Study of EDAR using a Portable Emissions Measurement System (PEMS)

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ABSTRACT: HEAT, LLC with the cooperation of the University of Tennessee and the National Transportation Research Center at Oak Ridge National Laboratory, ran a validation test using a Sensors, Inc., Semtech-DS Portable Emissions Measurements Systems (PEMS). Using cold starts and fans to create a flow over the vehicle, EDAR measured the exhaust plume as it crosses over its' scanning lasers. Data was compared by the use of trace gas ratios to CO_2. Excellent correlation between EDAR and the PEMS device is seen.

Validating a remote sensing device with in-situ devices is key to the endorsement of any remote sensing apparatus. Proof of the accuracy and sensitivity can be done with dry gas samples. Although flow rates on the order of vehicle exhaust are expensive to achieve. Usually 5 to 6 high compression cylinders are required to achieve flow rates on the order of the average vehicle's exhaust flow. The use of real vehicle exhaust is obviously more realistic than dry gas samples. HEAT, LLC in cooperation with the University of Tennessee and the National Transportation Research Center attained a 2008 Sensor, Inc. Semtech DS PEMS device to perform the study.

A validation study was performed using a remote sensing device called EDAR or Emissions Detection And Reporting and the PEMS. The static test performed used fans to create a flow over the vehicle and measuring the exhaust plume as it crosses over EDAR's scanning lasers. Fresh air flowed over the vehicle from a well-ventilated testing facility at the University of Tennessee. The PEMS device was stationary and the FID fuel was supplied with an external fuel source. The vehicle is cold when started, and the catalytic converter is allowed to warm.

Validation between a PEMS device and EDAR is implemented using ratios of CO, NO, and HC to CO_2. One must use ratios in order to compare systems, since as soon as exhaust leaves the tailpipe, trace gases change concentrations rapidly; therefore remote sensing does not use concentrations. Optical mass, such as mole/m^2, is used instead of concentrations. Total optical mass per scan is compared to the tailpipe percentages for the PEMS device. EDAR scans once across the rear of the vehicle every 25 milliseconds. The total optical mass of the entire scan is recorded. The entire plume is encompassed within the scan; therefore the total optical mass is proportional to the absolute amounts coming from the tailpipe. The total optical mass ratios are equated to the PEMS tailpipe concentration ratios.

A 2004 Yukon is situated in front of the EDAR system shown in Figure 1. A large 4' diameter fan blows the exhaust across our scanning lasers. One-minute scans are taken with EDAR while the PEMS system, using a tailpipe probe, is collecting data. Time scales are adjusted on the PEMS data due to different sampling rates and the delay due to travel time through the PEMS heated gas collection hose and chambers for different gases.

The vehicle was kept as cool as possible, so at each start of the vehicle the catalytic converter is not fully activated. We start taking data with EDAR and then start the vehicle within a few seconds. Sometimes a load is introduced either during the first 30-seconds or last 30-seconds of each one-minute scan. The vehicle was turned off after the end of EDAR data collection. Amounts of NO were noticeably dependent on the load.

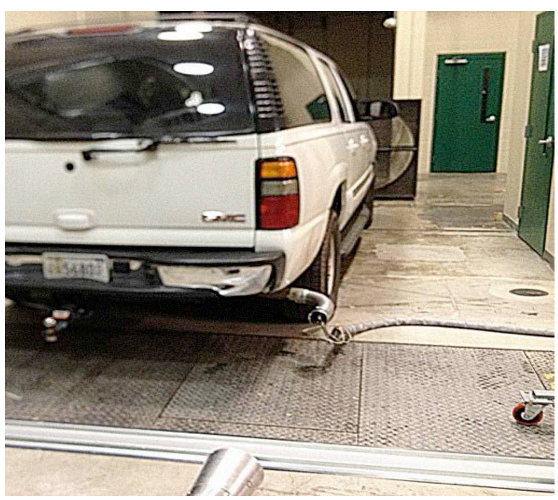

Figure 1: A 2004 Yukon is parked in front of the EDAR unit, above not pictured. EDAR lasers are scanning from above and across the exhaust plume, behind the Yukon. A large fan in front of blows fresh air. The tailpipe probe of the PEMS unit is shown inserted into the tailpipe.

The following figures show graphs of the ratios of CO/CO_2, NO/CO_2, and HC/CO_2 for both the EDAR device and the PEMS. The car is started at the beginning of each scan. As the catalytic converter warms up you will see the CO and HC drop. A load on the engine is introduced in the beginning of the scan and dropped halfway or 30 seconds into the data collection. Note the high NO during the load and the subsequent drop off. The CO and HC drop as the catalytic converter activates.

