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PEMS 2018 Abstracts Document

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Day 1 Abstracts:

Matthew Spears, EMA

Evaluation of a New Candidate HD NOx In-Use Compliance Metric

About a decade ago EPA implemented the first PEMS-based in-use compliance program, which applied a Not-to-Exceed (NTE) based in-use compliance metric. More recently, the European Commission implemented a Work-Based-Window, WBW—or equivalently, a Moving-Average-Window, MAW—compliance metric for its PEMS-based heavy-duty in-use engine requirements.

Today in the U.S., all new heavy-duty on-highway diesel-fueled engines are equipped with Selective Catalytic Reduction (SCR) after-treatment for NOx emissions control. These SCR systems are capable of ~99% NOx conversion efficiency under time histories of moderate- to high-load engine operating conditions. However, under light-load time histories, SCR could have 0% NOx conversion efficiency.

Because EPA's NTE zone excludes light-load and low exhaust temperature engine operating conditions, the NTE metric fails to capture light-load time histories that might hold opportunities to achieve greater NOx reductions. While the MAW metric captures longer time histories than the NTE metric, it too excludes some light-load engine operating conditions. For example, to avoid asymptotically high brake-specific results at light loads, the MAW excludes windows with average power less than 20% (or, in the future, 10%) of maximum engine power.

To achieve the goal of greater in-use NOx reductions, one hypothesis is that first a new compliance metric is needed, and that the new metric must not exclude any engine operation and that it must better reflect SCR NOx conversion efficiency's dependence on the time history of engine operating conditions.

This presentation reports on EMA's analysis of PEMS and emissions lab data to evaluate a new candidate in-use compliance metric. To avoid asymptotically high results, this metric is partially CO_2-specific, rather than entirely brake-specific. In an attempt to better reflect the time-history dependence of SCR NOx conversion efficiency, this metric uses asymmetrical averaging between NOx in its numerator and CO_2 in its denominator. This metric is complemented by a "CO_2 binning" approach to discriminate between various time histories of engine operation. This binning represents an attempt to achieve the goals of excluding no data, while at the same time creating the potential to more finely apply more stringent requirements, but only where cost-effective technologies and calibrations could be proven to be effective. Finally, a simplified version of this metric is explored, where the metric's data requirements could be fulfilled entirely by a single tailpipe NOx/O2 sensor.

Kent Johnson, UC Riverside

VW In-Use Testing Program

The recent vehicle Consent Decree requires Volkswagen of Germany (Volkswagen AG), Audi Germany (Audi AG), and the Volkswagen Group of America (VWGoA) to conduct portable emissions measurement system (PEMS) testing using an independent third-party emissions tester to measure regulated criteria air pollutants and CO_2 of certain series production vehicles of Model Years 2017, 2018, and 2019 via PEMS under conditions as set forth in the Consent Decree.

A total of 32 or more vehicles will be tested under this test program, with roughly an even split over the three model years. The total number of vehicles for the 2017 model year was 11. The testing is being conducted on-road in the Southern California area over routes that could include highway driving, stop-go city traffic, and heavy grade/high elevation, with a diversity of geographies and climatic conditions. The routes included a route in the LA Downtown area, a highway route between Oxnard and Santa Barbara, CA, and a route in the Santa Barbara mountains. An AVL M.O.V.E Gas PEMS iS was used for this work, which provides for measuring NO/NO_2, CO/CO_2, and THC emissions from diesel and gasoline vehicles and engines. Correlation testing at the VWGoA Test Center California (TCC) in Oxnard, CA was also conducted in conjunction with the testing on three vehicles. Correlation testing for each of the correlation vehicles was conducted over the Federal Test Procedure (FTP) certification test cycle, the highway fuel economy test (HWFET) cycle, and US06 cycle.

Steve Trevitz, Volvo Group Trucks Technology

The Role of Telematics – From Engine Development to Customer Support

The emergence of telematics data transfer has aided the development, testing, and customer support of heavy duty on-highway diesel engines. Advances in the transmission of remote vehicle data have paralleled the increased sophistication of power train technologies employed to remain competitive and compliant with the expanding scope of regulations involving criteria emissions, on-board diagnostics, and greenhouse gas emissions.

This presentation will describe how a basic "activity monitor" is instrumented on a vehicle in such a way that the data collected can be transmitted telematically. The natural expansion of this basic system can lead to the addition of sensors, micro-PEMS, and ultimately to 1065-compliant HDIUT PEMS.

After vehicles are purchased, telematics have advanced the capabilities of the service and maintenance function. Service personnel can remotely monitor the health of a vehicle to prevent problems or diminish their severity. A description of these tools and their application will be discussed.

Yi Tan, California Air Resources Board

Evaluation of a NO_X Tracking Concept Using Heavy-Duty Truck OBD Data

On-Board Diagnostics (OBD) monitors controlling emissions of heavy-duty diesel trucks (HDDT) and feedbacks the engine control unit (ECU) to optimize engine performance and emission control efficiency. Since the introduction of selective catalytic reduction (SCR) system to heavy-duty diesel trucks, on-board nitrogen oxide (NO_X) sensors became a central part of measuring NO_X concentrations in the exhaust and optimizing SCR performance in NO_X control. Measured NO_X emissions can be used to evaluate NO_X control efficiencies at real-world engine and vehicle operating conditions.

A NO_X tracking concept in the recently proposed amendments to the heavy-duty OBD regulation plans to monitor tailpipe NO_X emissions by binning them into 15 combinations of engine power and vehicle speed. This concept is in its final stages of development. In this presentation, we will demonstrate the NO_X tracking concept using engine and NO_X concentration data obtained from 72 diesel trucks over 10 different vocation types in California. We instrumented the trucks with OBD dataloggers and recorded second-by-second engine operation and NO_X concentration data over a minimum of four consecutive weeks. Using the OBD data, we will evaluate NO_X emissions across the 15 engine power and truck speed bins.

Carl Fulper, U.S. EPA

Evaluation of 7 years of Remote Sensing Data from Colorado to Compare the Real World Emissions Performance of Various Vehicle Makes and Models

ERG and EPA have analyzed seven contiguous years of on-road remote sensing (RSD) device data to characterize Colorado in-use fleet emissions for various Makes, Models, and Model Years (MYs). In particular, fleet average NOx emissions for different Make/Model/MY cohorts were compared. Several data sources, including the ERG VIN Decoder and the Colorado IM dataset, were used to help identify the specific vehicles of interest, and obtain information including Make, Model, engine size, and fuel type. NOx emissions of various vehicle categories were then compared to the general Colorado fleet, by month of RSD observation and by vehicle load at the time of the observation. A spreadsheet with average on-road emissions levels for the observed vehicle groups was also generated for use in identifying any additional vehicle groups with higher than expected on-road emissions.

