

EVALUATION OF CRANKCASE EMISSIONS ABATEMENT DEVICE

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EXECUTIVE SUMMARY

The New Condensator crankcase emissions abatement system (CEAS) system was installed on a 1996 Peterbilt over-the-road tractor with a 14.6 liter, 550hp Caterpillar engine. The CEAS captured heavy components in the crankcase vent stream, and returned light components to the engine intake, thereby eliminating 100% of the crankcase vent flow. Successful operation of the system was demonstrated while the truck was driven over the road at 56,000lb. gross combination weight for 13,400 miles. As part of the mileage accumulation, the truck was operated over a set route of 594 miles between Westover, WV and Mt. Sterling, KY before the installation of the New Condensator system and fuel economy was determined both by weighing the fuel (with temperature compensation for volume) required to refill the fuel tanks and from electronic control unit (ECU) fueling data. After installation of the CEAS, an additional six runs were performed on the same route, and the average fuel economy measured after installation was 4% higher by weight and 2.7% higher by ECU than for the run before installation. The Peterbilt was also operated on a chassis dynamometer both with and without the CEAS, and crankcase emissions were measured with a specially designed and constructed emissions measurement system for the runs without the CEAS installed. Particle count in the crankcase flow was measured using a Cambustion DMS500. Crankcase particulate matter (PM) was captured on filters after dilution. Based on testing on the chassis dynamometer over the Urban Dynamometer Driving Schedule (UDDS), the New Condensator system eliminated 37 mg of particulate matter, 16 mg of hydrocarbons (HC) and 0.225×10^{12} particles normally emitted to the atmosphere in the crankcase flow per mile of operation. Research using hopanes and stearanes as markers for lubricating oil showed that about one half of the particulate matter (consisting of solids and droplets) in the crankcase flow was lubricating oil. Tailpipe emissions measurement using the chassis dynamometer and the UDDS after the conclusion of the mileage accumulation showed that emissions with the CEAS were 1% higher in oxides of nitrogen (NO_x), 3% lower in HC, 9.4% lower in PM, 2.8% lower in carbon dioxide (CO) and 0.6% lower in carbon dioxide (CO₂).

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INTRODUCTION

This test program evaluated a novel system to capture undesirable diesel engine crankcase emissions and return the burnable light hydrocarbons to the engine intake. The desire was to evaluate the original crankcase emissions, which were removed from the atmospheric inventory by this system, as well as to quantify the effect that the system had on tailpipe emissions, vehicle operation, and fuel economy.

In 2007, the Environmental Protection Agency will begin measuring not only exhaust emissions from diesel engines, but emissions from the crankcase if it is not vented into the engine intake. The 2007 government standards for emissions of carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate matter (PM) will also become more restrictive. There is the additional concern that crankcase emissions from present day trucks and buses may impact the quality of air inside the vehicle as well as contributing to the general emissions inventory. This report presents data to characterize crankcase emissions and examines a crankcase emissions abatement system (CEAS), manufactured by New Condensator®. Rather than allowing crankcase emissions to leave via a vent tube, this CEAS captures some of the mist in the crankcase flow and re-circulates the remainder to the intake of the engine. Details of the New Condensator system can be found at www.worldnci.com.

OBJECTIVES

The objectives of this study were to:

- 1) Quantify the crankcase emissions and fuel consumed from a typical tractor-trailer.
- 2) Evaluate the effectiveness of the New Condensator CEAS in reducing vehicle emissions.
- 3) Examine the effect of the New Condensator CEAS on vehicle fuel economy during on-road testing.

To accomplish these objectives, WVU performed the following research tasks:

- (a) Conditioned truck and measure baseline fuel economy.
- (b) Measured tailpipe and crankcase emissions and fuel consumed on a chassis dynamometer.
- (c) Installed the CEAS and measured tailpipe emissions and fuel consumed on a chassis dynamometer.
- (d) Operated the vehicle on-road to examine fuel economy changes.
- (e) Re-measured tailpipe emissions and fuel consumed on the chassis dynamometer with the CEAS still installed.
- (f) Removed the CEAS and measured tailpipe, crankcase emissions and fuel consumed on the chassis dynamometer

TEST EQUIPMENT

Test Vehicle

The characterization of the system was performed using a 1996 Peterbilt truck. Characteristics of this vehicle are shown in Table 1.

Table 1: Test Vehicle Characteristics

Vehicle Type	Tractor
VIN	41XP5DB80TN36365
Manufacturer	Peterbilt
Model Year	1996
Gross Vehicle Weight (GVW)	46000 lbs.
Curb Weight	18530 lbs. (without trailer)
Dynamometer Test Weight	56,000 lbs.
Odometer Reading (pre-testing)	427724 miles
Transmission	18 Speed Manual
Engine	1996 Caterpillar C15 3406 Inline 6 Cylinder
Engine Displacement	14.6 Liters
Engine Rated Power	550 hp



Figure 1: Peterbilt tractor with crankcase blow-by sampling system in place.

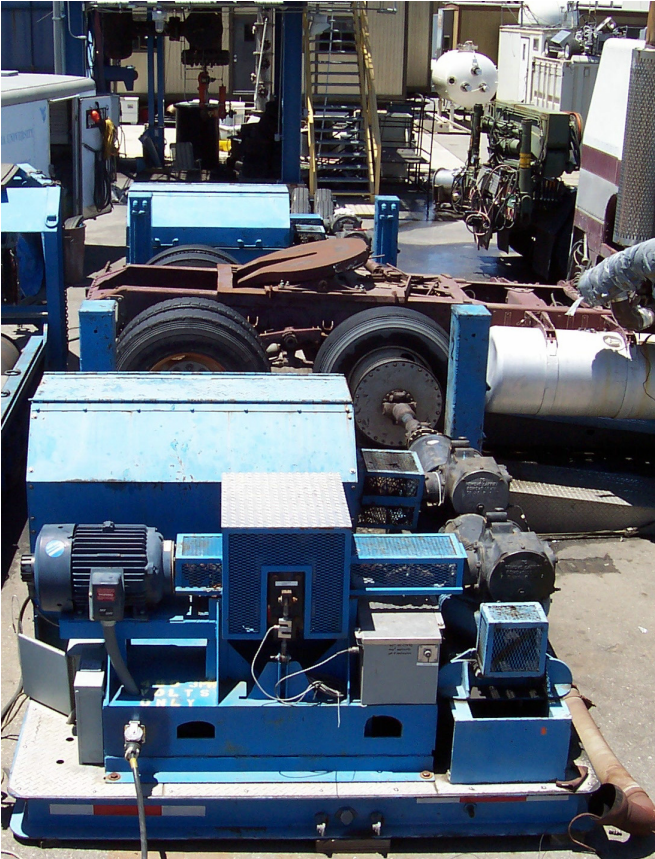


Figure 2: Typical setup of the chassis dynamometer when testing dual axle tractors.

Chassis Dynamometer

The WVU Transportable Heavy-Duty Laboratory conducted the emissions tests at the WVU facilities in Westover, WV. Detailed information pertaining to the design and operation of the Transportable Laboratory can be found in technical papers [1, 2, 3]. The dynamometer unit consisted of power absorbers and a set of selectable flywheels, which allowed simulation of tire rolling losses, aerodynamic drag and inertial load equivalent to a gross vehicle weight of up to 60,000 pounds. Torque cells and speed transducers continuously measured drive axle torque and speed. Road load drag on the vehicle was mimicked partially by the irreversible (frictional) losses in the laboratory, and was adjusted to the correct value at each speed using eddy current power absorbers with closed-loop torque control. A human driver operates the vehicle while following a speed trace displayed on a computer screen in the vehicle cab.

Chassis dynamometer testing is the most accurate and repeatable method of characterizing emissions from in-use heavy-duty vehicles and provides the most useful data for prediction of atmospheric emissions inventories, evaluation of clean-vehicle programs at transit agencies and truck fleets, and assessing the success of retrofit programs. Chassis dynamometer systems have been developed and used for many years and it has been demonstrated that they are reliable tools for studying vehicle emissions.

Emissions Measurement

The exhaust (tailpipe) emissions measurement system used a full-scale dilution tunnel measuring 18 inches in diameter and 20 feet in length. The exhaust was mixed with HEPA filtered ambient air and the quantity of diluted exhaust was measured precisely by a critical flow venturi system (CVS). Diluted exhaust was analyzed

using non-dispersive infrared (NDIR) analyzers for carbon monoxide (CO) and carbon dioxide (CO₂), and using chemiluminescent detection for oxides of nitrogen (NO_x). NO_x emissions were corrected for standard humidity. Hydrocarbons (HC) were analyzed using flame ionization detection (FID). Simultaneous pre-tunnel bag samples were taken during each test to establish ambient background gas concentrations. The gaseous emissions measurements were performed in accordance with the CFR Title 40, Part 86 Subpart N (CFR40) [4] to the extent possible. Fuel economy was determined using a carbon balance using fuel properties and exhaust emissions data.

Particulate matter (PM) was collected using 70-mm fluorocarbon coated glass fiber filter media and PM mass emissions were measured gravimetrically. Dilution tunnel background samples were collected for establishing particulate matter background levels. Even though the tunnel has HEPA filtered dilution air, PM backgrounds are essential because the dilution tunnel walls may shed particles that are re-entrained into the sample stream or outgas heavy hydrocarbons that condense onto the PM.

