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Heavy-duty Truck Emissions in the South Coast Air Basin of California

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California and Federal emissions regulations for 2007 and newer heavy-duty diesel engines require an order of magnitude reduction in particulate matter and oxides of nitrogen spurring the introduction of new aftertreatment systems. Since 2008 four emission measurement campaigns have been conducted at a Port of Los Angeles location and an inland weigh station in the South Coast Air Basin of California. Fuel specific oxides of nitrogen emissions at the Port have decreased 12% since 2010 while infrared opacity (a measure of particulate matter) remained low, showing no diesel particulate filter deterioration. The weigh station truck's fuel specific oxides of nitrogen emission reductions since 2010 (18.5%) almost double the previous three year's reductions and are the result of new trucks using selective catalytic reduction systems. Trucks at the weigh station equipped with these systems have a skewed oxides of nitrogen emissions distribution (half of the emissions were from 6% of the measurements) and had significantly lower emissions than similarly equipped Port trucks. Infrared thermographs of truck exhaust pipes revealed that the mean temperature observed at the weigh station (225 ± 4.5°C) was 70ºC higher than for Port trucks, suggesting that the catalytic aftertreatment systems on trucks at our Port site were below minimum operating temperatures.

INTRODUCTION

Beginning in 1961 with the California Motor Vehicle State Bureau of Air Sanitation legislating that all automobiles sold in the state be equipped with positive crankcase ventilation to reduce hydrocarbon emissions, ever tighter emission regulations have been issued to reduce new vehicle emissions.[1] Early on, the numerical dominance of light-duty spark-ignited vehicles drew the attention of regulators, leading to many innovations in fuel and combustion control systems to lower engine out emissions, and to sophisticated aftertreatment catalysis to further lower tailpipe emissions. While regulations for emissions from heavy-duty diesel vehicles (HDDV) initially focused on particulate matter (PM), by the late 1990s the importance of their nitrogen oxide (NO_x) emissions grew with the success of the light-duty emission controls.[2, 3]

In 1990 a series of Federal regulations for HDDV were implemented requiring NO_x emissions to be reduced from 10.7 g/bhp-hr to 4 g/bhp-hr and PM emissions to be reduced from 0.6 g/bhp-hr to 0.1 g/bhp-hr.[4] Before the development of advanced aftertreatment systems, the control of NO_x and PM emissions were generally mutually exclusive, and while PM emissions showed real reductions after these regulations, on-road NO_x emissions actually increased.[5-7] The increases were in-part the result of manufacturers employing defeat devices that favored fuel economy at the expense of NO_x emissions during certain engine operating conditions. This lost decade in HDDV NO_x controls, a subject of subsequent litigation, when coupled with the rapid growth in diesel fuel use in the 90s resulted in HDDV contributing a disproportionally large percentage of the on-road NO_x emissions.[8-11]

The new century brought additional regulatory pressure on HDDV emissions with new Federal regulations for 2004 engines (a result of the previously mentioned litigation) followed by regulations periodically phased in beginning with year 2007 engines, that would eventually

require an order of magnitude reduction in both NO_x (to 0.2 g/bhp-hr) and PM (to 0.01 g/bhp-hr) emissions. These low levels have required the industry to develop new engine management systems and aftertreatment devices not previously used in mobile applications. The two most notable aftertreatment devices being installed on HDDV are the diesel particulate filter (DPF) for PM control and selective catalytic reduction systems (SCR) for NO_x control. DPFs are ceramic or metallic size exclusion filters to physically trap soot particles emitted during combustion. These filters can be catalyzed or accompanied by an oxidation catalyst to promote soot oxidation with nitrogen dioxide (NO_2) and or equipped with a fuel injector to inject fuel to burn the trapped soot to prevent plugging. SCR systems include a specialized catalyst, which in combination with an added source of ammonia (NH_3); reduce nitric oxide (NO) and NO_2 emissions to nitrogen. All current SCR systems rely on injecting a 32.5% by wt. urea solution (marketed as diesel emissions fluid) that, when thermalized, releases the NH_3 for the reduction reaction.

The focus of this research has been to record and quantify on-road HDDV emission trends through repeated measurements at two locations in the South Coast Air Basin of California during a unique time period when a number of Federal (2007 and 2010 engine certification standards), State (California Drayage Truck and State Truck and Bus Rules) and local HDDV emission reduction regulations (San Pedro Bay Ports Clean Air Action Plan) were being implemented.[12-16] Compared to our previous work, this study extends the time period covered by two years (now 2008-2012) and, for the first time, reports emission measurements from HDDV with some of the more advanced aftertreatment systems.[17]

EXPERIMENTAL SECTION

This is the fifth year and fourth measurement campaign (2008-2010, 2012) to characterize and track HDDV emissions in the South Coast Air Basin of California. The data

have been generally collected in the spring at two measurement sites that have been fully described elsewhere.[17] The Port of Los Angeles measurements were collected on lane #1 at the Water St. exit gate from TRAPAC Inc. container operations (berths 135-139) near the intersection of Fries Ave. and Water Street in Wilmington, CA. Measurements were collected as the trucks accelerated away from the final checkpoint (0° grade) after a complete stop. An inland site at the Peralta weigh station operated by the California Highway Patrol was located on the eastbound Riverside Freeway (just west of exit 39 on California State Route 91). The trucks were measured after the scales on a slight incline (1.8° grade) while regaining speed to merge back onto the freeway. Because of major construction on SR-91 the Peralta weigh station was closed for an extended period of time during 2012, forcing a postponement of those measurements until September 2012.