When the spreadsheet was used to identify vehicle groups with higher than expected on-road emissions, several groups of vehicles were identified for further investigation. This included several Volkswagen models, with 2.0L and 3.0L diesel engines. This also included some gasoline and other some diesel models. The on-road dataset was used to provide additional information about these groups of vehicles, which was presented as plots comparing their emissions to fleet-wide emissions. In many cases, these groups of vehicles were found to have NOx emissions that were higher than the fleet average at all VSP levels, and repeatedly over a period of years.

Daryl Bear, Mesilla Valley Transportation Solutions

AN IMPROVED METHOD FOR DETERMINING THE REAL-WORLD IMPACTS OF VEHICLE FUEL EFFICIENCY TECHNOLOGIES

Mesilla Valley Transportation, one of the largest, locally owned, long-haul transport providers in western Texas and New Mexico, is well-known in their industry as an innovator/early-adapter of fuel efficiency technologies and cost-effective fleet management practices. To support their business approach, they formed a testing subsidiary, Mesilla Valley Transportation Solutions (MVTS). Over the past five years MVTS has utilized an innovative method for accurately and quickly assessing the real-world fuel consumption impacts of new technologies in their industry. The new method derives much from motorsports engineering including IndyCar, NASCAR, and Formula 1. It combines on-vehicle sensors and motorsports techniques with a "first principles" energy-balance algorithm to assess fuel consumption impacts in real-time. Even though its accuracy and statistical validity exceed those of the "industry standard" SAE J-1321 protocol, the real-time conclusions are obtained more quickly and cost-effectively than for the integrated, gravimetric approach of J-1321.

The MVTS fuel efficiency comparison method directly measures fuel consumption, vehicle speed, aerodynamic effects and many other parameters that impact the energy-balance on a moving vehicle. By doing so, the method greatly improves accuracy and repeatability to provide more trustworthy answers on fuel savings. MVTS has assessed the accuracy of their method in two primary ways. They have compared it directly to the J-1321 protocol and they have validated it using the real-world results obtained by their parent company in actual service over millions of miles on long-haul trucks. In the process, the MVTS method has uncovered several shortcomings of other fuel efficiency tests and the reasons behind those deficiencies. These insights have implications for the repeatability and accuracy of many kinds of replicate tests on in-use vehicles, including those using PEMS.

This presentation will describe the new fuel efficiency comparison method, how it has been compared to the J-1321 protocol and will give examples of projects that assessed the impacts of aerodynamic and other innovations in the transport industry.

Douglas Booker, National Air Quality Testing Services

Vehicle Interior Air Quality: Volatile Organic Compounds

The average person now spends more than 90% of their time indoors, with around one hour of this spent inside vehicles. This is referred to as Vehicle Interior Air Quality (VIAQ). This exposure is important to understand given the immediate proximity to significant pollutant sources (other vehicles), plus in urban areas, high outdoor concentrations. However, there are also significant sources of pollution from inside the vehicle. Volatile Organic Compounds (VOCs), responsible for the “new car smell”, can be emitted from an array of interior parts and components: the dashboard, interior panels, flooring materials, and many others. Within the confined space of a vehicle, VOCs emitted from these components may reach levels that are potentially harmful to human occupants, causing symptoms such as nausea, allergies, fatigue, stinging eyes, and headaches. Beyond affecting drivers’ and passengers’ well-being and comfort, such symptoms may have also consequences on safe driving.

NAQTS and Emissions Analytics have been developing the technology and methodology to deepen our knowledge of VOCs concentrations, sources, and species inside vehicles. Incorporating the latest developments in low-cost sensor technologies alongside thermal desorption gas chromatography mass spectrometry (TD-GCMS), we can better understand absolute concentrations, temporal signatures, and full speciation, resulting in a holistic understanding of VIAQ VOCs.

This presentation will focus on:

- The regulatory context of VIAQ
- The technology to measure inside vehicles: challenges and opportunities
- Initial findings - Characterising VOCs emissions from interior components
- How to effectively present this information to the general public

Nick Molden, Emissions Analytics LLC

The EQUA Index and use of PEMS for Optimal Market Information and Surveillance

The presentation will cover Emissions Analytics’ experience in using PEMS in the US and European markets. It will compare and contrast experiences between those two markets, through consideration of:

- The role of PEMS in identifying legal and illegal cycle-beating
- Characterizing off-cycle emissions
- Communicating real-world emissions of criteria pollutants to private and fleet buyers
- How the EQUA Index service for the North American market works
- Most effective presentation of real-world fuel economy and CO2 figures
- Optimal balance of randomness and predictability in PEMS testing, to be both authentic yet hard to cheat.

Andrew Burnette, infoWedge

RESULTS FROM, AND IMPLICATIONS OF A VEHICLE REMOTE SENSING PILOT STUDY IN EAST CENTRAL SCOTLAND

Hager Environmental and Atmospheric Technologies (HEAT) was contracted by East Central Scotland's Vehicle Emissions Partnership (VEP) to measure emissions from vehicles at several locations using HEAT's Emissions Detection and Reporting (EDAR) system. VEP is investigating various strategies for reducing pollution in "hot-spots" at the centers of large cities and the results of this pilot study were to help inform that effort. During 31/2 weeks in the spring of 2017, over one-hundred thousand valid measurements were collected at three sites. HEAT analysed the data and supplied two reports of the results for the two air pollution councils in the area.

EDAR uses a scanning laser technology to remotely measure the emissions of vehicles (e.g., CO_2, NO, NO_2 and $PM_{2.5}$), the temperature of their exhaust, their speed and acceleration and weather conditions as they pass under the unmanned system. Transcribed images of the measured vehicle license plates are matched to a registration database to obtain vehicle characteristics (e.g., model year, make, model, etc.). Those are then paired to the corresponding emissions data and the resulting database is analyzed.

In summary, the results of this pilot provided substantial evidence that the EU emissions certification classifications are not a reliable indicator of real world fleet pollutant emissions on the road. For example, many vehicles certified to the most stringent standards (Euro 6) emit up to six times higher than their certification standards. This result confirms similar results from other European studies using other methods. Perhaps even more interestingly, in spite of its short duration and relatively small sample (relative to the UK fleet size) the pilot study detected pattern design problems that result in certain vehicle makes and models emitting excessive pollution more frequently than other similar vehicles under similar operating conditions.

This presentation will briefly summarize the pilot project results, with a concentration on the patterns detected in the pilot database that result in certain vehicles emitting more in-use than their peers. A discussion of the likely impacts on pollution reduction strategies being considered in the Scotland (e.g., Low Emissions Zones and bus retrofits).

Carl Fulper, US EPA

UNDERSTANDING REAL WORLD ACTIVITY DATA FROM HEAVY-DUTY VEHICLES FOR USE IN EMISSION MODELS AND THE KEY DATA FIELDS THAT SUPPORT OUR MODELS

The Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator called MOVES is a publicly available tool used by researchers and policy makers to help understand motor vehicle emission sources at a national, county, and project level. EPA is continually seeking to improve its understanding and modeling of real-world vehicle operations.