Crankcase Emissions Evaluation

For the analysis of crankcase flow, a novel separate system to sample HC, CO, CO₂, NO_x, and PM was designed and constructed. Gaseous emissions samples were monitored by drawing a sample stream from the crankcase flow upstream of its entry into a 3 inch diameter dilution tunnel sized to accept full flow of crankcase emissions. At the entrance to the dilution tunnel, the crankcase flow was mixed with filtered ambient air. Flow control was accomplished using two parallel mass flow controllers with a combined capacity of 11 scfm. This capacity exceeded the maximum flow from the crankcase for the Peterbilt truck. Particulate matter emissions were collected using 90 mm filters located upstream of the mass flow controllers. Since the system flow was maintained at a value higher than that of the crankcase flow, this arrangement allowed the entirety of the particulate present in the crankcase flow to be captured.

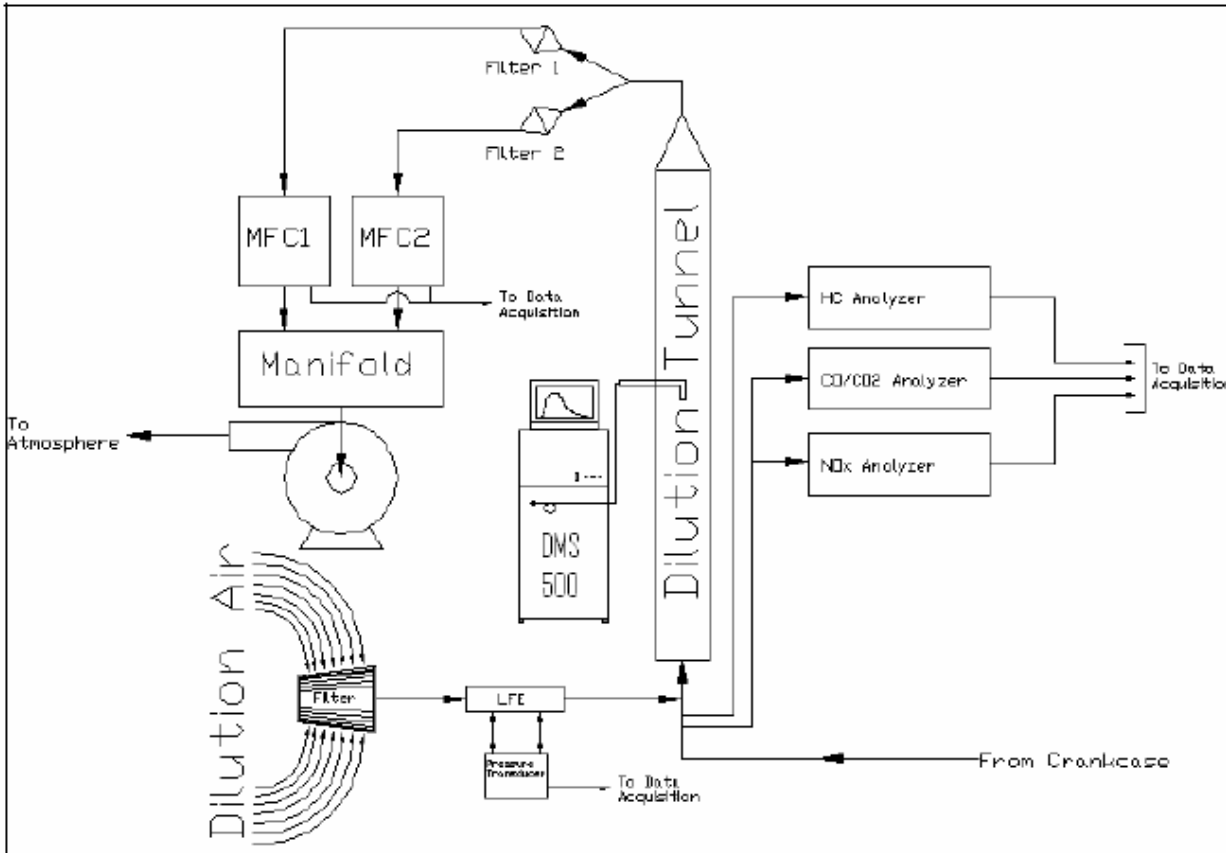


Figure 3: Schematic showing the crankcase blow-by sampling system.

Additionally, a DMS 500 particulate classifier system drew a small sample from the dilution tunnel to measure particle size distributions.

Crankcase PM Organic Fraction

Engine crankcase emissions arise from gas leakage past piston rings and valve guides. This gas must be vented from the crankcase and may carry lubricant droplets and products of thermal decomposition of the lubricant with it. The filters in the crankcase sampling system collected both particulate matter from the combustion process and the droplets originating from the crankcase. Several filters were sent to Desert Research Institute (DRI) and the amount of hopanes and stearanes, which arise from the lubricating oil, were determined. Additionally, a lubricating oil sample was also analyzed by DRI to determine its hopane/stearane concentration. By comparing the hopane/stearane concentrations from both the filter and the oil, the percentage of PM composed of oil could be ascertained. An example of the calculations involved in determining the amount of oil deposited on the filter for test 4552-03 is given below.

Hopane/Stearane Concentration in Oil: 2589 $\mu\text{g} / \text{g}$ Oil (Sum of individual component concentrations)

Hopane/Stearane on Filter (4552-03): 164 $\mu\text{g} / \text{filter}$ (Sum of individual components)

Total Oil on Filter = Hopane+Stearane on Filter / Hopane+Stearane Concentration in Oil

Total Oil on Filter = (164 $\mu\text{g} / \text{filter}$) / (2589 $\mu\text{g} / \text{g}$ Oil) = 0.0633 g = 63.3 mg

Driving Schedule for Dynamometer Testing

For both pre- and post-accumulation testing, the Urban Dynamometer Driving Schedule (UDDS) was utilized (Figure 4). The UDDS, also known as Test D, is a speed-time driving schedule developed using a Monte Carlo simulation with in-use vehicle driving data and appears in the US EPA Code of Federal Regulations, Title 40, Part 86. The UDDS has been widely used for characterization of performance of heavy-duty truck technology. The UDDS includes both freeway and non-freeway driving behavior.

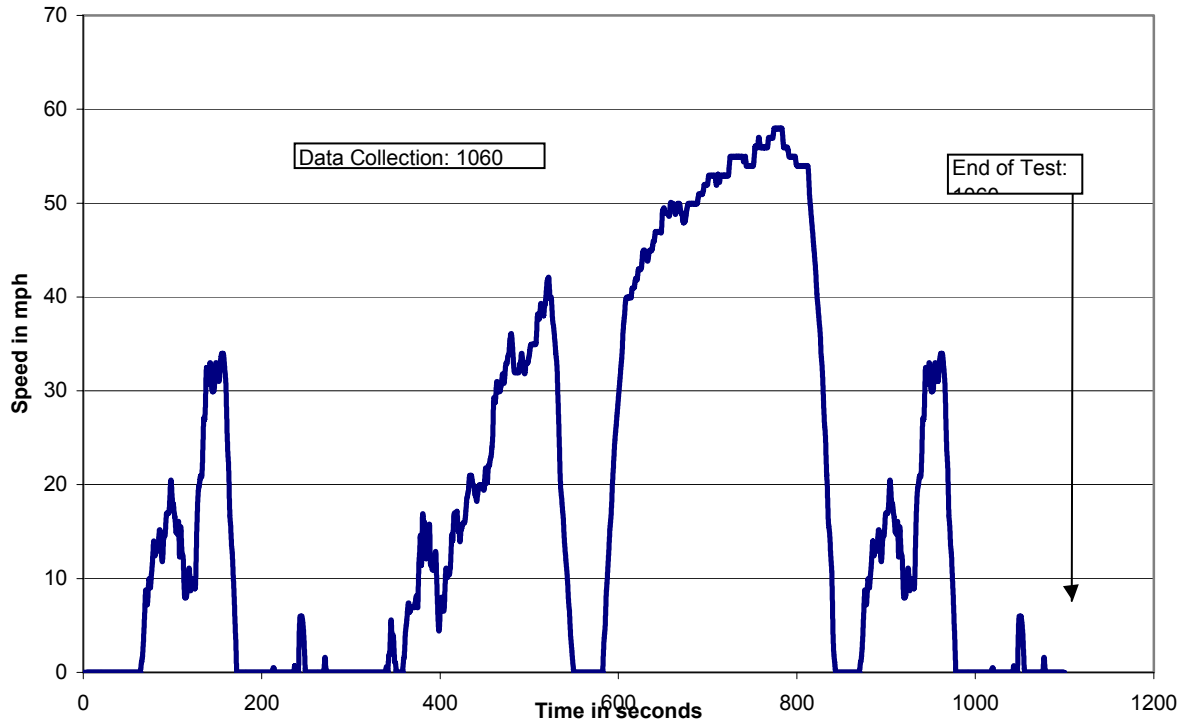


Figure 4: The Urban Dynamometer Driving Schedule (UDDS)

Test Fuel

A single batch of #2 diesel fuel was procured from a local depot at the start of this study solely for use during chassis dynamometer testing. At the end of the baseline chassis dynamometer testing, the remaining fuel in the tanks was transferred into 55 gallon drums and transferred back into the vehicle fuel tanks for the post-accumulation testing.

New Condensator CEAS

The New Condensator CEAS device, mounted on the vehicle firewall, received crankcase blow-by and returned flow to the intake of the engine. In this way it prevented 100% of the crankcase emissions from reaching the atmosphere directly. As can be seen in Figure 5, some of the non-gaseous compounds present in the crankcase blow-by were removed from the blow-by stream and retained by the CEAS. While the retained material was not analyzed in detail, it was apparent by visual/physical examination that it contained both lubricating oil and particulate matter.