Our remote vehicle exhaust sensor developed at the University of Denver, named Fuel Efficiency Automobile Test (FEAT), was used to collect the emission measurements. It has been extensively described in the literature.[18-21] The instrument consists of a dual element light source (silicon carbide gas drier igniter and a xenon arc lamp) and a detector unit with four non-dispersive infrared (IR) detectors that provide IR reference (3.9μm) and measurements of the gases carbon monoxide (CO, 3.6μm), carbon dioxide (CO_2, 4.3μm), and hydrocarbons (HC, 3.3μm). This detector unit is fiber optically coupled to two, dispersive ultraviolet spectrometers that measure NO, sulfur dioxide (SO_2), NH_3 between the wavelengths of 200 and 226 nm in one spectrometer, and NO_2 between the wavelengths of 430 and 447nm in the second spectrometer. The sensor measures only vehicle exhaust gases as a molar ratio to exhaust CO_2 because the path length of the plume is unknown. These ratios can be converted into fuel-specific emissions of grams of pollutant per kilogram of fuel burned (g/kg) by carbon balance using the molecular

weight of each species and the fuel's carbon mass fraction, after scaling the HC/CO_2 ratio to account for the poor quantification of certain hydrocarbon species in the IR spectrum.[22, 23] For diesel fuel we used a carbon mass fraction of 0.86 and a scaling factor of 2 and for natural gas we used a carbon mass fraction of 0.75 and a scaling factor of 3.13. IR %opacity readings report the reduction of the IR reference signal (3.9μm) caused by exhaust soot particles correlated to exhaust CO_2. Reductions in fleet average IR %opacity are proportional to reductions in the fuel-based soot mass and number emissions only to the extent that the observed particles maintain a constant size distribution and optical properties during the measurement. Data suggest an IR %opacity of 1% corresponding to between 1 and 4 grams of soot/kg of fuel.

Quality assurance calibrations were performed in the field, as dictated by the atmospheric CO_2 conditions, using three certified gas mixtures containing 6% CO, 0.6% propane, 6% CO_2, 0.3% NO and 0.04% SO_2 in nitrogen; 0.05% NO_2 and 15% CO_2 in air; 0.1% NH_3 and 0.6% propane in nitrogen. The measured gas ratios are normalized to the averaged results of these calibrations to adjust for any day-to-day variations in instrument sensitivity and changes in ambient CO_2 absorption caused by atmospheric fluctuations.

Because the majority of HDDVs in the US have elevated exhaust stacks, the remote sensing beam is required to be 4 – 4.5m above the ground for sampling. Two, guy wire stabilized, scaffolding towers were used on each side of the roadway, raising the source and detectors to the exhaust sampling height.[17, 24] Attached to the scaffolding were a pair of parallel IR beams (Maxi-beam, Banner Industries) 1.83 meters apart, located about 1.8 meters above the roadway to measure the speed and acceleration of the trucks. A third IR beam mounted on a tripod was used for detecting the front of the truck and triggering the 1 second emission measurement. Through the use of road markings and photography, we attempted to install the

measurement equipment in the same location for each campaign. A freeze-frame video image of the front of each truck was recorded along with the emission measurements. From this image the license plate number was used to retrieve non-personal vehicle data, such as make and model year (MY), from the state registration records of California, Illinois, Oklahoma and Oregon.

There currently are no emissions control equipment information provided through either vehicle registration or vehicle identification numbers for HDDV. With the advent of diesel aftertreatment systems (2007 and newer engines) data interpretation can be enhanced by knowing what type of aftertreatment device is installed and whether it is operating. To that end we incorporated two additional cameras in this campaign to explore exhaust system temperatures and to find HDDV that were equipped with SCR systems.

A FLIR Thermovision A20 IR camera (FLIR Systems) was triggered together with the license plate image capture system to record thermal images of the trucks exhaust system as they exited our site. These thermographs were visually read and assigned a maximum temperature between 90 to 350°C by comparing with a lab created standard using a stainless steel exhaust pipe. Because the emissivity of stainless steel has been reported to vary significantly (by up to an order of magnitude) our ultimate goal was to sample enough trucks at each location to effectively cancel any differences in emissivity encountered allowing an accurate determination of the difference in the two site's temperatures.[25]

The need for a source of ammonia for SCR systems has resulted in the addition of a dedicated urea tank, often distinguished by a blue cap. For many trucks these tanks are conspicuously visible on the driver's side of the truck. The third camera system added was a remotely triggered consumer grade digital camera (Canon) set up to photograph the driver side of

each vehicle. These pictures were visually reviewed to identify a urea tank to further classify that truck as a SCR equipped vehicle in the database.

We carried out five days of emission measurements at each of the sampling sites. Data were collected between Monday and Friday at the Port from April 30 to May 4 and at Peralta from September 24 to 28, 2012. The emission measurements and vehicle registration information for each site were assembled into a final database that is available for download from our website at www.feat.biochem.du.edu.