As one step in improving our understanding, EPA analyzed data from two large heavy-duty vehicle databases containing activity data from 420 vehicles from the Department of Energy, National Renewable Energy Laboratory and 90 vehicles gathered by the University of California-Riverside's Center for Environmental Research and Technology for the California Air Resource Board's research on heavy-duty vehicles. These two datasets represent over 140,000 hours of operation.

Each dataset was analyzed separately and combined to provide a better understanding of the similarities and differences between the data sets. This presentation will provide the data analysis methods and results characterizing the vehicle speed distributions, idle activity, starts and soak periods of several types of heavy-duty vehicles. The presentation will also focus on key data fields that need to be gathered from potable activity measurement systems (PAMS) and portable emission measurement systems (PEMS) to be able to achieve analysis.

David Miller, 3DATX

The Democratization of Vehicle Emissions Testing

The discussion covers the early development of Portable Emissions Measurement Systems, and some of the early trials, tribulations, and obstacles as well as the early uses. Also, how the development of "1065", "NTE", and other global regulations shaped modern PEMS and how the VW Scandal has re-ordered the usage of PEMS. Some of the latest global trends, challenges, and a little "vision-casting" will be presented. Trends from similar industries will be reviewed as comparisons, and how they are shaping the vehicles we drive/are driven in.

Imad A. Khalek, Southwest Research Institute

Evaluation of an On-board High-Sensitivity, Real-time Electronic Particulate Matter Sensor Using Heavy-Duty On-Highway Diesel Engine Platform

The California Air Resources Board (CARB) has instituted requirements for on-board diagnostics (OBD) that make spark-plug sized particulate matter (PM) sensors a critical component of the OBD system to detect DPF failure. Current PM OBD thresholds for heavy-duty on-highway vehicles is 0.03 g/hp-hr and for light-duty vehicles (2019+ Model Year LEV III) is 17.5 mg/mile. While the OBD threshold for heavy-duty vehicles is three times the laboratory standard, the threshold for light-duty vehicles is 5.8 times the current laboratory standard and 17.5 times the LEV III laboratory PM standard set for 2025. Thus, there is a need for high-sensitivity particle sensors to transition the light-duty OBD threshold to a current level of 9 mg/mi and a future level of 3 mg/mi. The ultimate goal is to have the same emissions in the laboratory and the real world, putting the sensor detection limit at 0.01 g/hp-hr and 1 mg/mi for heavy-duty and light-duty applications, respectively.

To meet current regulations, and potentially more stringent future regulations, real-time high sensitivity PM sensing offer a tremendous opportunity. The focus of this presentation is on the experimental evaluation of such real-time PM sensors manufactured by CoorsTek LLC. A 2011 model year on-highway heavy-duty diesel engine fitted with DOC/DPF/SCR/AMOX was used for the evaluation program. Sensors were tested at an emission level of ~ 0.02 g/hp-hr using five repeats each of FTP, NRTC, WHTC and RMC drive cycles. Exhaust emission levels were tuned using a bypass DOC flowpath fitted in parallel to the stock aftertreatment system. Eight sensors were benchmarked against state-of-the-art laboratory particle instrumentation that served as references. AVL micro-soot sensor (MSS) was used for realtime soot mass measurement and TSI engine exhaust particle sizer (EEPS) coupled with SwRI's solid particle sampling system (SPSS) was used for realtime solid particle number and size measurement. Additionally, CFR Part 1065 compliant PM filter measurements were performed from full flow CVS tunnel. Performance of sensors was compared with that of reference instrumentation to examine their accuracy and variability as well as lower detection capability on a concentration basis, flux basis and brake specific emission basis. Transient cycles were analyzed over multiple window lengths varying in particle emissions and ranging from 100 seconds to the entire cycle length. Relationships between sensors and reference instrumentation for each window was analyzed. Sensor to sensor variability along with sensor response to each drive cycle was studied. Further, sensor response was studied on a global basis with disregard to drive cycle.
This work should shed some light on the potential of using OBD sensors under current regulatory requirement and future more stringent OBD threshold and emissions monitoring requirements. The PM sensor evaluated in this program seems to offer an opportunity in lowering the OBD threshold to protect the public from higher PM emission exposure.

Karl Ropkins, University of Leeds

Particulate Sensing: Recent Work, Early Observations and Future Directions

Properly developed and deployed, smaller more-affordable PEMS systems could revolutionize our sector, significantly extending both the scope and scale of our real-world data gathering activities. The benefits for both emissions inventorying and modelling efforts are most apparent. However, the new technologies this work commercializes also have significant potential to filter out into multiple complementary applications, e.g. tools for Inspection and Maintenance (I&M) programs, expert systems for vehicle repair, vehicle fleet benchmarking, and engine and emission abatement system manufacturers in-house activities.

With this as our point-of-reference, we report on recent work on particulate measurement, the strand of PEMS instrument development with perhaps the greatest 'roll-out' potential. Firstly, briefly updating on previously reported work, we highlight the potential of monitoring strategies that integrate small sensor arrays and robust data handling to provide both conventional performance metrics (like concentration profiles and emission rates) and also multi-dimensional information that could provide diagnostic insight into the underlying problems driving higher emissions. Then we provide an overview of on-going work to characterize sensor performance with respect to particulate and exhaust gas properties and also, perhaps more importantly, address sensor-by-sensor variation because quality assurance is one of the hidden issues that needs to be considered when working with low-cost sensors. We also consider the analytical compromises required to build an instrument suitable for use in, for example, I&M or commercial garage practices at a price-point that will make it viable, as well as the possible benefits of at-point-of-repair vehicle emissions measurement.

Finally, we end with one example, a recent finding, that illustrates the inherent value of all such efforts to evolve our emission monitoring capabilities.

Shun Fukami, Horiba Ltd.

Development Tools for Advanced On-Board Emissions Measurements of NMHC and Particulates, Plus a Coaching Tool for Increasing RDE Test Yield

Since the introduction in 2013, HORIBA continues to develop and refine the modular components and software that comprise the OBS-ONE line of PEMS products. OBS-ONE already meets the global requirements for certification, type approval and in-service conformity (US HDIUT, Euro VI and 6d) including gaseous, particle mass and particle number measurements. HORIBA recently introduced a new FID module, designated MA, that includes simultaneous measurement capability of both THC and methane. The MA utilizes the common non-methane cutter method for methane determination; facilitating direct on-board NMHC determination. An overview and performance evaluation of the MA are presented. HORIBA's OBS-ONE-PN utilizes the robust condensation particle counting (CPC) methodology and is already widely used in Europe for RDE testing. Given the current heavy focus on sub 23 nm particles, a production PN was modified to include detection of smaller particles in order to evaluate the feasibility of on-board measurement of these sub 23 nm particles. An overview and performance evaluation of the modified PN are presented. On the software front, HORIBA has recently introduced a new coaching tool, designated RDE+ Coach, that assists drivers with conducting official RDE tests by real-time monitoring of their trip specific and boundary specific progress. RDE+ Coach is available for common mobile platforms and can be used in conjunction with PEMS or stand-alone. RDE+ Coach has the potential to significantly improve valid RDE test yield. An overview of RDE+ Coach is presented.