Figure 5: New Condensator CEAS system installed on the test vehicles firewall.

METHODOLOGY

Baseline Fuel Consumption

Prior to performing the emissions and fuel economy testing, WVU obtained baseline fuel consumption data by operating the truck without the CEAS installed, with a loaded trailer at 56,000 lb GVW while recording fuel consumption using on board ECU data collection. The route used was a round trip to Mt. Sterling, Ky.

Baseline Emissions Measurements

Phase 1 testing was performed to establish baseline vehicle emissions and evaluate the device prior to mileage accumulation on the test vehicle. For the pre-accumulation baseline testing, the vehicle was exercised over the UDDS while both tailpipe and crankcase emissions were collected. After the device was installed, tailpipe emissions were characterized.

Mileage Accumulation

This portion of this study served to condition the CEAS and the engine with the CEAS installed by operating the test vehicle under normal conditions. During this accumulation period, the test vehicle hauled a flatbed trailer loaded to bring the total weight of the tractor and trailer to 56,000 lbs, so as to mimic engine loads expected on an in-use tractor.

Post-Accumulation Emissions Measurement

At the conclusion of the mileage accumulation period, tailpipe emissions and fuel economy were evaluated both before and after removal of the CEAS. Post-accumulation crankcase emissions were not evaluated.

RESULTS & DISCUSSION

Baseline Fuel Consumption

The test vehicle was driven from the WVU test facility in Westover, WV to Mt. Sterling, KY, a round-trip distance slightly less than 600 miles, during the baseline fuel consumption data collection exercise. Fuel consumption data from the baseline run are shown in Table 2. The difference in fuel economy between that determined by subtracting the fuel weight after the trip from that taken before the trip and that taken from the vehicle ECU was less than 1%. Fuel consumption reported by the ECU was corrected to compensate for fuel density changes resulting from varying fuel temperature.

Table 2: Baseline fuel consumption from both fuel weight (scale) and recorded ECU data.

	Initial Odometer Reading	Final Odometer Reading	Distance	Fuel Consumption by Scale	Fuel Consumption by ECU	Fuel Economy by Scale	Fuel Economy by ECU
	(miles)	(mile)	(miles)	(gallons)	(gallons)	(mpg)	(mpg)
Baseline	427103	427697	594	119.6	120.3	4.97	4.94

Baseline Emissions Measurements

Subsequent to the on-road baseline fuel economy test, the test vehicle was mounted on the chassis dynamometer and exercised over the UDDS while emissions and fuel economy (via a carbon balance) were measured. Table 3 shows tailpipe emissions and fuel economy averaged over three successive test runs both with and without the CEAS installed. Results from each individual test are contained in Appendix B where test 4552 was without the CEAS installed and 4555 was with the CEAS installed. In the runs without the CEAS installed, the sample filters were overloaded during the testing, and the filter flow could not be maintained at the setpoint (4 scfm) for the last 600 seconds of the UDDS and slowly dropped to 3 scfm by the end of the test. This biases the PM measurement over the UDDS and also alters sample filter capture efficiency. After the CEAS was installed, the sample filter flowrate setpoint was reduced to 3 scfm and the filter was not overloaded. The 0.54 g/mile number is therefore reliable but the 0.65 g/mile value is in question. However, later chassis dynamometer data are shown in Table 8 below.

Table 3: Baseline tailpipe emissions and fuel economy results from dynamometer testing (the PM value of 0.65 g/mile is discussed in the text)

Run Seq. No.	CO (g/mile)	NO _x (g/mile)	FIDHC (g/mile)	PM (g/mile)	CO ₂ (g/mile)	Economy (mpg)	Economy (BTU/mile)	Distance (miles)
without CEAS	7.24	18.2	0.43	0.65	2603	3.83	34377	5.47
with CEAS	7.55	18.2	0.49	0.54	2666	3.74	35207	5.50
% change	+4%	0%	+14%	-17%	2%	-2%	2%	

The crankcase emissions for the testing without the CEAS installed are shown in Table 4 and the crankcase emissions as a percentage of tailpipe emissions are shown in Table 5. For references in reviewing Table 4 and Table 5 the total fuel consumed by the engine is approximately 800 g/mile. When compared to tailpipe emissions, crankcase emissions are relatively low. In the case of NO_x, and CO₂, the crankcase emissions were insignificant when compared to tailpipe emissions. In the case of CO, the crankcase CO emissions as a percentage of tailpipe CE averaged 1.25% while crankcase PM and HC emissions were significant in relation to tailpipe emissions, 3.66% and 5.73% respectively. In examining PM and HC, the comparative numbers assume that the entire mass captured on the particulate filter consists of particulate arising from the combustion process

in-cylinder. However, as is shown later, approximately 50% of the mass collected on the particulate filter is actually lubricating oil, which could be considered hydrocarbon emissions when viewing the vehicle as a whole.

Table 4: Baseline crankcase emissions results from dynamometer testing.

Test	HC (g/mile)	NO _x (g/mile)	CO (g/mile)	CO ₂ (g/mile)	PM (g/mile)
4552-02	0.016	0.018	0.108	2.86	0.037
4552-03	0.016	0.016	0.085	2.66	0.036
4552-04	0.016	0.017	0.080	2.67	0.036
Average	0.016	0.017	0.091	2.73	0.037

Table 5: Crankcase emissions as a percentage of tailpipe emissions.

	HC	NO _x	CO	CO ₂	PM
4552-03	3.76%	0.10%	1.41%	0.11%	5.18%
4552-04	3.62%	0.09%	1.22%	0.10%	6.07%
4552-05	3.66%	0.09%	1.14%	0.10%	5.73%

Figure 6 and Figure 7 show, respectively, continuous tailpipe CO₂ and NO_x emissions both before and after the CEAS was installed. Beyond expected slight run-to-run variations arising from slight changes in driving behavior, there were no significant differences in continuous CO₂ and NO_x.

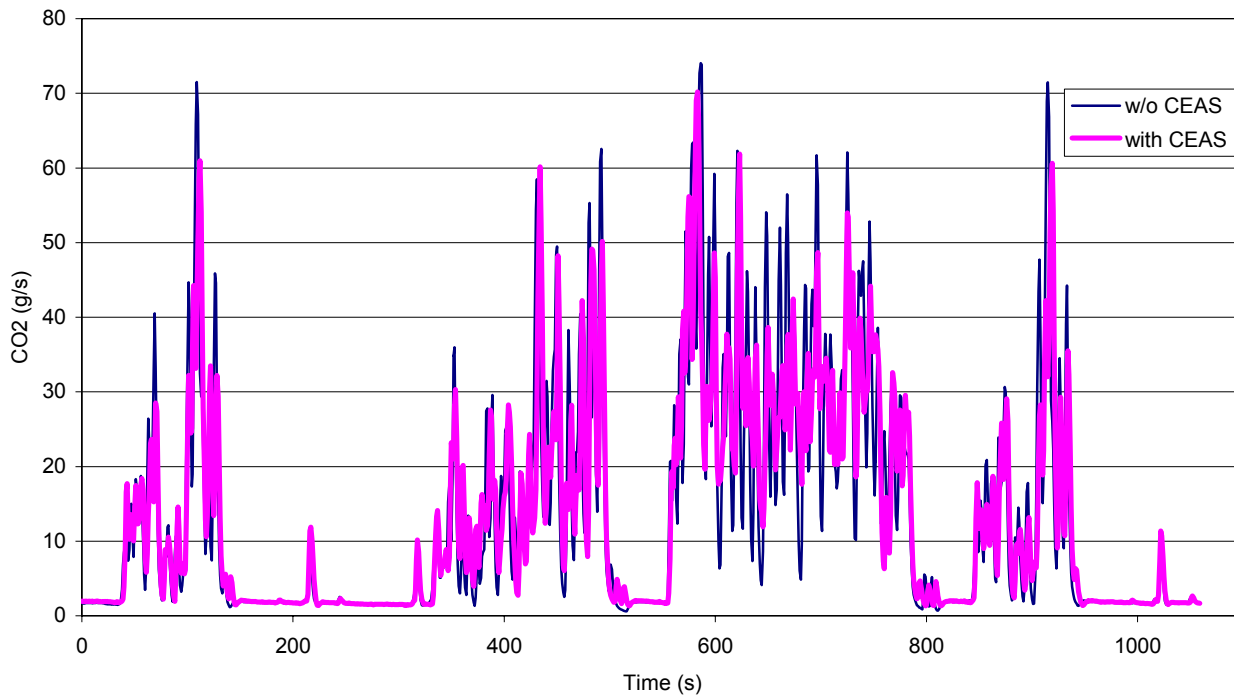


Figure 6: Continuous carbon dioxide emissions from the baseline chassis testing.