RESULTS AND DISCUSSION

Table 1 lists the sampling dates, number of trucks sampled, mean chassis model year, emissions with standard errors of the mean calculated from the daily means, and mean speed and acceleration for the 2012 measurements. Reported gNO_x/kg of fuel emissions only include the measured NO and NO_2 emissions and have been calculated by converting the measured gNO/kg of fuel into gNO_2/kg of fuel equivalents and summing with the measured gNO_2/kg of fuel emissions. Figure 1 shows the multi-year g/kg of fuel emissions for NO, NO_2, NO_x and IR %opacity for both locations. Note that the elapsed time between the 2010 and 2012 measurements is about a third of a year longer for the Peralta weigh station data because of the construction delay.

Since 2008, gNO_x/kg of fuel emissions have decreased by 55% at our Port location. With the completion of the Port's mandatory truck replacement program in 2010 the decrease in NO_x emission slowed to 12% as expected.[17] The IR %opacity measurements are unchanged since 2010 (reductions of 53% since 2008) indicating no major DPF deterioration over the last two years. These emission reductions are similar to those reported for similar model drayage trucks operating at the Port of Oakland.[26] At Peralta overall gNO_x/kg of fuel emissions have decreased

Table 1. 2012 Summary of Measurement Dates, Vehicle Information, Fuel Specific Emissions and Standard Errors of the Mean.

Location Dates	Trucks (Mean MY)	gCO/kg	gHC[a]/kg	gNO[b]/kg / gNO_2/kg / gNO_x[c]/kg	gNH_3/kg	IR %Opacity	Speed[d] Acceleration[e]
Port of LA 2012 April 30–May 4	1746 (2009.3)	8.2±0.6	3.7±0.1	12.1±0.2 / 2.0±0.3 / 20.6±0.6	0.5±0.1	0.33±0.02	7.8±0.1 0.9±0.04
Peralta 2012 Sept. 24-28	2547 (2004.0)	7.3±0.5	0.6±0.6	11.9±0.2 / 1.8±0.1 / 19.9±0.3	0.02±0.02	0.69±0.07	22.2±0.4 1.9±0.07

[a] grams of HC using the FID adjustments noted in the text.

[b] grams of NO

[c] grams of NO_2

[d] kilometers per hour

[e] kilometers per hour / sec

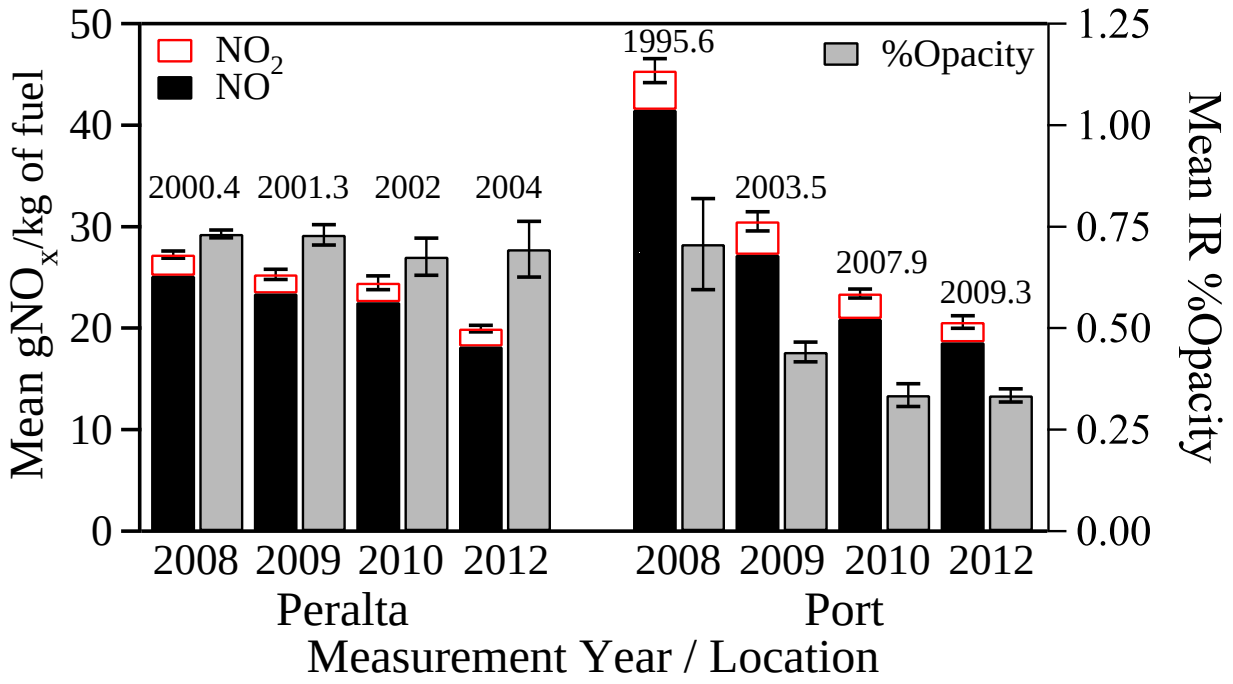

Figure 1. Measurement year 2008 through 2012 mean gNO/kg of fuel, gNO_2/kg of fuel, gNO_x/kg of fuel (left axis) and mean IR %opacity (right axis) versus measurement year for the two sampling locations. All of the nitrogen species are plotted as grams of NO_2. The error bars reported are standard errors of the mean for total NO_x and were calculated from the daily means. The mean chassis model year for the data set is listed above each pair of measurement bars.

by 27% with the largest drop occurring since the 2010 measurements (18.5%). The overall trend for the mean IR %opacity at Peralta shows no statistically significant change since 2008, however, the standard error of the mean has increased significantly suggesting a more skewed emissions distribution.