Leta Woo, Emisense

Application of PMTrac® Sensors for Low-cost PM Threshold Testing

Particulate matter (PM) sensing technologies are needed to ensure the proper functioning of gasoline or diesel particulate filters (DPFs), which remove soot from the exhaust and can become compromised during vehicle operation. In-situ sensor technologies that directly measure exhaust are typically based on either resistive techniques that detect soot accumulation or electrostatic methods that determine real-time particle concentrations.

We present work investigating the use of low-cost electrostatic sensors for fast threshold testing to augment current opacity tests used to detect compromised DPFs, either in "Smog Shops" or as cellular-enabled continuous monitoring devices. For this study, we present data collected by Southwest Research Institute (SwRI) and other EmiSense partners utilizing sensors based on PMTrac® technology. We further present possible system architectures and test methodologies for rapid remote detection of PM.

Ronald Wankers, AVL

RDE 3 - A challenge for the vehicle and the PEMS

The European RDE Regulation has a substantial impact on the range of the environmental conditions under which both the PEMS systems and the vehicles need to be compliant. Real driving conditions include widely changing ambient pressure conditions (altitude) as well as widely changing operating temperatures, e.g. during cold start operation. Today regulators are developing extended specifications for PEMS systems which are taking these situations into account. Data which verifies compliance of the AVL MOVE GAS PEMS iS will be shown.
On the other hand side, also the vehicles which are to be brought into the market are strongly challenged today. It is becoming obvious that the vehicle development process, as it is lived today will not allow to guarantee compliance with the extended requirements. Important new phases of the AVL “RDE Development Process” will be shown.

March 23rd, 2018
Day 2 Abstracts:

<u>Andre Forcetto</u>
Developing Real Driving Emissions For Brazilian Reality

There is a big concern in the European Union (EU) with the fact that the emissions of regulated pollutants by passenger cars (PC) under actual conditions of use can be about 7 to 40 times higher than that found in laboratory type-approval tests, leading to the need to control NOx and particle number (PN) emissions in the real world. Evaluating Real Driving Emissions (RDE) with portable emissions measurement system (PEMS) is also important to ensure that a manufacturer doesn't use fraudulent solutions in order to achieve legal standards. RDE is growing in importance all over the world; in Brazil there is a forecast that RDE can be introduced for PC type-approval proposes in some years, mainly based on EU legislation. However, it is necessary to understand the differences between Europe and Brazil to develop a RDE procedure that actually brings an effective environmental gain. Thus, the goal of this paper is to show the Brazilian RDE characteristics and discuss how European RDE should be adapted or complemented to local reality. The typical EU profile considers, among other factors, topography with plains with median altitude bellow 350 m, Diesel engines in PC and NOx and PN as main pollutants, when in Brazil, firstly, topography has a lot of hills and valleys in some important big urban areas with altitude close to 1,000 m; second, there is high concentration of vehicles in metropolitan regions and consequently constant traffic jams, low average speeds and short travels; third, Diesel is prohibited for PC; fourth, gasoline has an addition of 22% of ethanol (the highest proportion in the world) and ethanol 100% is also commercially available; fifth, in the Brazilian fleet most automobiles are flexfuel (able of burning any proportion of gasoline and ethanol) and motorcycles are a significant part of the fleet. Finally, the main air pollution problem in Brazilian metropolitan regions, such as Sao Paulo, is ozone (O3) and fine particulate matter (PM2.5), both secondary pollutants that have as precursors NOx, emitted mainly from heavy duty vehicles (HDV) and industries, and volatile organic compounds (VOC) coming from evaporative losses and unburned fuel from PC. Therefore, due to these Brazilian specific characteristics, RDE procedure cannot be the same as the European RDE and must be rethought in at least six points: 1) boundary conditions: higher altitude and ambient temperature must be accepted as "normal", as well the limit for cumulative positive altitude in the test trip shall be extended; 2) test circuit: can be shorter because only urban and rural trip is enough to cover almost all PC utilization; 3) average speed: shall be lower, even in main avenues is difficult to keep within the right interval; 4) pollutants: future legislation in Brazil tends to evaluate PN just in laboratory tests, by other hand the control of hydrocarbons and NOx in RDE tests is very important; 5) flexfuel vehicles: the different levels of pollutants produced from ethanol or gasoline shall be taken into account, so that both fuels must be evaluated for type-approval proposes; and 6) motorcycles account for about 15% of metropolitan traffic and still grow while PC fleet is stable, so PEMS must be lightweight and compact at a point to be able to mount it on a motorcycle and so include this important group in RDE controls. There is a long way to implement RDE in Brazil with many and complex factors in sight but it is possible and very important to do so because RDE / PEMS will certainly bring environmental improvements.
Key-words: air pollution, vehicular pollution, Real Driving Emission, PEMS

Cavan McCaffery, UC Riverside

Real-World Evaluation of PM and PN Emissions from Light-duty GDI Vehicles Using PEMS

Many studies have shown that the atmospheric pollution levels of particulate matter (PM) are not decreasing despite the introduction of stricter vehicle emission regulations. The difference between conditions of the type approval cycles defined by the vehicle emission regulations and the real driving can contribute to the differences between expected and actual pollution levels. This has led to the introduction of in-use vehicle emission monitoring and regulations by means of portable emissions systems (PEMS). With recent developments in the US and the European Union (EU), PEMS is becoming an important regulatory device. Both the Environmental Protection Agency (EPA) and the California Air Resource Board (CARB) have begun testing the ability of PEMS to accurately measure real driving emissions.

There is currently a widespread concern about the actual particulate emissions of gasoline direct injection (GDI) vehicles, which have dynamically penetrate the US market and are expected to eventually replace the less efficient port fuel injection (PFI) vehicles. Although GDI engines are knows to significantly improve fuel economy and lower greenhouse gas emissions (GHG) when compared to PFI engines, they produce higher PM emissions due to the direct spray of gasoline into the combustion chamber. This leads to locally rich, diffusion-governed liquid fuel combustion that creates more PM formation. Gasoline particulate filters (GPFs) are an effective route to reduce the PM mass and the number of ultrafine particles under a range of driving conditions and at the same time meet California's PM mass emission standards.

The objective of this study is to examine the PM mass, black carbon, particle number, and gaseous emissions of a current technology GDI vehicle during on-road testing with and without a catalyzed GPF. Testing was performed on three routes with different topological characteristics, representing urban, rural, and highway driving conditions. The vehicle was tested in triplicated in downtown Los Angeles, Mt. Baldy, and in San Diego. The results of this work will be discussed in the context of the impact of GPF and driving patterns on tailpipe emissions and fuel economy.