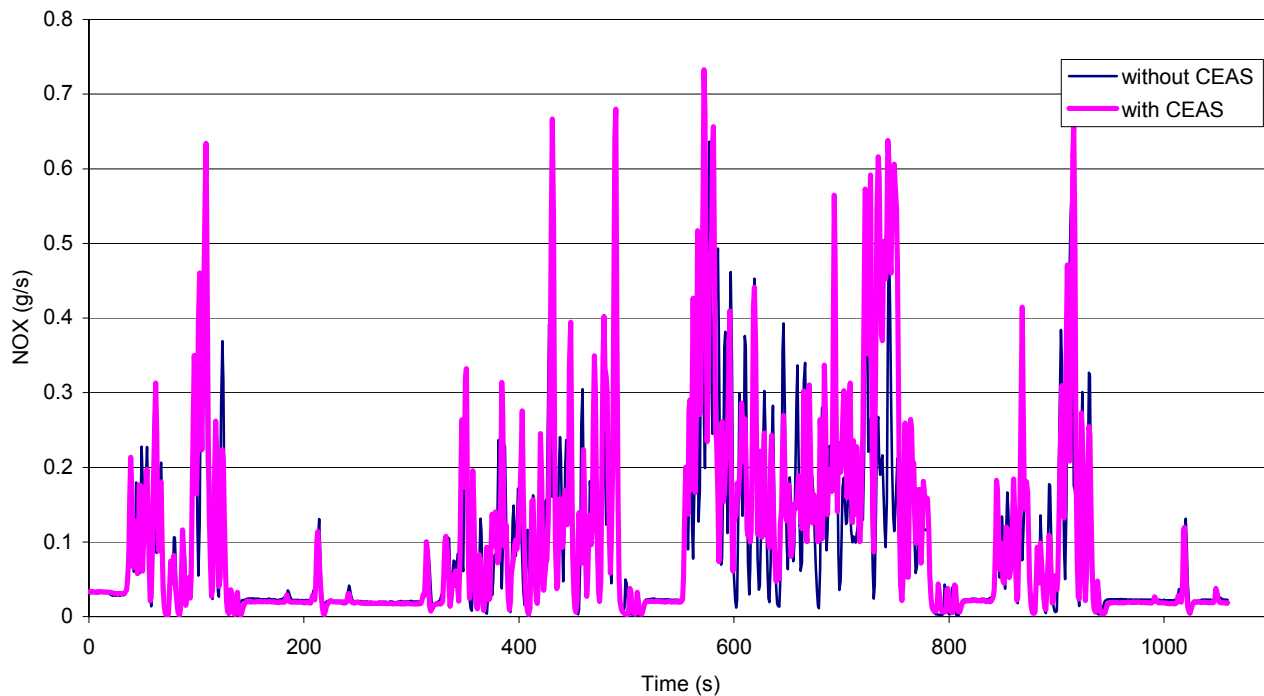


Figure 7: Continuous oxides of nitrogen emissions from the baseline chassis testing.

Crankcase Blowby Lubricating Oil Content

The amount of lubricating oil present in the crankcase blow-by was determined by determining the levels of hopane and stearane compounds on the filters in the crankcase blow-by sampling system and comparing these levels to the levels found in the lubricating oil. Both the filters and a lubricating oil sample were analyzed by Desert Research Institute (DRI). The analysis methodology employed by DRI is contained in Appendix A.

Figure 8 shows the concentration of each compound in the oil sample and in the crankcase blow-by filters used for test 4552-05. Since the concentrations levels of each of the hopane/stearane species from the oil sample and filters are similar, the assumption that all of the hopane/stearane compounds found on the filters arose from lubricating oil present in the crankcase blow-by can be made with confidence.

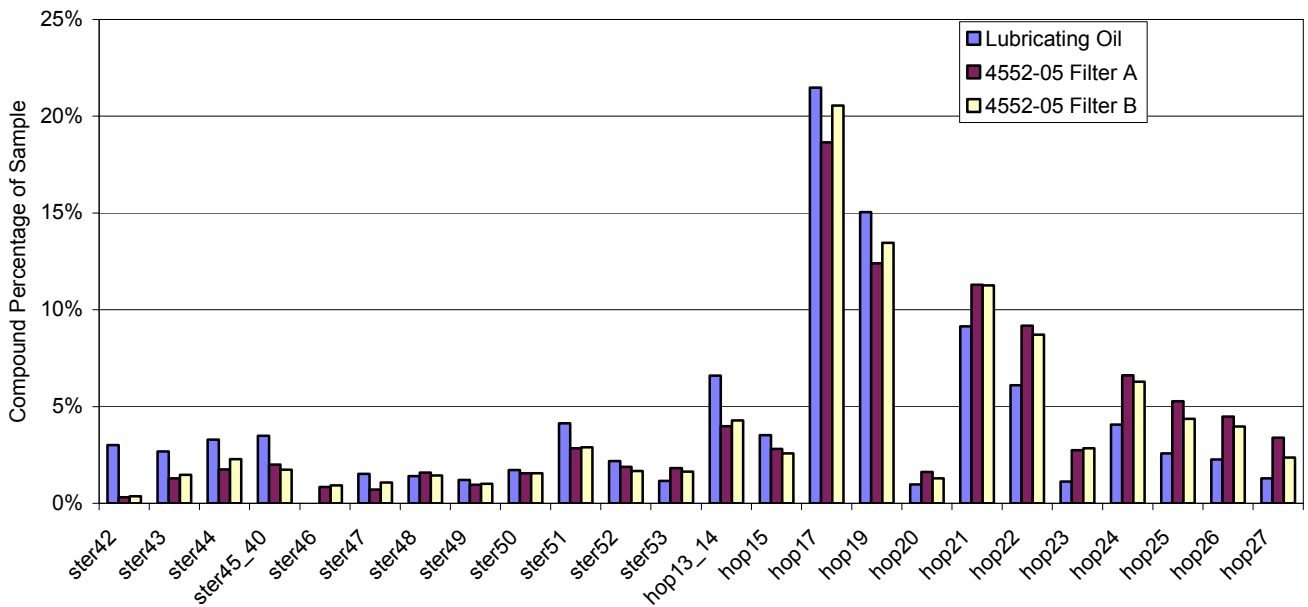


Figure 8: Concentration of hopane/stearane compounds in lubricating oil and crankcase blow-by sample filters.

The mass of lubricating oil on each filter was determined by dividing the total amount of hopane and stearane compounds found on the filter (ug hopane+stearane / filter sample) by the total concentration of hopane and stearane compounds in the lubricating oil (ug compound / g lubricating oil). This mass was then compared to the total mass collected on the filter (Table 6) to reveal what percentage of the filter mass was PM from combustion carried past the piston rings and into the crankcase and what percentage was lubricating oil.

Table 6: Comparison of crankcase oil and particulate matter data.

Test Number	Test Type	Filter Code	Mass of Oil on PM filter (mg)	Total Mass on PM Filter (mg)	Ratio of Oil / TPM
4553_01	Background	Red	0.79	0.92	0.86
4553_01	Background	Red	0.97	0.92	1.06
4553_01	Background	Green	1.68	1.91	0.88
4552_03	UDDS	Red	28.69	70.88	0.40
4552_03	UDDS	Green	72.17	133.01	0.54
4552_03	UDDS	Green	63.24	133.01	0.48
4552_05	UDDS	Red	41.21	70.40	0.59
4552_05	UDDS	Green	67.12	131.58	0.51

For the background tests, where the sampling system was operated in its normal fashion while the test vehicle was not run, the percentage of oil on the filters was close to 100%. This does imply that, even with the engine not running, some oil was captured by the filters. WVU suspects that a small amount of oil residue from previous testing may have been captured by the filters but that the total mass on the background filters was not significant when compared to those from UDDS testing.

For the UDDS testing, the percentage of oil on the filters ranged from 40-59% with an average of 50.4%. This implies that, for this test vehicles exercised over the UDDS, half of the filter mass was made up of lubricating oil while the other half was particulate matter from in-cylinder combustion, wear and other sources.

Mileage Accumulation

After completion of the baseline testing, the test vehicle, with the CEAS installed and the vehicle loaded to 56,000 lbs., was operated over the same route (from Westover, WV to Mt. Sterling, KY and back) and both fuel weighing and ECU data were collected. After this fuel economy run, the vehicle was operated for 8,300 additional miles to condition the CEAS system. Following this mileage accumulation, five additional fuel economy runs were made with the test vehicle under the same loading conditions. These fuel economy runs were made over the same route as the previous fuel economy runs. For the CEAS runs 2-6, which were made after the 8,300 mile accumulation, the average fuel economy was 5.17 mpg from scale measurements and 5.07 mpg from ECU data.

Table 7: Pre- and post-accumulation fuel economy data.

	Date	Initial Odometer Reading	Final Odometer Reading	Distance	Fuel Consumption by Scale	Fuel Consumption by ECU	Fuel Economy by Scale	Fuel Economy by ECU
		(miles)	(mile)	(miles)	(gallons)	(gallons)	(mpg)	(mpg)
Baseline	11/16/05	427103	427697	594	119.6	120.3	4.97	4.94
CEAS Run 1	12/15/05	427731	428325	594	120.5	123.9	4.93	4.79
CEAS Run 2	1/10/06	435975	436569	594	113.8	111.8	5.22	5.31
CEAS Run 3	1/13/06	436569	437162	593	114.6	108.7	5.17	5.46
CEAS Run 4	1/19/06	437162	437755	593	114.0	118.2	5.20	5.02
CEAS Run 5	2/3/06	437799	438393	594	115.7	118.8	5.13	4.99
CEAS Run 6	2/8/06	438392	438986	594	116.3	119.7	5.11	4.61

Following the final fuel economy run, the vehicle was operated under the same loading conditions while an additional 2,100 miles before post-accumulation testing. In total, the vehicle was operated successfully for 13,400 miles with the CEAS installed. The crankcase remained fully closed for this whole period.

Post-Accumulation Emissions Measurement

After the mileage accumulation, the vehicle was mounted on the chassis dynamometer and exercised over the UDSS while tailpipe emissions were taken. A total of 10 tests was performed including a conditioning warmup test and three hot-start tests with the CEAS still installed, a conditioning warmup test and four hot-start tests with the CEAS removed. Results for each individual test are shown in Appendix B where test 4611 runs were those with the CEAS installed and test 4614 were tests with the CEAS removed and summary results are shown in Table 8.