Figure 2 plots the mean gNO_x/kg of fuel emissions as a function of chassis model year for the 2012 Peralta weigh station data. The uncertainties are standard errors of the mean calculated from the daily means and the highlighted model years are milestone years for changes in

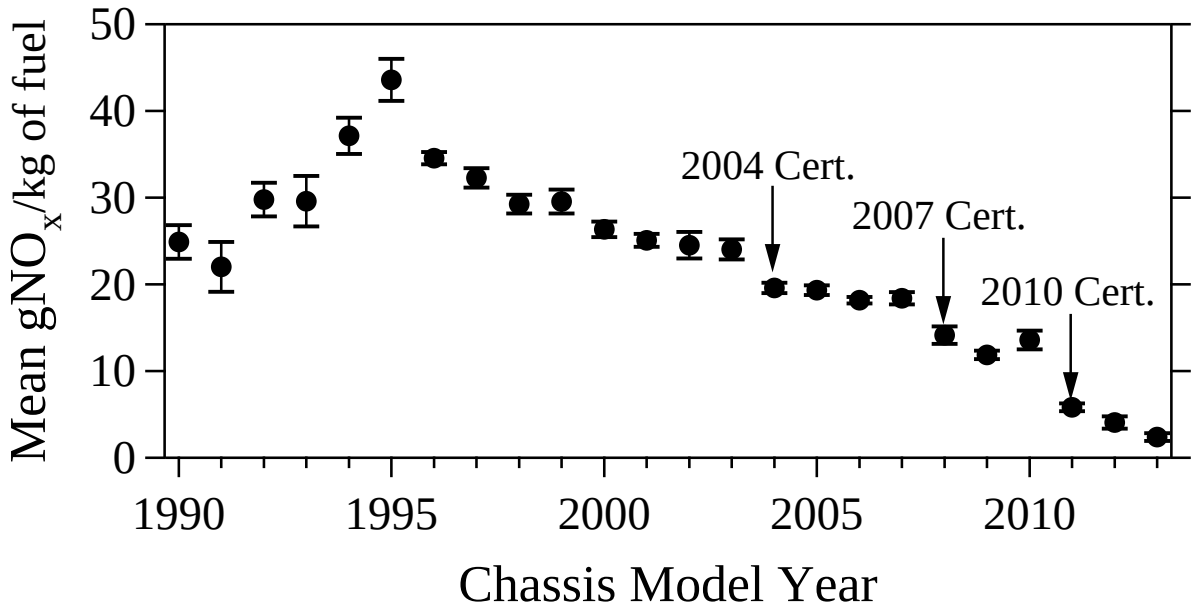

Figure 2. Peralta 2012 mean gNO_x/kg of fuel emissions (plotted as grams of NO_2) versus chassis model year. Federal heavy-duty diesel engine certification changes are labeled for the 2004, 2007 and 2010 standards. The error bars are the standard errors of the mean determined from the daily means.

California and Federal emission certification standards. HDDV emission regulations are only applicable against the engine's manufactured year and we generally find that the chassis model year (acquired from the motor vehicle registration records) is one year older. The exception to this rule was the 2004 certification standard that, as a result of a legal settlement, was introduced early by the engine manufacturers and coincides with the chassis model year.[8, 9]

The data plotted in Figure 2 are a look back into time of the trials, tribulations and successes of HDDV NO_x regulations. Between 1990 and 2003 there were three NO_x emission reductions that lowered the Federal gNO_x/bhp-hr standard from 6.0 to 4.0. The on-road emissions show a large increase in the mid-90s, which was the subject of the previously mentioned litigation, with a gradual return to where we started by 2003.[6] This was followed with

a 50% reduction in the standard in 2004 resulting in a meaningful on-road reduction, but only about half of the expected benefit. Beginning with 2007 engines (2008 chassis MY) a complicated banking and trading credit system was implemented with the ultimate goal being that all heavy-duty diesel engines are to meet a 0.2 g/bhp-hr NO_x standard (an order of magnitude reduction from the 2004 standard). The on-road data show an additional 30% stepwise reduction beginning with the 2008 models (lower NO_x engines were introduced early to gain future credits) and, unlike previous standard changes, the 2011 and newer models do not show a single step change but a steep linear reduction. The 2013 model emission of 2.4 gNO_x/kg of fuel represents an 82% reduction from the 2004-2007 levels, but in the driving mode that we measure, are still above the 2010 standard of approximately 1.33 gNO_x/kg of fuel (assuming 0.15kg of fuel are consumed per bhp-hr).[27]

The large reductions occurring in the 2011 and newer models are the direct result of the introduction of SCR systems. Figure 3 is a box and whisker plot of the data from Figure 2 grouped by chassis model years that generally coincide with the engine certification standards. The box defines the 25th, 50th and 75th percentiles with the whiskers extending from the 10th to the 90th percentile and the open circles the measurements above the 99th percentile and below the 1st percentile. The filled square denotes the mean for each group. The 2011+ grouping is further subdivided into trucks identified through the driver side photographs as having a blue capped urea tank (2011+ Urea Cap, 151 measurements on 117 trucks).