Chris Frey, North Carolina State University

Comparison of Real-World Vehicle Emissions for Gasoline-Ethanol Fuel Blends

Most gasoline sold in the U.S. is a 10-percent by volume blend of ethanol with gasoline, referred to as E10. Commercially sold gasoline-ethanol blends are "match blended," which means that the gasoline blend stock is refined to a different composition than neat gasoline so that after it is blended with ethanol it meets a fuel supplier target composition. In contrast, ethanol could be "splash-blended" with gasoline, in which neat gasoline is used as a blend stock. Furthermore, fuels can be refined and blended to achieve a particular octane rating. In electronically-controlled fuel injected engines, ignition timing advance is controlled as a function of engine load and may be set differently depending on fuel properties. Thus, for example, ignition timing advance may be different as a function of octane rating. Differences in ignition timing affect time-temperature history of gases in the cylinder, which can affect combustion efficiency and engine-out emissions. The purpose of this study is to evaluate the effect of different gasoline-ethanol blends on real-world fuel use and emission rates. Methodology includes measuring five vehicles using Portable Emission Measurement Systems. Each vehicles was measured on four fuel blends, including neat gasoline (E0), 10% ethanol by volume (E10) "regular" (E10R) and "premium" (E10P), and 25% ethanol by volume (E25). E10P and E10R differ in octane rating. Physical and chemical properties of each fuel were measured by a third party laboratory. Real world measurements were conducted for each of the 20 vehicle-fuel combinations on a 110 mile route in the Raleigh, NC area using a HEM Data OBD mini-logger, GPS receivers with barometric altimeters, and two portable emission measurement systems (PEMS). The PEMS include a GlobalMRV Axion R/S and a 3DATX ParSYNC. The Axion measures exhaust concentrations of CO_2, CO, and HC using non-dispersive infrared, NO using an electrochemical sensor, and PM using a laser-light scattering method. The ParSYNC measures CO_2 using NDIR, NO and NO_2 using electrochemical cells, and PM using three detection methods based on light-scattering, ionization, and opacity. After defueling, each vehicle underwent a 25 mile conditioning cycle on the next fuel. Second-by-second emission rates were binned into Vehicle Specific Power (VSP) modes, and the modes were weighted according to average real world cycles and selected speed trajectories commonly used in chassis dynamometer measurements. Cycle average fuel economy and emission rates are compared among the four fuels and five vehicles.

Marc Besch, West Virginia University

REAL-WORLD EMISSIONS FROM HDIUT PROGRAM - NTE VS WORK-BASED WINDOW, SENSITIVY AND LIMITATIONS OF THESE METHODS

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The introduction of the heavy-duty in-use testing (HDIUT) program by the United States Environmental Protection Agency (U.S. EPA), in collaboration with heavy-duty engine/vehicle manufacturers, changed the paradigm of engine certification by augmenting it with emissions compliance under real-world operating conditions. In order to provide real-world emissions assessment for heavy-duty vehicles during typical operation a quantification method to compare results to a pre-defined compliance threshold, namely the NTE method, had been developed. Similarly, the European Union (EU) introduced a method to quantify in-use emission using a work-based window (WBW) approach. Both methods are subject to a range of definitions and exclusions that are governed by pre-defined boundary conditions. While the WBW method was introduce at a later stage, the NTE method was developed by the U.S. EPA more than a decade ago and was based on engine and after-treatment technology as well as driving conditions and vehicle usage patterns that were present during the inception of the in-use compliance program.

As technology has dramatically changed, it is of importance to explore the impact of boundary conditions and subsequent method modifications that could lead to more robust quantification tools.

The NTE-based method to evaluate real-world data for emissions compliance has come under scrutiny by both OEMs and regulators because of a large amount of data being discarded from the analysis. As such, the primary objective of this study was to perform a detailed parametric analysis on both NTE and work-based-window emissions-quantification methods to understand the relative sensitivity of different parameters. This analysis was then used to identify short-comings of the existing compliance methodology and provide a basis for development of possible modifications to the relevant requirements.

The in-depth analysis of this large amount of real-world vehicle operating data will elucidate on conditions where the NTE and WBW methods might not adequately characterize in-use emissions. To this extent, threshold limits for data exclusions and boundary definitions for the Not-to-Exceed control area were exercised over a wide range of conditions. A fractional factorial design of experiments approach was then used in conjunction with ANOVA analysis to understand interactions between different boundary parameters. The corollary provided a means to identify the most dominant parameter that affect number of valid NTE events or work-windows with respect to event/window-averaged NO_x emissions.

Stephanie Maalouf, California Air Resources Board

Constraining Variability of On-road Emission Testing for Light Duty Vehicles

While dynamometer testing is highly controlled and reproducible, on-road PEMS (Portable Emissions Measurement Systems) testing presents the real world driving patterns and emissions. Real-world emission testing of light duty vehicles using PEMS has been increasing exponentially since it provides invaluable information on real-world emission rates and engine performance. Although highly variable, PEMS testing has been key in discovering anomalies in emissions and in finding defeat devices used by manufacturers.

On-road PEMS testing has presented its own challenges relating to testing variability. The California Air Resources Board (CARB) has conducted extensive PEMS testing on various light-duty vehicles including a study correlating PEMS to dynamometer and other various studies with on-road PEMS testing under different variabilities that are faced in the real-world such as various loads experienced by the vehicle, usage of cabin climate control, etc. Other variables include but are not limited to traffic patterns, driver characteristics, altitude changes, idling periods, soak time, and differing ambient conditions.

These studies show how the differences in on-road PEMS emissions on similar tests are a result of either the different sources of variabilities or from the vehicle's output. It will also show how some of these factors have only negligible effect on most vehicles, but that other factors can significantly affect measured emission rates.

<u>Harry Bradley,</u> Cambustion Ltd.,

Transient RDE NOx Emissions from Gasoline and Diesel Vehicles

Transient emissions are a defining feature (and possibly the greatest challenge) of RDE testing. A set of two-channel fast response gas analyzers has been adapted for on-board use with resolution advantages over standard PEMS equipment for fully and accurately measuring transient emissions and aligning them with other engine control parameters. With response times of just a few milliseconds, the simultaneous measurement of pre- and post-catalyst emissions provides real time catalyst conversion efficiency and the combination of the fast tailpipe data with GPS provides accurate street positioning of pollutant "hot spots" with high spatial accuracy. Example data recorded from conventional gasoline, diesel and PHEV vehicles shows the effect of speed bumps, traffic signals, start/stop and general congestion on emissions. The plotting of the emissions "spikes" against air-fuel ratio and other ECU parameters provides insight for engine calibrators in to their causes and possible solutions.

