Appropriate high temperature CPC fluid was essential to enable high temperature CPC. Another study showed PN repeatability and reproducibility of 0.6% and 99.4% of total variation. Variation in reproducibility was identified as being related to the test process rather than the instrument.

Emissions Modeling

A significant update to the EPA MOVES inventory model (MOVES2014) included new data, control programs, and processes. Of note were improvements in evaporative emissions, light- and heavy-duty emissions, as well as activity, and fuel and temperature effects. MOVES outputs were shown to be sensitive to the region-supplied data, particularly fleet age/mix, vehicle miles traveled (VMT) fractions, and speed distributions. The model has many users, including internationally; Monterrey, Mexico, for example, is developing regional inputs to evaluate emission control scenarios.

The California Air Resources Board (CARB) Emissions Factor (EMFAC) inventory model is undergoing a significant update in 2014. The heavy-duty diesel fuel volumes have been validated to sales data. In another study, a new real-time heavy-duty diesel engine model was created starting with EMFAC that more accurately captures aftertreatment behavior. EMFAC was also compared to the Integrated Bus Information System (IBIS), which contains a mathematical empirically-based emission model for transit buses. IBIS will help transit agencies with vehicle procurement.

The Community Multiscale Air Quality (CMAQ) model was used to evaluate the impact of recent mobile source regulations on ozone concentrations in the eastern and western United States in 2018 and 2030. Results showed significant reductions in the East, but fewer in the West.

Fuel Effects on Emissions from Heavy-Duty Vehicles

Emissions were compared for current diesel and natural gas-fueled heavy-duty vehicles, finding that NO_x emissions and global warming potential were lower for natural gas. A comparison of the latest conventional and hybrid bus technologies at low operating temperature demonstrated that the hybrid bus showed fuel economy and emissions benefits, but discovered that both vehicles showed higher in-use NO_x than expected. A study of a variety of heavy-duty trucks fueled with biodiesel blends found NOx increases of 1–4% for diesel blends containing 5% and 10% soy-based biodiesel (B5 and B10), no difference in NO_x for animal-based biodiesel blends, and general reductions of PM, carbon monoxide (CO), and total hydrocarbons (THC) from the addition of biodiesel.

Fuel Effects on Emissions from Light-Duty Vehicles

Spark Ignition Direct Injection (SIDI) vehicle technology market share increased to 24% in 2012, so it is important to understand the resulting changes in regulated, PM, mobile source air toxics (MSAT), volatile organic compounds (VOC), carbonyls, and polyaromatic hydrocarbons (PAH) emissions. Both wall-guided (WG-SIDI) and spray-guided (SG-SIDI) SIDI emissions were tested using three ethanol and three isobutanol blends. The SG-SIDI vehicle had significantly lower PM mass, soot, and PN compared to the WG-SIDI vehicle. Addition of ethanol produced a decrease in PM for the WG-SIDI vehicle, but the SG-SIDI vehicle showed no significant change in PM with either oxygenate.

Direct injection (DI) of liquid petroleum gas (LPG) and gasoline were compared in a specially-adapted vehicle. LPG-DI counteracted the reduction in volumetric efficiency inherent to port fuel injection of LPG. LPG-DI reduced emissions of CO_2, THC, NO_x, PM, PN, VOC, and PAH compared to gasoline. However, acetaldehyde and acrolein emissions increased and fuel economy decreased.

A Taiwanese study of fuel effects in two 125 cc motorcycles found that CO, THC, benzene, toluene, ethylbenzene, xylene (BTEX), and alkane, alkene, and aromatic group emissions decreased; acetaldehyde emissions greatly increased; and NO_x was not significantly affected by an increase in ethanol content of gasoline.

Emissions of 15 light-duty vehicles were measured using three test fuels of varying properties including ethanol content from 0% to 15%. The data were intended to validate predictive models developed during the EPAct/V2/E-89 study and used the same test fleet. Results were directionally consistent with model predictions for some pollutants, but inconclusive for others due to lack of statistical significance. Substituting particulate matter index (PMI) for aromatics and T90 fuel properties in the EPAct/V2/E-89 data set improved the fit of the PM models. An interaction between PMI and ethanol suggests that the PMI formula could be improved to accommodate ethanol blends.

Emissions Control Measures, Inspection and Maintenance, and On-Board Diagnostic Systems

On-board diagnostic system (OBD II) data collected in inspection and maintenance (I/M) programs showed that "not-ready" rates for evaporative control systems are about five times higher than for other systems. I/M programs that enforce OBD checks have lower failure rates than programs in which OBD is advisory only. This effect was corroborated with Oregon data that showed vehicles in I/M areas had a lower rate of malfunction indicator light (MIL) events and sought repair more quickly than vehicles in non-I/M areas. A novel method for an on-board check of the evaporative canister involved monitoring substrate temperatures during known adsorption (refueling) and desorption (purging) events.

A PEMS-based on-road emissions test for light-duty vehicles in Europe to verify in-use compliance with Euro 6 NO_x limits was described. Heavy-duty diesel emissions were measured by driving vehicles through a portable "tunnel" with sample ports at the top (see Figure 5). This showed good correlation with PEMS results and may be used for I/M testing, clean-screening, and identification of high-emitters. A "smoky" diesel truck enforcement program in the M5 East Tunnel in Sydney, Australia, identified high-emitting vehicles using opacity sensors and video cameras (see Figure 6).

Figure 5. (top) Method for real-time testing of heavy-duty diesel trucks.

Figure 6. (bottom) Opacity sensors and video cameras identify high-emitting vehicles in a tunnel in Australia.

Efforts by CARB to control new-vehicle and in-use emissions from heavy-duty trucks were described. Although current emission control systems (e.g., particulate filters and SCR systems) were highly effective when properly functioning, in-use durability was shown to be a concern. Modeling of heavy-duty diesel engines showed that improving waste-heat recovery to help meet CO_2 standards may reduce exhaust temperature and SCR activity.

Next Workshop

Ongoing interest in emissions reduction technologies and measurement methods produces a continuing need for collaboration among researchers to improve data, measurement methods, and modeling capabilities. The 25th Coordinating Research Council Real-World Emissions Workshop is scheduled for March 22–25, 2015, in Long Beach, CA. Proceedings of the 24th Workshop are available online at www.crcao.org. **em**