The stepwise reductions in gNO_x/kg of fuel emissions as previously discussed are evident in the pre-2011 truck groupings. Each of these groups interquartile range is similar in size and shape with similar means and medians, indicating a near normal distribution and the extent of the measurements beyond the 99th percentile have similar magnitudes. Beginning with the 2011 MY

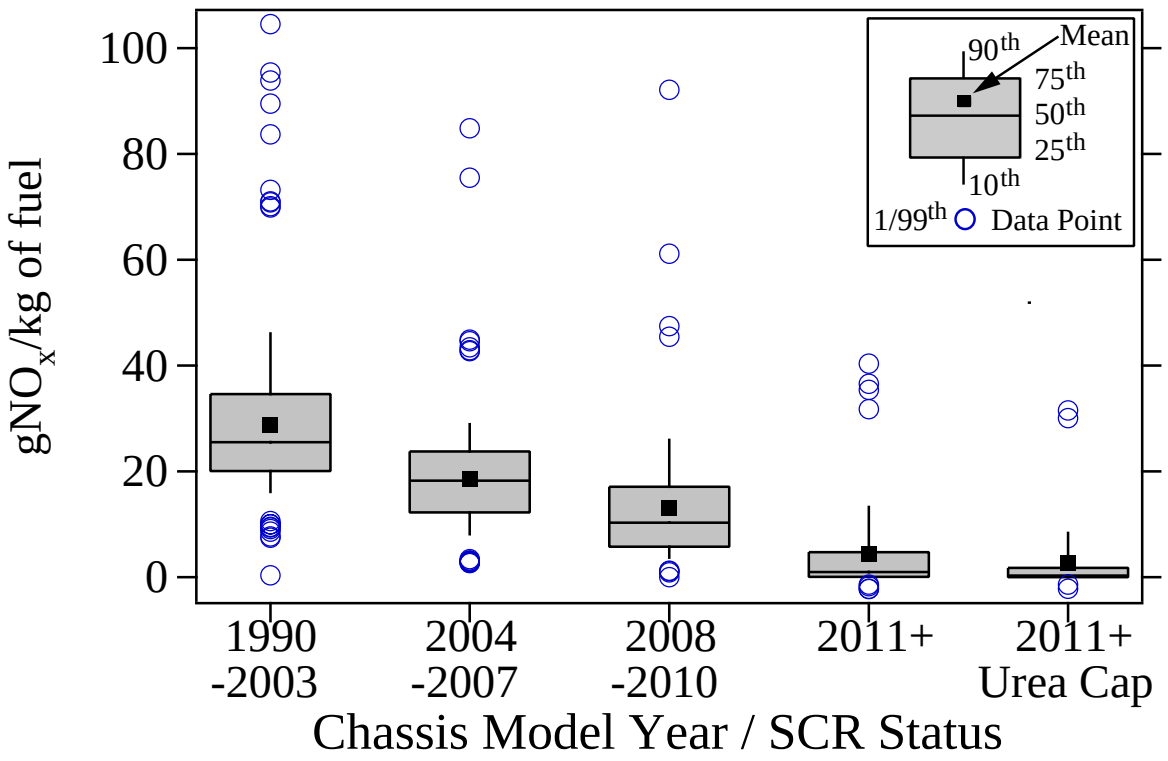

Figure 3. A box and whisker plot of the 2012 Peralta gNO_x/kg of fuel (plotted as grams of NO_2) emissions grouped by chassis model years. The box defines the 25th, 50th, and 75th percentiles with the whiskers defining the extent of the 10th to the 90th percentile and the open circles are individual measurements below the 1rst percentile and beyond the 99th percentile. The mean for each group is plotted as the solid square. The 2011+ grouping is further subdivided into trucks positively identified as having a urea tank (2011+ Urea Cap).

and newer trucks, not only has there been a significant reduction in the mean emissions (see Figure 2), but reductions have occurred across all of the percentiles, with the interquartile range contracting significantly and the extent of the extreme measurements being cut in half. The SCR equipped trucks are driving these reductions, as shown by the last plotted subgroup (2011+ Urea Cap), though not all of these trucks had the SCR system operational when the measurement occurred. At Peralta the 2011 MY and newer trucks gNO_x/kg of fuel emissions distribution is

now skewed much like a light-duty distribution with half of the gNO_x/kg of fuel emissions being emitted by 9% of the measurements.[28] Of the 2011 MY and newer trucks we identified with an SCR systems only 6% of the measurements account for half of the gNO_x/kg of fuel emissions.