<u>Xin Wang, Beijing Institute of Technology</u>

Development of Emission Factors for Inland Vessels in China

This presentation summarizes the inland vessel emission factor development work conducted by Beijing Institute of Technology armed with Vehicle Emission Control Center, Ministry of Environmental Protection. Unlike ocean-going vessels, inland vessels are small in size, old in engine technology but enormous in preservation. Typical operating conditions of inland vessels only comprise arrival, cruise and departure, which differ from OGVs since inland vessels usually have no auxiliary engine on-board. Concentration peaks of CO, HC and PM emissions were found mainly during arrival and departure maneuvering due to frequent changes in engine load. NOx emissions were also high during maneuvering, and maintained at a considerately high level in cruise condition. High concentrations of particle number emission with Dp smaller than 0.1 micron were noticed in maneuvering conditions, which could be a contributor to fine particle contamination of surrounding cities. Compared to downstream cruise, upstream cruise could give much larger emission factors, and PM emission was in particular sensitive to the direction of water flow. On a ton-kilometer basis, emission factors of CO, HC and NOx for an average inland vessel are about 1 to 3 times higher than those for a China-III certified bus. However, such a difference could be as high as 17 to 47 times in terms of PM emission.

<u>Shaojun Zhang, Tsinghua University</u>

The Challenge to Emission Controls and Recent Development of PEMS Regulations for Heavy-duty Vehicles in China

Heavy-duty vehicles (HDVs) are important sources of ambient PM2.5 pollutions in China, and adversely increase public health and climate burdens. Since 2005, researchers in Tsinghua University have worked independently or together with collaborators to collect real-world emission factors for HDDVs in China by using portable emissions measurement systems (PEMSs) 1-3. Previous measurement profiles during 2008- 2012 supported the development of the first version of a national emission inventory (NEI) guidebook for road transportation sector, which was released by the Ministry of Environmental Protection in 2015. A notable finding revealed the significant challenge to NOX emission controls for HDVs then (Pre-China IV HDVs and China IV SCR-equipped buses), whose real-world NOX emissions were not improved as regulations became increasingly stringent 1.In the past five years, China has been making tremendous efforts to improve ambient air quality and mitigate pollutant emissions. Emission controls of HDVs are one of the prioritized tasks required by Chinese central and local governments. Not only China IV and China V HDV emission standards have been fully implemented to tighten the controls of NOX and PM emissions, but also national-level PEMS testing protocols (China V and VI) are under development to enhance in-use conformity. Researchers in Tsinghua University are funded by Ministry of Science and Technology and other agencies to further enlarge the PEMS dataset, develop specie-resolved PEMS methods 4-5, and improve emission models for policy decisions (EMBEV-series models and NEI guidebook). Meanwhile, vehicles instrumented by fast-response pollutant analyzers are developed as mobile measurement platforms to chase on-road HDVs. This chasing method is cost-effectively capable of monitoring emissions for massive individual vehicles 6, and the reliability and accuracy are confirmed by comparative tests with PEMS method. These recent on-road measurement studies, using PEMS 7 or/and chasing, indicate that China IV HDVs have show little to none improvement in real-world NOX emissions compared with the China III counterparts, although they claim to adopt SCR systems as required by the regulations. According to black carbon measurement profiles the progress on PM emission controls on HDVs in China is significant, yet high emitters are still in presence due to the usage of fraudulent engines. Lean-burn nature gas engines without NOX aftertreatment are widely used by public transit buses in China. However, the real-world NOX emission factors of these nature gas buses are comparable or higher than diesel buses. Therefore, our recent on-road HDV measurements illustrate widespread problems with implementing China IV standard. Comprehensive PEMS programs supplemented by other on-road testing protocols (e.g., OBD provisions, chasing, remote sensing) are required to further tackle the unalleviated challenge to NOX emission controls for HDVs in China.

SHORT COURSE:

A Brief Overview of Ground-level Ozone Pollution

Presenter: William Porter, UC Riverside

As a secondary pollutant, ground-level ozone is generally not emitted directly from human activity, but rather through chemical reactions involving both natural and anthropogenic precursors. While the underlying chemistry of ozone formation is relatively straightforward, the diversity of local emissions, meteorology, long-range transport impacts, and other region-specific factors around the world can make it difficult to understand and predict how changes in human activity will affect ozone pollution trends at any given location. Here we will discuss some of the basics of ozone formation, transport, and loss, and identify some of the key factors used to determine the sensitivity of local ozone levels to changes on the surface.

2018 PEMS Poster Abstracts:

Spatial Variation of Real-World Microscale Vehicle Activity and Emissions

Tanzila Khan, North Carolina State University

Quantification of the spatial distribution of 1 Hz (microscale) vehicle emissions is needed to help identify emission hotspots and to target measures to reduce hotspot intensity. To provide insight regarding why the emission hotspots occur, it is useful to identify concurrent spatial trends for potential explanatory vehicle activity variables including speed, acceleration, road grade, and Vehicle Specific Power (VSP). Assessment of the role of such vehicle activity metrics in contributing to hotspots helps decision makers, transportation experts, and air quality experts develop strategies to reduce emission rates. Thus, the objectives are to: (1) identify real-world microscale vehicle emission hotspots; and (2) investigate spatial trends of explanatory variables associated with hotspot.

North Carolina State University (NCSU) conducts real-world emission measurements of light-duty gasoline vehicles (LDGVs) using Portable Emission Measurement Systems, an on-board diagnostic scantool, and global positioning system receivers with in-built barometric altimeters. LDGVs have been measured on designated study routes comprised of 110 miles of driving, originating from NCSU to Research Triangle Park via North Raleigh. These routes include minor arterial, major arterial, and freeway, road types with posted speed limits varying from 25 mph to 70 mph. Furthermore, the routes includes junctions featuring signalized intersections, roundabouts, and ramps. The road grades along these routes vary within ±10%. From the measurements, second-by-second vehicle activity and emissions have been quantified, including vehicle speed, acceleration, road grade, VSP, and rates of fuel use and emissions of nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO2). In previous work, spatial resolution was evaluated based on various segment lengths to identify the most useful segment length for locating emission hotspots. Segments of ¼ mile length were found to be the best trade-off between high spatial resolution versus adequate 1 Hz data sample size per segment.

ArcGIS 10.3.1 will be used to analyze the spatial variation of real-world microscale vehicle activity and emission rates based on one LDGV measured on the 110 mile study route. For each ¼ mile segment, the second-by-second mass emissions will be summed and divided by travel distance to estimate the segment average grams per mile emission rates of each pollutant. Emission hotspots for each pollutant will be identified based on the cumulative frequency distribution of the segment average emission rates. The threshold for emission hotspots will be based on the 90th percentile of inter-segment variability in emission rates. The correlation in inter-segment emission rates with segment average vehicle activity, including average speed, average positive acceleration, average road grade, and average positive VSP, will be assessed. The average and range of segment emission rates will be compared among road and junction types. Categorical and Regression Tree (CART) analysis will be used to identify the combination of vehicle activity metrics that lead to high emission rates associated with the hotspots.

Train Speed Trajectory Simulation Based on Real-world Measured Train Speed Trajectory Data

Weichang Yuan, North Carolina State University

Speed trajectories are a critical input for modeling second-by-second fuel use and emissions of diesel-electric trains. Train speed trajectories can be measured using Global Positioning System (GPS) receivers. Such measurements can be made for individual trips to evaluate the corresponding fuel use and emission rates. Trip speed trajectories can vary from one run to another. However, the quantification of inter-run variability speed trajectories based on measurements may not be practical due to budget, time, and resource constraints. Furthermore, it may not be possible to measure speed trajectories for all segments of a trip using GPS receivers, for example, if portions of the trip are in tunnels. The purpose of this study is to demonstrate a method to simulate multiple speed trajectories for each segment of a diesel-electric train route based on a sample of measured speed trajectories.