Table 8: Post-accumulation tailpipe emissions data.

	CO	NO _x ¹	FIDHC	PM	CO ₂	mile/gal	BTU/mile	Miles
with CEAS (3 runs)	5.71	20.2	0.32	0.53	2530	3.95	33382	5.52
without CEAS (2 runs)	5.85	20.0	0.33	0.58	2547	3.92	33600	5.53
% change	2.8%	-1.0%	3.1%	9.4%	0.6%	-0.7%	0.7%	0.2%
without CEAS + 100% fan (2 runs)	5.91	19.0	0.37	0.57	2758	3.62	36380	5.49

For all but the final two tests, the vehicles cooling fan was set to automatically engage according to temperature while the fan was operated in manual mode. For the final two tests, the fan was engaged for the whole test. The result of operating with the fan engaged 100% of the time was an approximately 7% drop in fuel economy (3.92mpg to 3.62mpg). The decision to switch the fan on manually for the final two tests was the result of observing emissions spikes (especially CO₂) in earlier post-accumulation UDSS testing as a result of the fan

engaging when the coolant temperature rose. Based on this information, WVU performed a closer examination of ambient temperature during chassis dynamometer testing (Table 9) in the case that large differences in ambient temperature would have affected the amount of time the cooling fan would be engaged during the chassis tests. As can be seen, the ambient temperature did not vary significantly, averaging approximately 70°F during the pre-accumulation testing and approximately 80°F during the post-accumulation testing. Based on this information, it is unlikely that ambient temperature and, consequently, fan operation, had a significant impact on emissions or fuel economy. It should also be noted that ambient temperatures during all of the chassis testing (with the exception of 4555-01) fell within the 68-86 °F range mandated by the EPA for heavy-duty engine certification testing.

Table 9: Ambient temperature during chassis dynamometer testing.

Test ID	Test Type	Average Ambient Temperature (F)
4552-02	Baseline	68.5
4552-03	Baseline	69.5
4552-04	Baseline	70.0
4555-01	CEAS	66.5
4555-02	CEAS	69.0
4555-03	CEAS	70.0
4611-02	Post-Accumulation CEAS	76.5
4611-03	Post-Accumulation CEAS	78.5
4611-04	Post-Accumulation CEAS	80.0
4611-05	Post-Accumulation CEAS	81.0
4614-02	Post-Accumulation Baseline	78.0
4614-03	Post-Accumulation Baseline	79.5
4614-04	Post-Accumulation Baseline	81.0
4614-05	Post-Accumulation Baseline	79.5

Table 10 shows a comparison of tailpipe emissions and fuel economy from both the pre- and post-accumulations chassis dynamometer tests.

Table 10: Averaged emissions and fuel economy for pre- and post-accumulation testing both with and without the CEAS installed. The 0.65 g/mile PM value was discussed previously in the report text.

	CO (g/mile)	NO _x (g/mile)	FIDHC (g/mile)	PM (g/mile)	CO ₂ (g/mile)	Economy (mpg)	Economy (BTU/mile)	Distance (miles)
Baseline without CEAS	7.24	18.2	0.43	0.65	2603	3.83	34377	5.47
Baseline with CEAS	7.55	18.2	0.49	0.54	2666	3.74	35207	5.50
Post-accumulation with CEAS	5.71	20.2	0.32	0.53	2530	3.95	33382	5.52
Post-accumulation without CEAS	5.85	20.0	0.33	0.58	2547	3.92	33600	5.53

Crankcase and Tailpipe Particle Emissions

The particle size distribution was measured using a Cambustion DMS500 [6-9], which is capable of measuring multiple size bins in real time. The basic principle of the instrument is to load the particles with a known charge using corona discharge, and send them through a classifier which consists of a high voltage central rod and outer rings with different voltages. The particles are then deflected to the rings according to their charge, which is an indication of their size. These particles create currents when they land on the rings and these currents are converted into a distribution using an inversion matrix in the software.

Figure 9 shows the concentration of particles in the crankcase blow-by in units of number of particles (N) per unit volume (cubic centimeters – cc). Figure 9 shows that the particulate concentration generally followed engine power during the tests. It also shows that the particulate concentration stabilized after the engine had warmed as the cold start concentration is higher than that from the hot start tests.

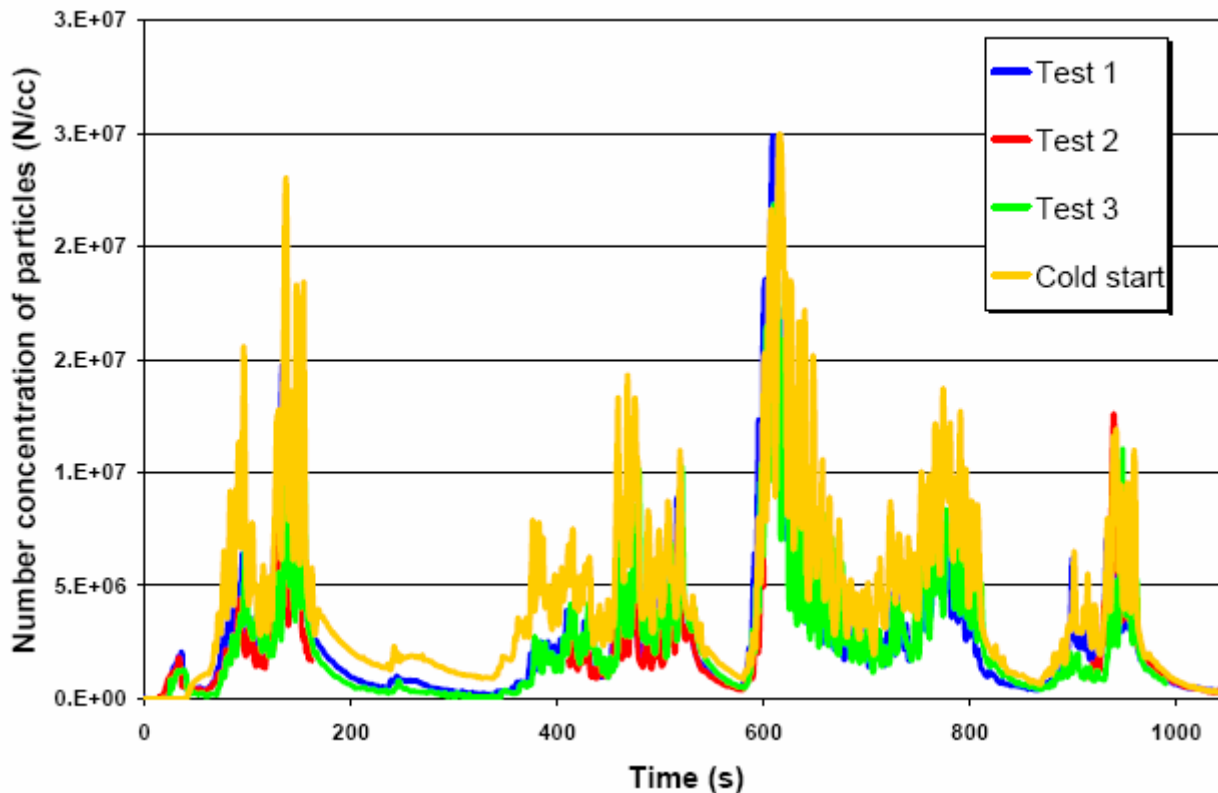


Figure 9: Number concentration of particles in the crankcase blow-by stream as measured using the DMS500 particle sizer (Test 1: 4552-03, Test 2: 4552-04, Test 3: 4553-05).

Figure 10 shows the total number of particles present in the crankcase blow-by for a hot-start UDDS test while Figure 11 shows the actual size distribution for those particles where red indicates the higher concentrations and blue indicates lower concentrations. From Figure 11 we can see that the particle size with the highest concentration is approximately 70nm.