The 2007 regulations also required an order of magnitude reduction in HDDV PM emissions (0.1 g/bhp-hr in 2004 to 0.01 g/bhp-hr) requiring the introduction of DPFs in 2008 MY trucks. These generally included an oxidation catalyst, or the DPF itself was catalyzed to generate NO_2 to oxidize the captured soot particles and prevent plugging. This led to an increase in the observed NO_2/NO_x ratio in the exhaust of these trucks.[17, 29] However, the increases were much larger at the Peralta weigh station (2012 mean ratios for 2008 MY and newer trucks of 0.18) than observed at the Port location (2012 mean ratios for 2008 MY and newer trucks of 0.10). One possible explanation for these differences is that the operating temperature of the catalyst in the trucks measured at our Port location was too low for optimal oxidation of NO lowering the production of NO_2. Port activities prior to our measurement location includes a lot of low speed, stop and go driving which works to curtail exhaust temperature.[30]

To investigate this possibility a FLIR Thermovision A20 infrared camera was incorporated into the measurement system to image the exhaust systems of the exiting trucks. The system captured 1,969 images from Peralta and 766 images at the Port location (including trucks not in the plate matched database) which contained a recognizable elevated exhaust pipe (low exhausts, mostly LNG powered trucks at the Port, were not included). The images were visually inspected and assigned a maximum observed temperature between 90 and 350 °C.

Individual measurements collected by this process can be problematic. We previously mentioned that emissivity changes in the pipe material can lead to inaccurate readings but more common is the difficulty in discerning if a low temperature reading is from a truly cold exhaust

pipe or a pipe that has been heat shielded. Some trucks have exhaust pipes where the heat shielding conforms to the pipe, visually disguising its presence. We believe that the best approach for these data is found in comparing the site averages as we expect these misinterpretations to occur in similar proportions at both locations. While these errors could affect the mean absolute temperatures reported at each site they should cancel each other out when reporting the temperature difference.

Figure 4 shows the distribution of those readings (the 360°C bin is for readings in excess of 350°C) and Table 2 details the mean and median measured exhaust temperatures for each location. Standard errors of the mean determined from the daily means are reported for each site's data set. To gauge what, if any, effect ambient temperature differences (ambient temperatures at the Port in 2012 were about 7°C lower) between the two sites might have, we have included means for two self-restricted early morning periods at Peralta where ambient temperatures were more comparable to the Ports. Finally we compare exhaust temperature measurements from ten (one equipped with an SCR) trucks measured at both locations.

As shown in Table 2 there is a consistent observed temperature difference of about 65 to 70°C regardless of the group chosen. Ambient temperature does not appear to be a significant factor as the two early morning groupings at Peralta have similar means. The similar temperature difference observed in the matched truck data set is important since the common exhaust pipe material eliminates the possibility of any emissivity measurement errors. These exhaust temperatures should be considered a lower limit for what one would expect at the DPF or SCR which will be closer to the engine. Nonetheless these data suggest that a large percentage of vehicles observed at our Port location have catalytic devices that are below minimum operating temperatures of 200 to 250°C.[31-34]

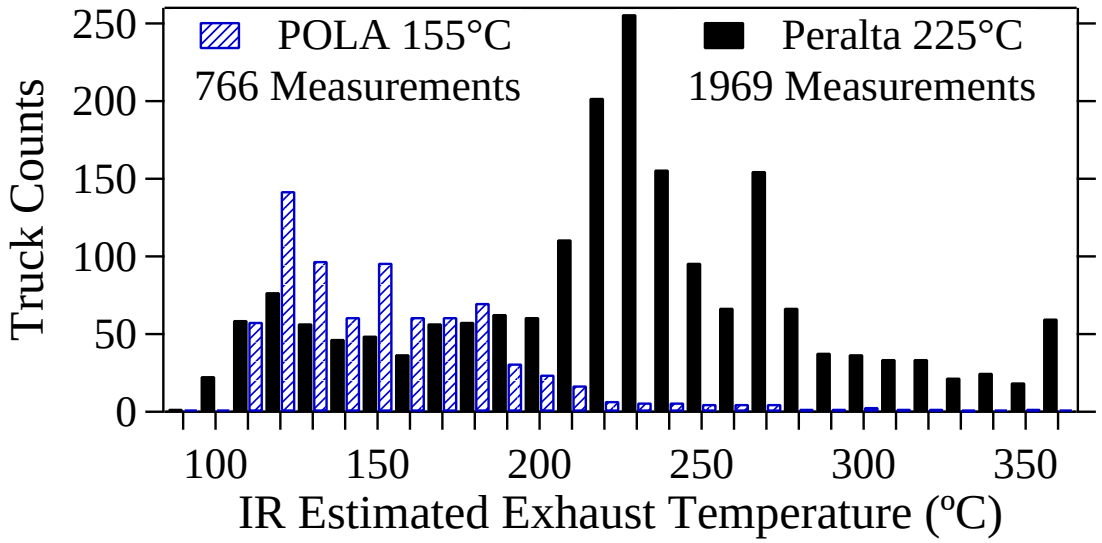

Figure 4. Distributions of infrared estimated exhaust temperatures for trucks at our Port of Los Angeles location (hatched bars) and the Peralta weigh station (solid bars). The mean temperature and number of measurements for each location are included in the legend. The highest temperature bin (360°C) contains all trucks with apparent exhaust temperatures exceeding 350°C.

Table 2. Mean and Median Infrared Estimated Exhaust Temperatures.