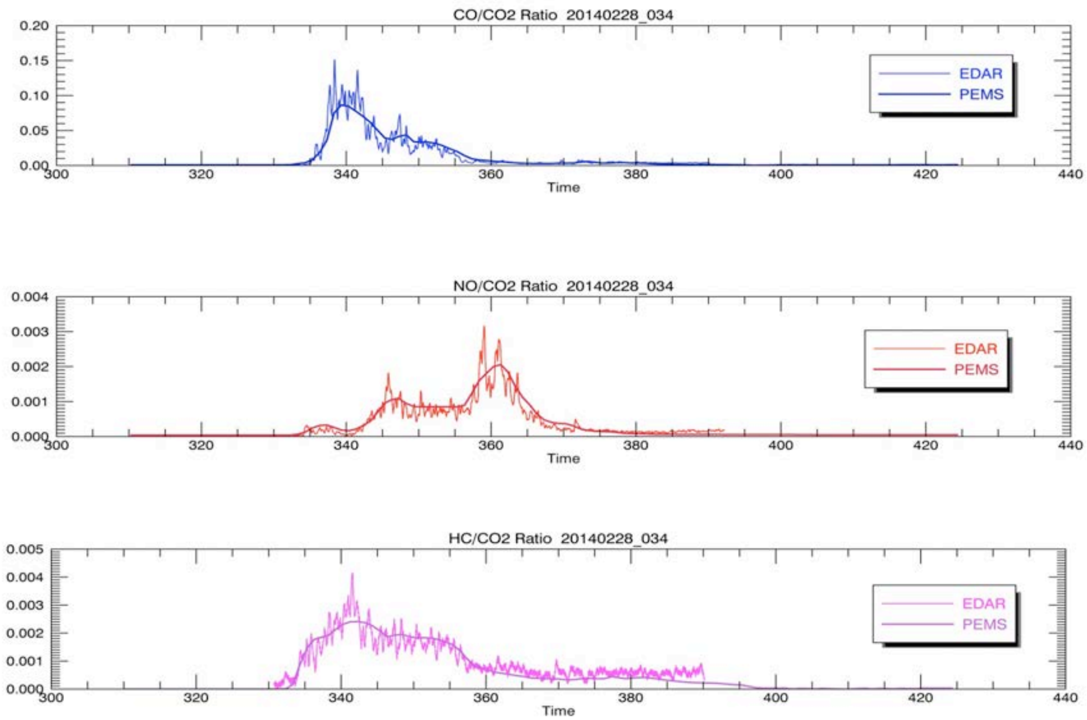

Figure 2: The vehicle is started at the beginning of each scan. The figures above show graphs of the ratios of CO/CO_2, NO/CO_2, and HC/CO_2 for both the EDAR device and the PEMS. A load on the engine was introduced in the beginning of the scan and released halfway into the data collection.

The following figures show graphs of the ratios of CO/CO_2, NO/CO_2, and HC/CO_2 for both the EDAR device and the PEMS. A load on the engine is introduced halfway into the data collection. Note the high NO during the load. The CO and HC dropped as the catalytic converter warms.

The ratios match well. The sampling rate of the PEMS device 1.2 seconds is much lower than EDAR's 0.025 seconds. EDAR is not measuring concentrations, but the amount of molecules in a slice of the exhaust plume. HC amounts showed some non-linear effects with the PEMS Flame Ionization Detector or FID device.

The FID device is counting carbon atoms so correlation is non-linear with respect to the fact EDAR is counting molecules. A correction factor is calculated using PEMS data from propane and butane dry gas simulated exhaust cylinders. FIDs are less sensitive to some organic molecules such as ethanol. EDAR is sensitive to such molecules.