The Amtrak Piedmont passenger rail service between Raleigh and Charlotte, NC is used as a source of calibration and validation data for the trajectory simulator. There are 16 unique segments on this route. A segment is defined as the one-way path between two adjacent stations. Speed trajectories were measured by riding the trains with GPS receivers. The measured speed trajectories were post-processed to remove outliers and noise using cubic-spline interpolation and the Savitzky-Golay filter, respectively. Ten processed speed trajectories for each of the 16 segments were used as calibration data for the simulator. The simulator generates 100 speed trajectories for each segment by mimicking the Markov Chain process. The simulation randomly samples from the range of empirically-observed transitions of speeds and accelerations on a second-by-second basis. The 100 simulated speed trajectories are constructed based on acceleration, cruise, and deceleration modes to match the known segment travel time and distance. An out-of-sample set of 10 additional trajectories for each segment is used to validate the simulated trajectories. As validation, the sum of square errors (SSE) based on comparing speed versus distance between simulated and measured speed trajectories will be calculated. Empirical cumulative distribution functions (CDFs) of SSE for each segment will be plotted. To demonstrate inter-run variability in energy consumed per segment, energy consumption indices accounting for the energy consumed by starting resistance, running resistance, and acceleration resistance will be calculated for each segment. Box-and-whisker plots will be used to display variations of the energy consumption indices for the 16 segments.

Development of a Multicomponent Mixture Containing NO and NO2 for RDE Testing

Anuj Kumar, Air Liquide

The Real Driving Emissions (RDE) test based on the application of portable emissions measurement systems (PEMS) aims to measure emissions from a vehicle while it is driven on the road. With the growing focus on RDE testing, the requirement to analyze both Nitric Oxide (NO) and Nitrogen Dioxide (NO2) as well as other pollutants such as carbon monoxide (CO) and carbon dioxide (CO2) have become important for on-road testing. European Commission has also developed this complementary Real-Driving Emissions (RDE) test procedure and introduced in 2017 to meet 'not to exceed' emissions limits along with a conformity factor. Correct measurement of these pollutants in vehicle emissions using PEMS require calibration protocols and accurate calibration gas standards. Minimizing the number of calibration gas mixtures required for the calibration of PEMS analyzers can provide a huge advantage in terms of calibration time and transportation convenience. Therefore, Air Liquide developed a multicomponent gas mixture containing NO, NO2, CO and CO2.

Producing these multi-components mixtures containing both NO and NO2 with defined stability is challenging so far due to their gas phase reaction and reaction with internal surface. However, the challenges have been overcome by employing a specialized cylinder treatment and filling method. In this work, we present a shelf-life study of a gas mixture containing 2,800ppm NO, 900ppm NO2, 4.5% CO, and 17% CO2 in balance nitrogen. Multiple cylinders filled at the same time were analyzed at regular time intervals to monitor the concentration of each molecule for over one year. This multicomponent gas mixture was produced successfully. This cylinder treatment technology along with the filling protocols allowed stability of the gas mixture with in 2% of accuracy for each batch. These stable mixtures will help PEMS users in simplifying their calibration protocols on standard process or specific application such as the RDE for vehicle emissions testing.

Reducing No_x emissions FROM GENERATORS in London, USING SCR TECHNOLOGY AND HYBRIDISATION OF THE FLEET

Carl D. Desouza, King's College London

The London Atmospheric Emissions Inventory attributes 7%, 11%, and 2% to NO_X, $PM_{2.5}$, and CO_2, respectively, to non-road mobile machinery (NRMM) in London [London Data Store, https://data.london.gov.uk/]. Generators are one of the most commonly used types of NRMM on construction sites, and the register of construction machinery for London [www.nrmm.london] quantifies generators as the 4th most common NRMM type, which is 6% of the fleet. They therefore contribute significantly to NO_2 and $PM_{2.5}$ pollution problems in London, which is a major concern for public health. Exhaust after-treatment technologies to reduce NO_X are being trialed on constant speed engines, to improve air quality from construction sites. The use of diesel-battery-hybrid generators is also being promoted as a way of reducing the impact of air pollution, as well as saving fuel. This study aimed to compare the emissions from diesel generators with and without exhaust after-treatment, and diesel-battery hybrid systems, during operation.

Emission factors of seven generators with different capacities (60, 80, 100, 125, 200, 320, and 500 kVA) were measured using a UN-ECE R-49 & Commission Regulation (EU) No. 582/2011 compliant portable emissions measurement system (PEMS). The engines used by the generators varied in age (MY 2011 to 2015), engine size (48kW to 400kW), and operational hours (1962 to 18,708 hours). The ISO 8178 standard D2 cycle was used to test the generators, which were all Stage III-A, since older stage constant speed engines are no longer approved for use in Greater London [GLA's Supplementary Planning Guidance, 2014]. Measured emission factors showed that minimum NO_X emissions were recorded at 25-50% engine operation. Selective catalytic reduction (SCR) was trialed as an exhaust gas after-treatment, for the 320kVA generator, and the emissions factors were compared with the pre-SCR trial emissions factors.

The measured emission factors were coupled with the register of construction machinery and activity data, to quantify the emissions from generators in London. This resulted in emissions of 186.08t NO_X, which corresponds to 5.9% of the NRMM current emissions inventory. The SCR emission factors were applied to the >100kVA generators. This resulted in emissions of 54.32t NO_X, which corresponds to 1.73% of the NRMM current emissions inventory.

To assess the impact of hybridization of the generator fleet, activity data was acquired from a generator hire company, which detailed hourly site load demand, as well as hybrid and diesel generator operation. The measured emission factors were coupled with this activity data to assess whether adopting hybrid technology reduces emissions of NO_X, $PM_{2.5}$, and CO_2, compared to standard diesel generator use. Only data for generators less than 100kVA were available, but these showed that hybridization decreased the emissions of NO_X by 9%, $PM_{2.5}$ by 11%, and CO_2 by 10%. This takes into consideration the non-linearity in the emissions relative to the power output and the inherent round trip efficiency of the battery charge and discharge cycle.

If hybridization were rolled out to the <100kVA generator fleet in London, it would decrease emissions by 2.9% for NO_X. If SCR were implemented to >100kVA generator fleet in London, it would decrease NO_X emissions by 70%.

Comparison of Three Commercially Available PEMS for Locomotive Emissions Measurement

Nikhil Rastogi, North Carolina State University

Diesel engines used for passenger service emit a suite of pollutants including NO_x, PM, CO, and HC.