Groupings	Measurements Port of LA / Peralta	Port of LA Mean / Median (°C)	Peralta Mean / Median (°C)
All Data	766 / 1969	155° ± 3.8° / 150°	225° ± 4.5° / 230°
Peralta Before 10am	695		220° ± 3.0° / 230°
Peralta Before 9am	401		219° ± 3.6° / 230°
10 Matched Trucks	13 / 11	152° / 130°	237° / 230°

This will not only act to lower NO_2/NO_x ratios as observed, but will also restrict the potential effectiveness of SCR systems to further reduce NO_x emissions at the Port. Table 3 compares the mean and median emissions from trucks identified with urea tanks at our two locations. Errors are standard errors of the mean determined from the daily means. For some of these trucks we also obtained IR exhaust temperatures and the mean values and the numbers of measurements are listed in the last column and the individual readings are plotted in Figure 5. Only at Peralta is the mean IR exhaust temperature likely above the critical catalyst operating temperature. Both those species that are removed by the oxidation catalyst (CO and HC) and the reduction catalyst (NO and NO_2) are multiple factors lower in the trucks at the Peralta weigh station. Mean NH_3 emissions at Peralta show no apparent instances of urea over-dosing, and are almost two orders of magnitude below the average NH_3 emissions of light-duty gasoline fleets.[35, 36] A 2011 Mack tractor with an SCR system was measured at both locations. At the Port this truck's gNO_x/kg of fuel emissions and exhaust temperature were 31.2 g/kg and 120°C and at Peralta 0.3 g/kg and 230°C (solid symbols in Figure 5). The SCR system was operational at the weigh station and not at the Port likely due to low temperatures.

Table 3. Fuel Specific Emissions Summary and Exhaust Temperatures for SCR Equipped Trucks.

Site (Number)	gCO/kg Mean *Median*	gHC[a]/kg Mean *Median*	gNO[b]/kg Mean *Median*	gNH_3/kg Mean *Median*	gNO_2/kg Mean *Median*	gNO_x[c]/kg Mean *Median*	Mean IR Exhaust Temperature °C (Number)
Port of LA (32)	7.0±2.8 *2.66*	2.5±0.7 *1.26*	11.0±0.7 *9.88*	-0.04±0.02 *-0.01*	1.8±0.4 *1.69*	18.7±0.8 *17.23*	143°±2° (6)
Peralta (152)	1.6±0.7 *1.33*	-1.0±1.7 *-0.42*	1.4±0.3 *0.07*	0.007±0.005 *-0.0008*	0.4±0.1 *0.18*	2.6±0.6 *0.31*	228°±12° (85)

[a] grams of HC using the FID adjustments noted in the text.

[b] grams of NO [c] grams of NO_2

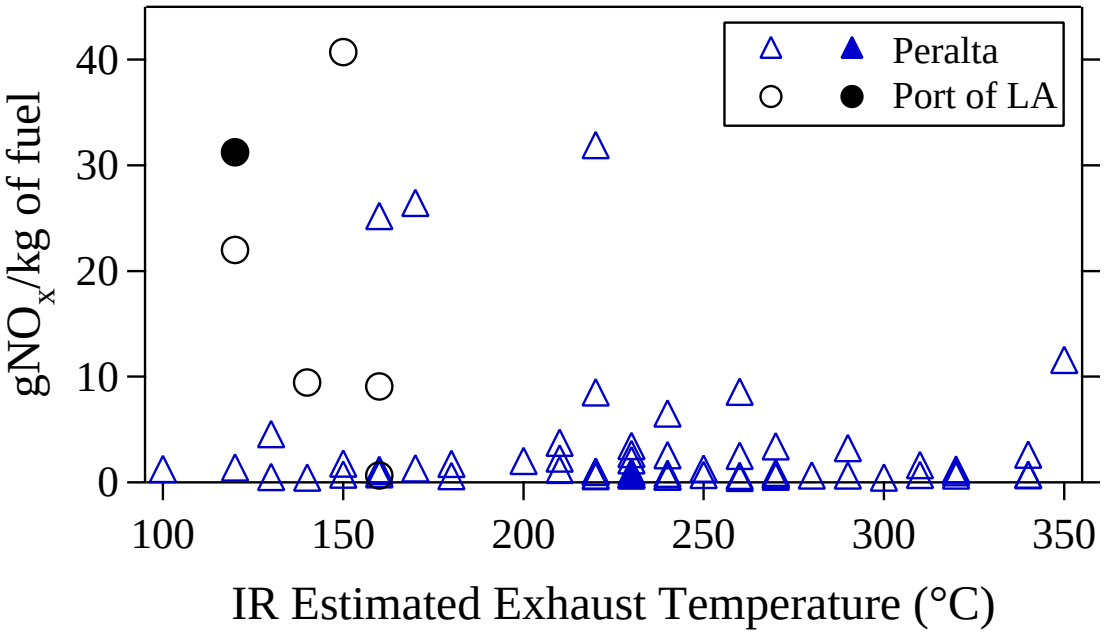

Figure 5. gNO_x/kg of fuel emissions versus estimated infrared exhaust temperature (degrees Celsius) for 2012 Peralta (blue triangles) and Port of Los Angeles (black circles) trucks identified with a urea tank. The filled symbols are measurements of the same truck.