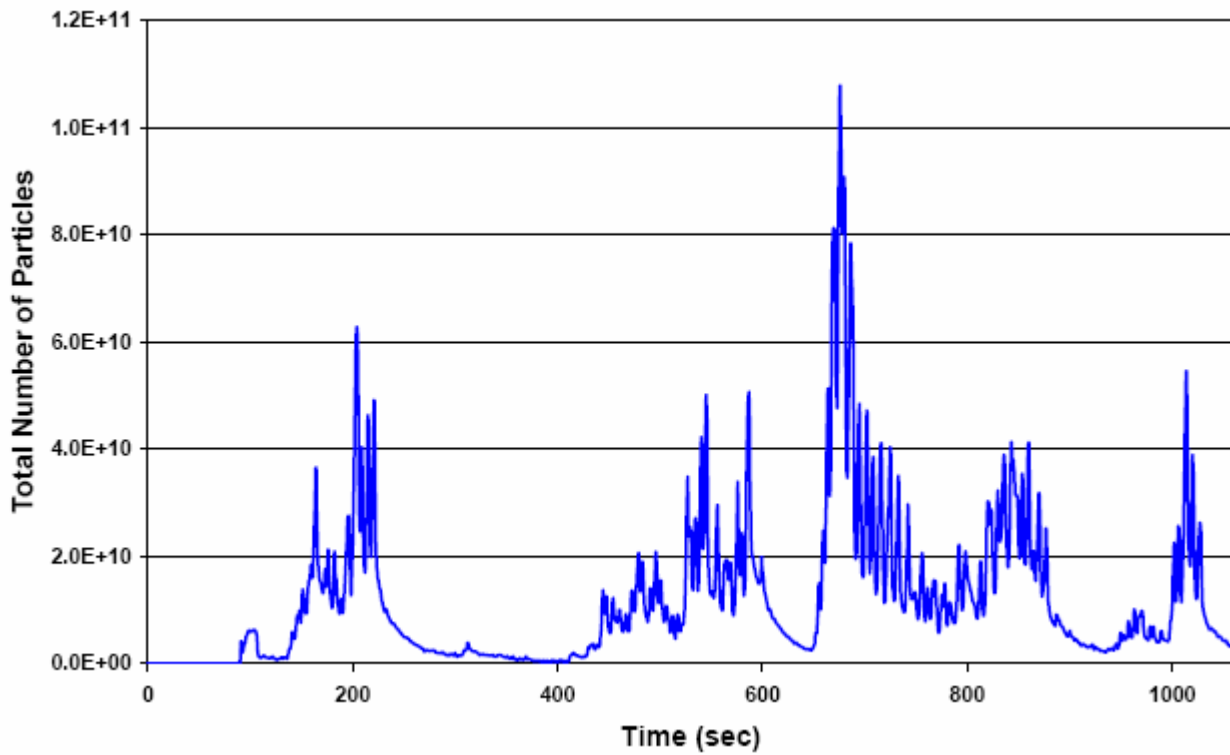


Figure 10: Total number of particles present in the crankcase blow-by stream for a hot start UDDS test.

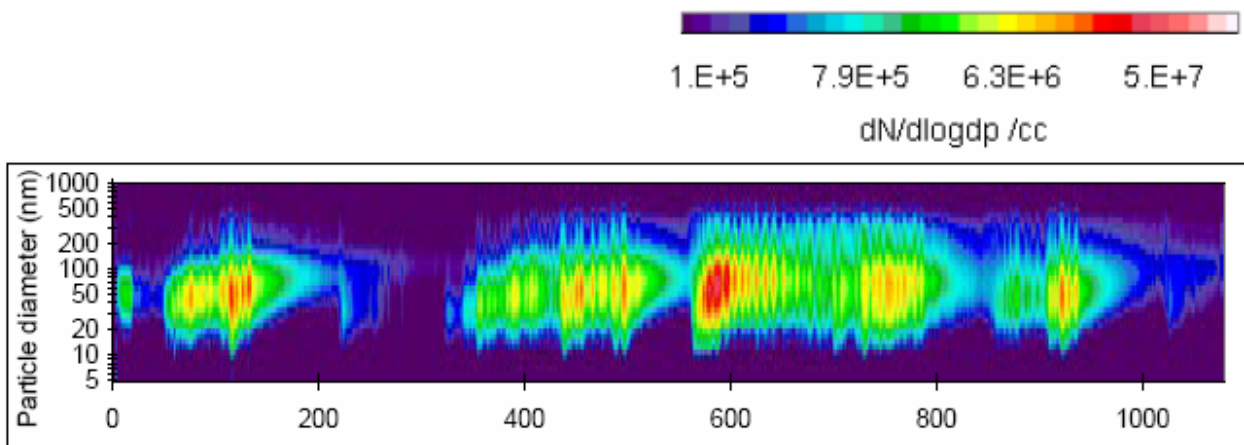


Figure 11: Particle size distribution present in the crankcase blow-by stream for a hot-start UDDS test.

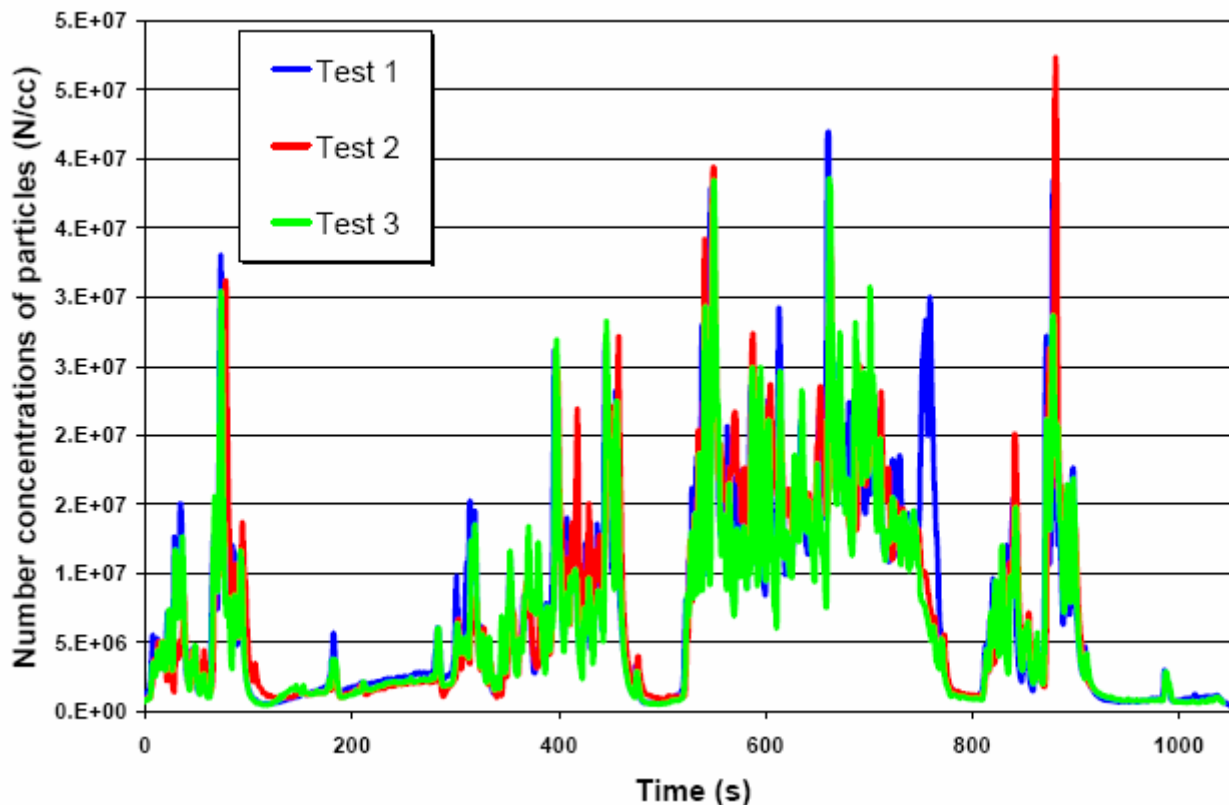


Figure 12: Continuous particle concentration in the dilute tailpipe exhaust from three hot-start UDDS tests (Test 1-4555-01, Test 2: 4555-02, Test 3: 4555-03).

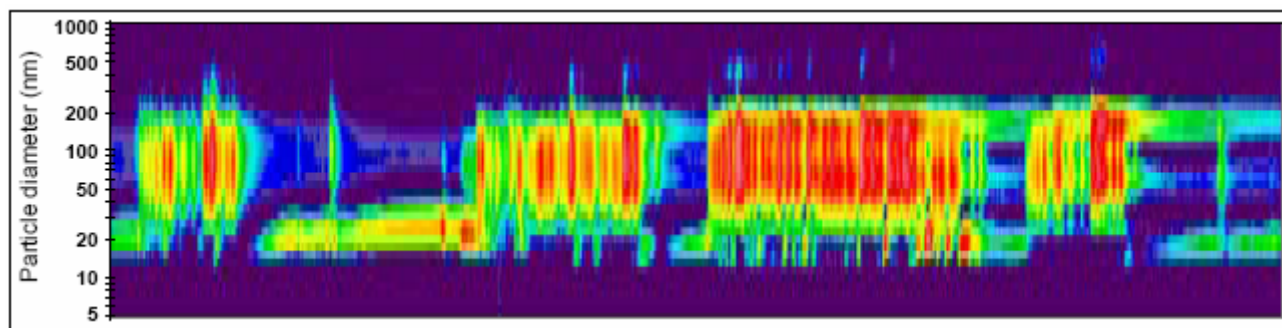


Figure 13: Continuous particle size distribution in the dilute exhaust from a hot-start UDDS test.

Figure 12 shows the continuous particle size concentration in the dilute tailpipe exhaust for the three hot-start UDDS tests while Figure 13 shows continuous particle size distribution from one of the hot-start UDDS tests. A comparison of crankcase blow-by size distribution (Figure 11) with tailpipe size distribution (Figure 13) shows that the tailpipe particle size was distributed over a larger size range (20-200nm) than that from the crankcase (70nm). A closer examination of the continuous particle emissions is shown in Figure 14 where the particle concentrations for the 20.5nm and 86.6nm ranges are plotted against time for a hot-start UDDS.