Locomotive tests in the U.S. include exhaust gas and PM concentration measurements. As an alternative to certification tests conducted at a limited number of facilities, measurements can be conducted at the railyard (RY) or over-the-rail (OTR) using Portable Emission Measurement Systems (PEMS). In RY tests, the locomotive is operated at steady state for a pre-defined duration at each of the throttle notch positions. Real-world locomotive operation involves shifting among throttle notch positions during transient operational conditions. Thus, the OTR tests are more representative of actual train operation and are preferred for quantifying emissions.

Space constraints, high temperatures in the engine compartment, and safety considerations in the locomotive cab motivate selection of PEMS for OTR measurements. Several different PEMS models are available commercially. Each of the PEMS has a different size, weight, sensors functionality, cost, accuracy and precision. The goal of this study is to compare three commercial PEMS for locomotive emission tests: (1) a 1065-compliant PEMS; (2) a mini-PEMS; and, (3) a micro-PEMS.

SEMTECH-DS manufactured by Sensors Inc. is a 1065-compliant PEMS. It uses Non-Dispersive Infrared (NDIR) for measuring CO_2 and CO, Heated Flame Ionization Detection (HFID) for HC, and non-dispersive ultraviolet to measure NO and NO_2. The Axion PEMS manufactured by Global MRV is a mini-PEMS. It measures CO_2, CO, HC, NO and laser light scattering PM. The Axion uses NDIR to measure CO_2, CO and HC, and electrochemical cell to measure NO. A parSYNC PEMS manufactured by 3DATX Corporation is a micro-PEMS. The parSYNC consists of three PM sensors based on ionization, light scattering, and opacity. Each sensor records voltages corresponding to different PM size distributions. The parSYNC also measures CO_2 using NDIR, and NO and NO_2 using electrochemical cells. It does not measure CO and HC, which are typically very low in diesel exhaust. These three PEMS will be compared side-by-side based on RY measurements of a 3,000 hp prime mover engine for an F59PH locomotive. The comparability of the measurements will be assessed. Other factors, such as ease of installation and operation, will also be compared.

Real-world Emissions of Gaseous Pollutants from City Taxis in China

Liqiang He, Tsinghua University

On-road vehicle emissions are one important air pollution source resulting in significant health impact. Among the on-road vehicles, light-duty gasoline vehicles (LDGVs) are estimated to contribute 70% of total automobile carbon monoxide (CO) emissions, 75% of total hydrocarbon (THC) and 30% of nitrogen oxides (NOX) in China. For the sake of environment, governments have made a lot of efforts to control LDGV emissions, and city taxis are one important fleet of great concern. Although taxi vehicles account for a small proportion of total LDGV population (e.g., 1% in Beijing), their annual mileage levels could be higher than private passenger cars by ten times. High use-intensity and associated risks of emission deterioration triggered considerably greater tailpipe emissions from city taxis in China. To investigate real-world gaseous emissions characteristics (CO, THC and NOX) of high-use-intensity taxis in China, we applied portable emissions measurement systems (PEMSs) to measure 63 taxis in six cities during 2008-2016. These tested taxi vehicles comply with China 3 to China 5 emission standards. The results indicate that the average emissions factors for CO, THC and NOX are significantly reduced from China 3 to China 5. Nevertheless, only newer China 5 taxis could have lower real-world emission factors than the regulatory limits in laboratory (e.g., NEDC procedure), and a major part of China 3 and China 4 taxis far exceed the limits. For example, the conformity factors of NOX emissions, defined as the emission ratios of real-world emission factor to regulatory limit, could be up to 30 for China 4 taxis with extremely high mileage levels (e.g., >600,000 km). A good correlation is identified between CO and THC (R2=0.71) for all the tested taxis, while correlations between NOX and CO/THC are less significant. The TWC converters are efficient after-treatment devices to control the exhaust emissions from gasoline vehicles. Deterioration, malfunction and illegal tampering of three-way catalytic (TWC) converters all could led to high emissions of taxis vehicles. For example, the average emissions factors of CO, THC and NOX for China 4 taxis with TWC malfunctional OBD warnings are higher than those of normal China 4 taxis by 11 times, 19 times and 6 times, respectively. Therefore, TWC renewal programs for high mileage taxis are implemented in some megacities (e.g., Beijing, Shenzhen. In this study, comparative experiments of five China 3 taxis with deteriorated and renewed TWC converters were conducted. The results show that their emission factors of CO, THC and NOX are reduced by 76%, 77% and 63% after using new TWC converters, and below the regulatory limits. We suggest that future real drive emissions (RDE) rules in China consider to add CO limits to enhance in-use compliance requirements for CO and THC. For LDGVs in other cities, the TWC renewal programs for taxis should be followed to improve emission controls for high mileage gasoline vehicles.

Characterizing Particulate Polycyclic Aromatic Hydrocarbon Emissions from Diesel Vehicles Based on a PEMS

Xuan Zheng, Tsinghua University

Increasing evidence has been reported showing strong associations between heavy duty diesel vehicle (HDDV) emissions and adverse health impacts. The International Agency for Research on Cancer (IARC) has upgraded the carcinogenicity of diesel emissions from Group 2A (probably carcinogenic) to Group 1 (carcinogenic with sufficient evidence) and highlighted the additional health impacts caused by diesel particulate matter (DPM), which is a complex mixture of carcinogenic chemicals such as polycyclic aromatic hydrocarbons (PAHs). Particulate PAHs (p-PAHs) emitted from diesel vehicles, present in respirable size ranges, in urban areas are of particular concern because of their higher intake fraction than other diesel emission sectors. Laboratory dynamometer tests, road tunnel and roadside experiments have been conducted to quantify p-PAH emissions from diesel vehicles. While providing valuable information, these

measurement methods have limited capabilities of characterizing p-PAH emissions either from individual vehicles or under real-world driving conditions. To fulfill this research gap, we employed a portable emissions measurement (PEMS) to collect real-world particle samples from diesel vehicles and characterize species-resolved p-PAH emissions (EPA’s priority PAH compounds excluding naphthalene) under real-world driving conditions by gas chromatography-mass spectrometry. These HDDVs were declared to comply with China II to China V standards and supposed to use improved engine and after-treatment technologies to meet the increasingly stringent emission limits. The results indicated 3 and 4-ring p-PAHs accounted for a dominant fraction (95%) of p-PAH emission and over 80% reduction in p-PAH emission factors comparing the China V and China II emission standard groups (113 μg kg-1 vs. 733 μg kg-1). The toxicity abatement in terms of Benzo[a]pyrene equivalent emissions was also substantial because of the substantial reductions in highly toxic components. By assessing real traffic conditions, the p-PAH emission factors on freeways were lower than those on local roads by 52% ± 24%. A significant correlation (R2~0.85) between the p-PAH and black carbon emissions was identified with a mass ratio of approximately 1/2000. Previous studies often used ambient p-PAH concentrations to serve as organic makers for supporting source apportionment. However, our measurement data suggest such methods should be used with great caution, because several typical emission ratios between PAH compounds (e.g., molecular diagnostic ratios) could range widely.