The data clearly show the exceptional NO_x reductions that these new aftertreatment systems are capable of achieving. At both locations there are instances when the SCR systems do not appear to be fully operational and the gNO_x/kg of fuel emissions are considerably higher with these few trucks accounting for the majority of the NO_x emissions. At the Port location we suspect that operating temperature is the primary factor, but at Peralta there may be additional conditions that have not been met besides temperature to explain why the SCR system is inoperative. It could be related to a maintenance issue, such as low urea levels, or a more serious emissions control device malfunction event that results in a period of elevated NO_x emissions

before restricting the power output of the engine. Whatever the cause this raises a very important issue in that ensuring that these systems remain operational as designed will need to be a priority if future NO_x emission reductions are to be fully realized. In addition, modeling the NO_x benefits one can expect from HDDV turnover is no longer as simple as using the Federal engine certification standards since these new aftertreatment systems add additional operating requirements that have to be met to achieve the full benefits. Vehicle operation at the Ports is characterized by frequent stops, low speed driving, and idling that may prove a poor fit for the new SCR technology leading to higher not lower NO_x emissions.[34]

We pointed out earlier that overall emission trends for smoke plotted in Figure 1 showed large reduction in IR %opacity for Port trucks but little change at Peralta. However, the standard error of the mean has increased for each successive data set collected at Peralta. Figure 6 plots the mean gCO/kg of fuel (left axis and open squares) and mean IR %opacity (right axis and filled circles) versus chassis model year for the 2012 Peralta data. The errors plotted are standard errors of the mean calculated from the daily means. There is a noticeable and significant break in the IR %opacity readings beginning with the 2008 chassis model year (2007 manufactured engines which were required to meet the 0.01 g/bhp-hr PM emissions standard) like that observed at the Port. If we compare the mean IR %opacities of 2008 to 2013 MY trucks (mean of 0.48 and 30% of the plate-matched fleet) with the remaining fleet (mean of 0.78) we find a 38% reduction in IR %opacity. This is not as large of a reduction as observed at our Port location (54%) but still significant. The reductions in smoke emissions among the newest trucks that have entered the Peralta fleet since 2008 are responsible for the increasing skewness in the emissions distribution and the resulting increases in the standard errors of the mean. Their fleet fraction, however, is

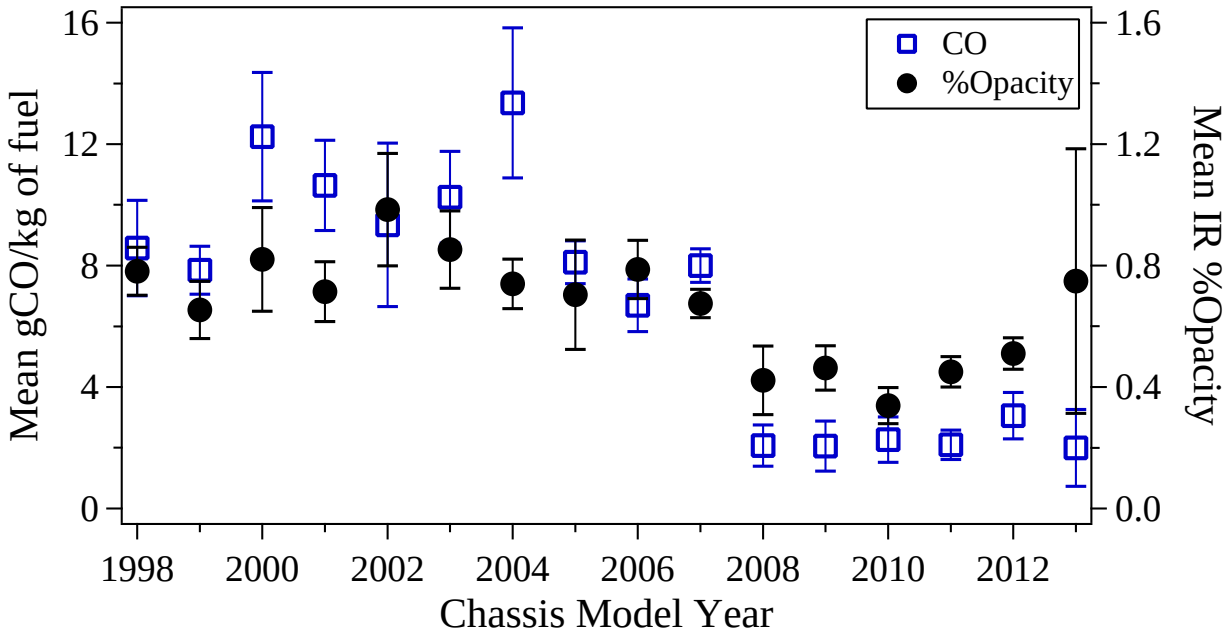

Figure 6. Peralta 2012 mean gCO/kg of fuel (left axis and open squares) and mean IR %opacity (right axis and filled circles) versus chassis model year. The errors plotted are standard errors of the mean calculated from the daily means.

still not large enough for statistically significant reductions in IR %opacity on a fleet-wide basis to be observed by this instrument at this site.

Since most DPF applications also involve some type of oxidation catalyst, whether as part of the DPF or an additional device, we would also expect to see reductions in CO and HC emissions in the 2008 and newer trucks. At Peralta the HC data are too noisy to unequivocally see any benefit, but the gCO/kg of fuel data, plotted in Figure 6, show a MY pattern similar to that seen for the IR %opacity measurements with a 76% reduction for the 2008 and newer trucks when compared to the rest of the fleet.

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