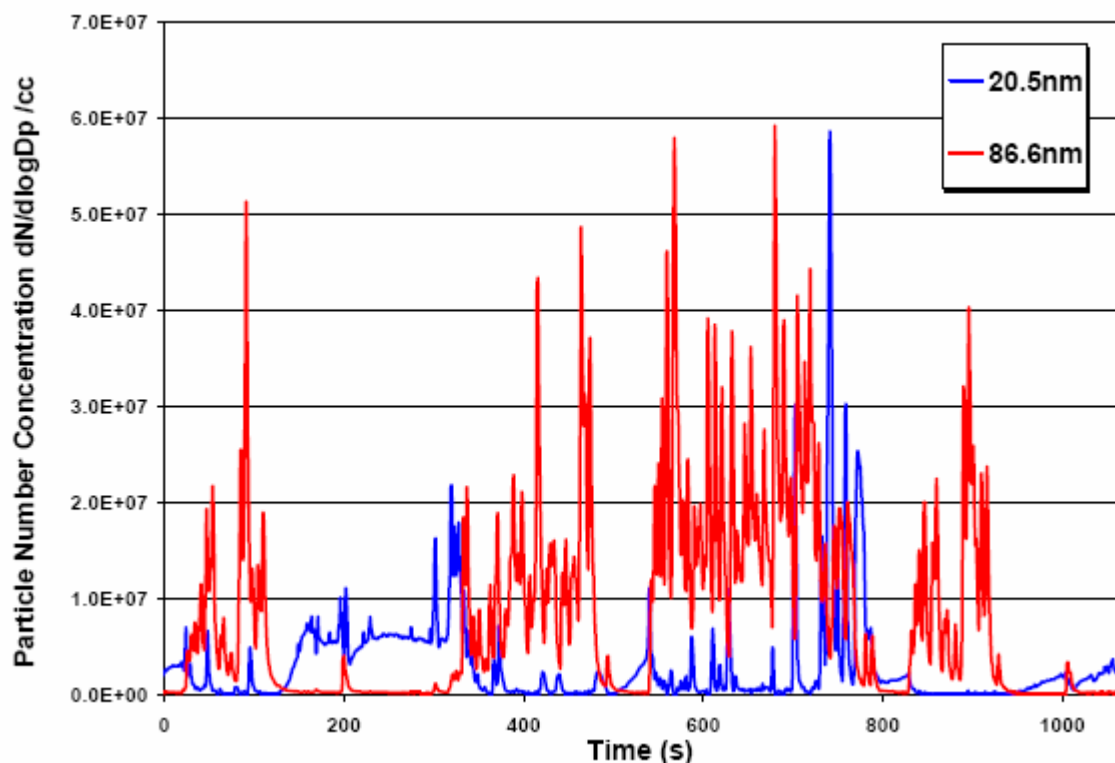


Figure 14: Continuous particle concentrations for two size ranges from the dilute tailpipe exhaust over a hot-start UDDS.

CONCLUSIONS

The New Condensator CEAS was installed on a Peterbilt tractor with a 1996 Caterpillar C15 3406 engine, and emissions and fuel economy were measured before and after installation.

Based on testing on a chassis dynamometer over the Urban Dynamometer Driving Schedule, the New Condensator system eliminated 37 mg of particulate matter, 16 mg of hydrocarbons and 0.225×10^{12} particles emitted in the crankcase flow per mile of operation. The CEAS successfully eliminated 100% of the crankcase emissions over 13,400 miles of on-road operation. Before installation of the CEAS, the fuel economy of the Peterbilt tractor-trailer on a prescribed road route was found to be 4.97 miles per gallon at 56,000 lb gross combination weight. With the CEAS installed, six runs over the same route yielded an average reduction in fuel consumed of 3.9% (5.17 miles per gallon).

Analysis of particulate filters taken from the crankcase blow-by showed that, in the case of this test vehicle, approximately 50% of the matter collected on the filters was the result of oil from the crankcase while the other 50% could be attributed to combustion PM escaping past the cylinder rings and into the crankcase, and to other sources such as engine wear.

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Appendix A - Summary of DRI Standard Operating Procedure used for Hopane and Stearane Analysis

(This description is a summary version of the Desert Research Institute Standard Operating Procedure, provided to WVU by Barbara Zielinska of DRI)

Analysis of Semi-Volatile Organic Compound by GC/MS

This method describes the analysis of semi-volatile organic compounds (SVOC) in air. The SVOC in this case consist of (non-polar) Hopanes and Steranes. Filters are extracted and combined dependent on analyses. The analysis method is gas chromatography/mass spectrometry (GC/MS). Mass spectrometry provides definitive identification of SVOCs.

The chromatographic system consists of a Varian CP-3800 gas chromatograph equipped with an 8200 CX Autosampler and interfaced to a Varian Saturn 2000 Ion Trap Mass Spectrometer. The alternative system consists of a Varian CP-3800 gas chromatograph with a model CP-8400 Autosampler and interfaced to a Saturn 2000 Ion Trap Mass Spectrometer. Column is a CP-Sil8 30mx0.25 mmX025XX (Chrompack).

Filter Cleaning Procedure

Teflon-impregnated glass fiber (TIGF) filters (Pall Life Sciences, Type T60A20) are cleaned by sonication for 10 minutes in dichloromethane (CH₂Cl₂) twice, with the solvent replaced and drained, and sonicated for 10 minutes in methanol twice with the solvent replaced. Filters are then dried in a vacuum oven at -15 to -20 in Hg, 50° C for minimum of 24 hours, weighed (if necessary), placed in foil packages that have been fired at 500° C for 4 hours, placed in Uline metallic ZipTop static shielding bags, and stored at room temperature.

Hopane And Stearane Extraction

Prior to extraction, the following deuterated internal standards are added to each sample (filter, PUF/XAD/PUF): cholestane- d₆ 0.375 ng/μl The amount of internal standards added should correspond to the expected range of concentrations found in real samples.

Extraction of Filter

Depending on analyses, the Filter will be extracted in the following combinations. Solvents are selected to optimize the polarity range desired for analyses. Filters are extracted twice with approximately ~170 mL of dichloromethane (CH₂Cl₂) using the Dionex ASE for 15 min/cell at 1500 psi and 80°C. Since PUF media degrades when extracted with dichloromethane, the PUFs are extracted twice with ~170 mL of acetone using the Dionex ASE for 15 min/cell at 1500 psi and 80°C. This method gives good recovery for PAH, aliphatic hydrocarbons (alkanes), and hopanes and steranes.

Treatment of Extracts

Extracts are concentrated to ~1ml by rotary evaporation at 35 °C under gentle vacuum, and filtered through a 0.2 μm Anotop™ 10 Whatman leuc-lock filter on 4 mL glass syringe), rinsing the flask 3 times with 1 ml dichloromethane and acetone (50/50 by volume) each time. Filtrate is collected in a 4 mL amber glass vial for a total volume of ~4 mL. Approximately 200 μl of acetonitrile is added at this time and the extract is split into two fractions. Each fraction is then concentrated using a Pierce Reacti-Therm under a gentle stream of ultra-high purity (UHP) nitrogen with a water trap (Chrompack CP-Gas-Clean moisture filter 17971) to 100-200 μL. The final extract volume is adjusted to 100 μL with acetonitrile.

Oil Sample Preparation and Analysis

The oil sample was prepared by dissolving 100ul of the oil in 900ul hexane for a 1ml solution. Of that 1 ml sample, 200ul was taken for semiprep chromatography to reduce analytical interferences. For the semiprep chromatography, a 12ml x 2g SiOH SPE (Supelco) column was used. Cholestane-d6 was added prior to extraction for quantitation by internal standard. The cartridge was washed with benzene and hexane, and hopane and sterane containing fractions were eluted with hexane. Eluant was concentrated under N2 gas to 1ml final volume and analyzed by GC-ITMS. Sample density was determined by weighing a 4ml aliquot of the oil. The results (in ug/sample) are for the fraction analyzed by GC-ITMS. Results were divided by the oil equivalent volume of 20ul and multiplied by 1000 to convert from ul to ml oil. That result was divided by the oil density of 0.894g/ml to get ug/g oil.

Analysis Instrumentation

The samples are analyzed by the electron impact (EI) GC/MS technique, using a Varian CP-3800 gas chromatograph equipped with a 8200 CX Autosampler and interfaced to a Vairan Saturn 2000 Ion Trap Mass Spectrometer or Varian CP-3400 gas chromatograph with a model CP-8400 Autosampler and interfaced to a Saturn 2000 Ion Trap Mass Spectrometer.

Injections are 1 µl in size in the splitless mode onto a 30m long 5% phenylmethylsilicone fused silica capillary column (J&W Scientific type DB-5ms): CP-Sil8 Chrompack (30m x 0.25mm x 0.25 mm) for PAH, hopanes and steranes, alkanes and polars; and CP-Sil24 Chrompack (30m x 0.25mm x 0.25 mm) for N-PAH.

Identification and quantification of the analytes are made by Selected Ion Storage (SIS), by monitoring the molecular ions of each analyte and each deuterated analyte.

Preparation Stage

The instrument (GC/MS) preparation steps are as follows:

- 1) Check for air and water in the system (Ion Time = 100, a total ion current (TIC) below 700 is preferred).
- 2) Adjust calibration gas pressure for Ion Trap instrument (75% preferred).
- 3) Check calibration gas pressure ~ 75%.
- 4) Perform autotune for electron multiplier setting, mass calibration, and RF ramp.

Identification and quantification of the analytes are made by Selected Ion Storage (SIS), by monitoring the molecular ions of each analyte and each deuterated analyte.

Calibration

Calibration curves are made by the molecular ion peaks of the analytes using the corresponding deuterated species as internal standards. If there is no corresponding deuterated species, the one most closely matching in volatility and retention characteristics is used. National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) 1647 (certified PAH), with the addition of the internal standards listed in Section 6.1.1-6.1.4 and the targeted PAH not present in this mixture, is used to make calibration solutions. Six concentration levels for each analyte of interest are employed. The calibration curve for each calibrated compound is constructed. After the calibration is completed, a standard solution is injected to perform calibration checks. If deviations from the true values exceed $\pm 20\%$, the calibration procedure is repeated or new calibration levels must be prepared. One replicate analysis and one calibration check is performed for every 10 injections of samples. If difference between true and measured concentrations exceeds $\pm 20\%$, the system is recalibrated. During batch processing, calibration is performed before each batch.