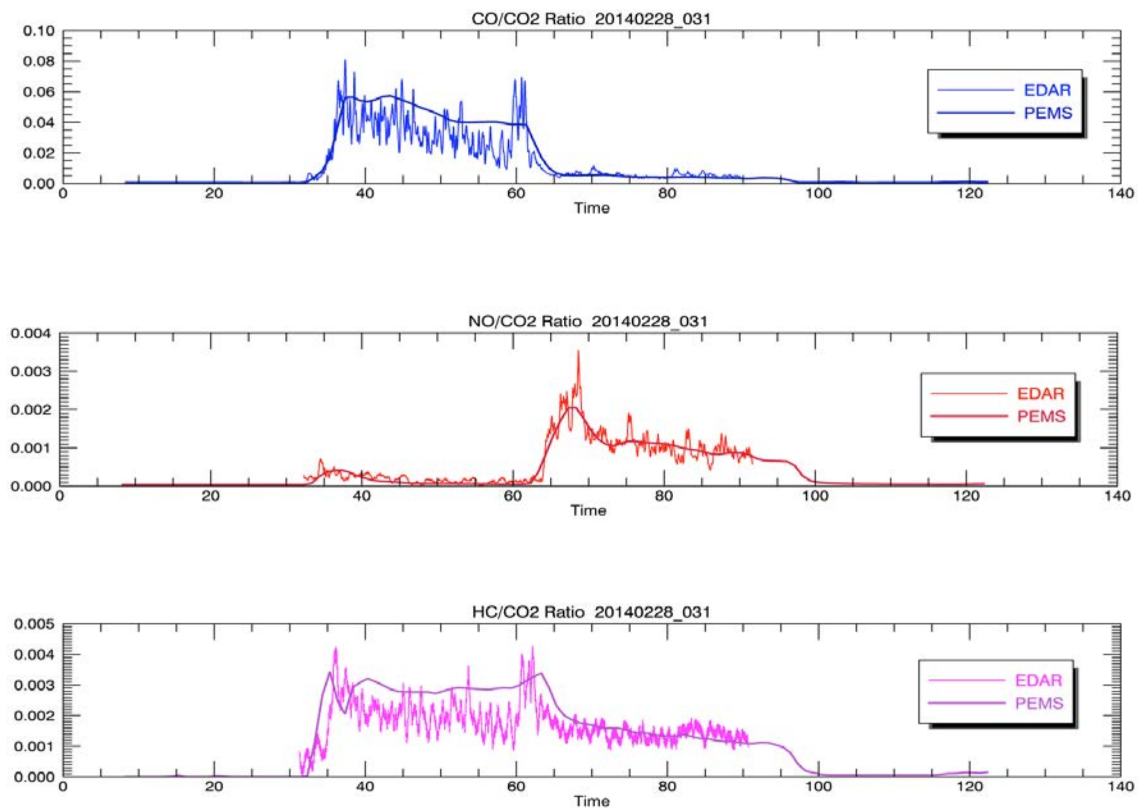

Figure 3: The figures above show graphs of the ratios of CO/CO2, NO/CO2, and HC/CO2 from top to bottom for both the EDAR device and the PEMS. A load on the engine was introduced in the end of the scan. Notice the large increase in the NO as the load is applied.

A 3-D plot shown in Figure 4 illustrates the geometry of the EDAR system. EDAR measures the optical depth from above the plume. There are approximately 500 samples across the floor of the lab represented by the x-axis. The scans, represented by the y-axis, is actually a representation of time. You are seeing how the plume changes over a one-minute period.

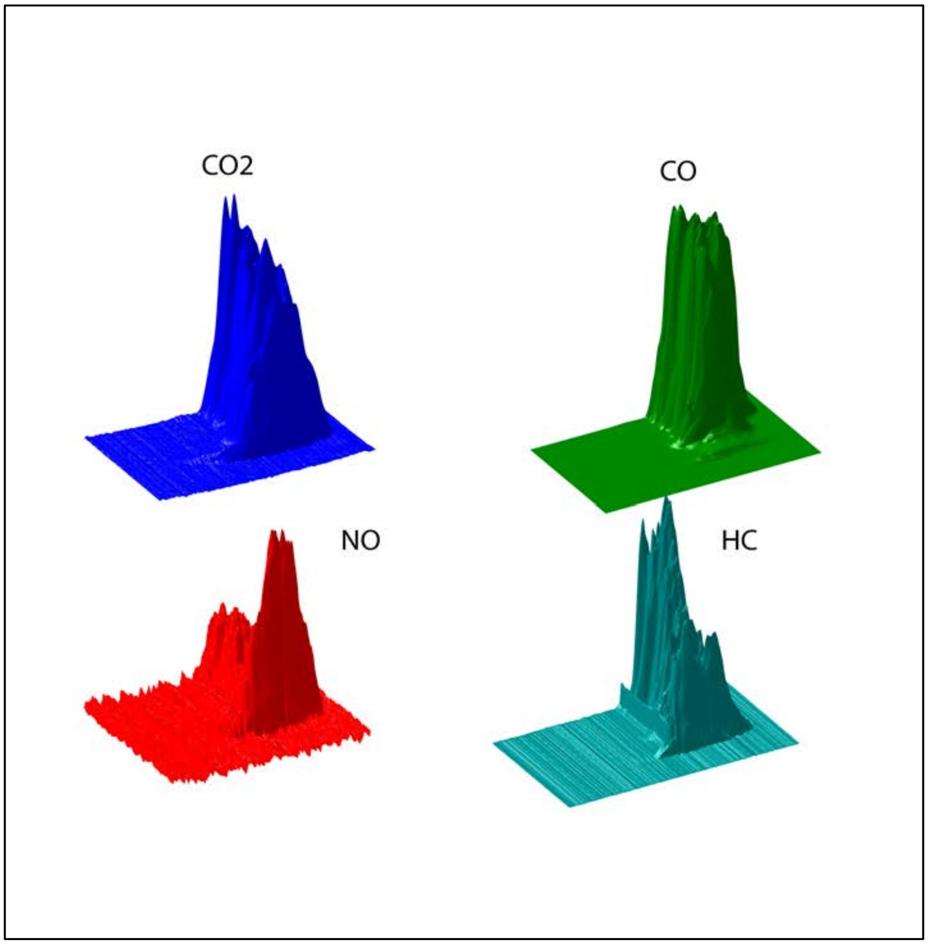

Figure 4: Shows a 3-D representation of a one-minute scan. The y-axis is the scan number and the x-axis is the samples number. The z-axis represents optical mass.

In conclusion, even though the PEMS device uses entirely different methods of detection, the ratios of the trace gases to CO_2 match well. Actually, due to the absolute nature of the way EDAR measures the trace gases, EDAR can be more accurate than in-situ device.