Reporting

Each sample is reported initially in terms of mass per sample ($\mu\text{g}/\text{sample}$). Ambient concentrations in terms of mass per volume (i.e., ng/m^3 or other units if requested) are reported based upon the sample volume adjusted for ambient temperature and pressure, or reported as “standard” volume.

Method Detection Limits (MDLs)

Method detection limits are 0.01-0.03 $\text{ng}/\mu\text{l}$ for PAH, hopane and sterane, and alkane compounds, and 0.03-0.04 $\text{ng}/\mu\text{l}$ for polar compounds.

Measurement Uncertainty

Measurement uncertainty is reported as one-sigma standard deviation between replicate tests (when 3 tests conducted under same conditions) or the combined root mean square of the analytical measurement uncertainty, which is defined by the following equation:

$$\sqrt{(\text{replicate precision} \times \text{analyte concentration})^2 + (\text{analyte detection limit})^2}$$

This equation incorporates the analyte detection limit for each compound so when concentrations approach zero the error is reported as the analyte detection limit. When multiple samples are pooled the difference between samples is typically greater than the precision of any of the analytical techniques employed. Most data has relatively small reported measurement uncertainty's which shows the reproducibility of the samples. When larger errors (>30% of reported concentration) are observed, it is typically because the concentrations of the analyte were close to the detection limit of the measurements.

Species Examined

Table A 1: Species examined in DRI analysis of crankcase filters and oil sample.

Compound Name	Compound Abbreviation	Field Name
C27-20S5a(H),14a(H)-cholestane	ster42	ster42
C27-20R5a(H),14 β (H)-cholestane	ster43	ster43
C27-20S5a(H),14 β (H),17 β (H)-cholestane	ster44	ster44
C27-20R5a(H),14a(H),17a(H)-cholestane&C29-20S13 β (H),17a(H)-diasterane	ster45+40(cholestane)	ster45_40
C28-20S5a(H),14a(H),17a(H)-ergostane	ster46	ster46
C28-20R5a(H),14 β (H),17 β (H)-ergostane	ster47	ster47
C28-20S5a(H),14 β (H),17 β (H)-ergostane	ster48	ster48
C28-20R5a(H),14a(H),17a(H)-ergostane	ster49	ster49
C29-20S5a(H),14a(H),17a(H)-stigmastane	ster50	ster50
C29-20R5a(H),14 β (H),17 β (H)-stigmastane	ster51	ster51
C29-20S5a(H),14 β (H),17 β (H)-stigmastane	ster52	ster52
18a(H),21 β (H)-22,29,30-Trisnorhopane & 17a(H),18a(H),21 β (H)-25,28,30-Trisnorhopane	hop13+14	hop13_14
C29-20R5a(H),14a(H),17a(H)-stigmastane	ster53	ster53
17a(H),21 β (H)-22,29,30-Trisnorhopane	hop15	hop15
17a(H),21 β (H)-30-Norhopane	hop17	hop17
17a(H),21 β (H)-Hopane	hop19(17A,21B-Hopane)	hop19
17 β (H),21a(H)-hopane	hop20	hop20
22S-17a(H),21 β (H)-30-Homohopane	hop21	hop21
22R-17a(H),21 β (H)-30-Homohopane	hop22	hop22
17 β (H),21 β (H)-Hopane	hop23	hop23
22S-17a(H),21 β (H)-30,31-Bishomohopane	hop24	hop24
22R-17a(H),21 β (H)-30,31-Bishomohopane	hop25	hop25
22S-17a(H),21 β (H)-30,31,32-Trisomohopane	hop26	hop26
22R-17a(H),21 β (H)-30,31,32-Trishomohopane	hop27	hop27

Table A 2: Results of analysis of crankcase blow-by fillters. The color designations are to differentiate the two parallel sample streams.

pmi	4533_01 red	4533_01 red	4553_01 grn	4552_03 red	4552_03 grn	4552_03 grn	4552_05 red	4552_05 grn
hop13_14	0.112	0.123	0.216	3.507	7.765	7.854	4.255	14.908
hop15	0.073	0.074	0.117	2.323	5.131	4.338	2.997	8.94
hop17	0.354	0.456	0.849	11.947	35.379	32.531	19.903	71.417
hop19	0.26	0.295	0.536	8.275	23.866	21.618	13.221	46.787
hop20	0.033	0.03	0	1.038	2.61	2.261	1.722	4.504
hop21	0.217	0.267	0.548	7.567	21.092	17.977	12.049	39.146
hop22	0.157	0.222	0.375	6.23	17.965	15.234	9.786	30.294
hop23	0.041	0.027	0	2.151	4.871	4.958	2.932	9.868
hop24	0.113	0.198	0.242	4.831	12.229	9.919	7.048	21.859
hop25	0.08	0.125	0.162	4.328	9.297	6.361	5.628	15.187
hop26	0.09	0.102	0.214	3.521	8.989	5.736	4.78	13.767
hop27	0.065	0.082	0.118	2.928	5.851	4.335	3.622	8.2
ster42	0.02	0.023	0	0.343	0.584	0.805	0.328	1.237
ster43	0.058	0.033	0.095	1.735	3.27	2.747	1.378	5.094
ster44	0.049	0.045	0.179	1.563	3.356	3.532	1.867	7.924
ster45_40	0.084	0.068	0.108	1.636	3.604	3.326	2.14	6.032
ster46	0.043	0	0	0.638	1.241	1.934	0.898	3.214
ster47	0.031	0	0	0.658	1.498	1.952	0.752	3.722
ster48	0.058	0.055	0.141	1.026	1.925	1.876	1.687	4.989
ster49	0	0.039	0.072	0.98	2.257	2.115	1.028	3.508
ster50	0.054	0.041	0.05	1.478	2.789	1.74	1.665	5.376
ster51	0.042	0.109	0.153	2.442	5.583	4.907	3.035	10.043
ster52	0.019	0.04	0.063	1.766	2.969	2.737	2.008	5.822
ster53	0.003	0.061	0.102	1.351	2.714	2.926	1.941	5.669

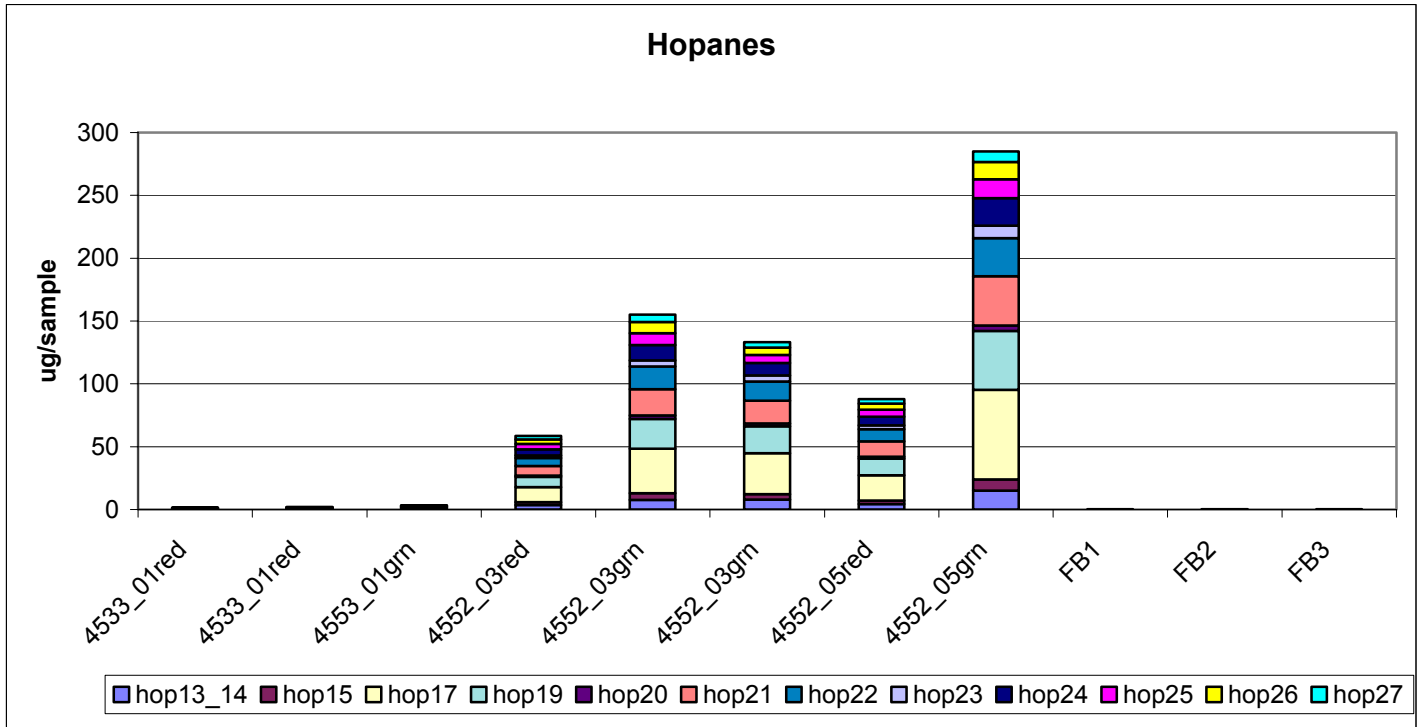


Figure A 1: Mass of hopane compounds on crankcase blow-by filters determined by DRI.

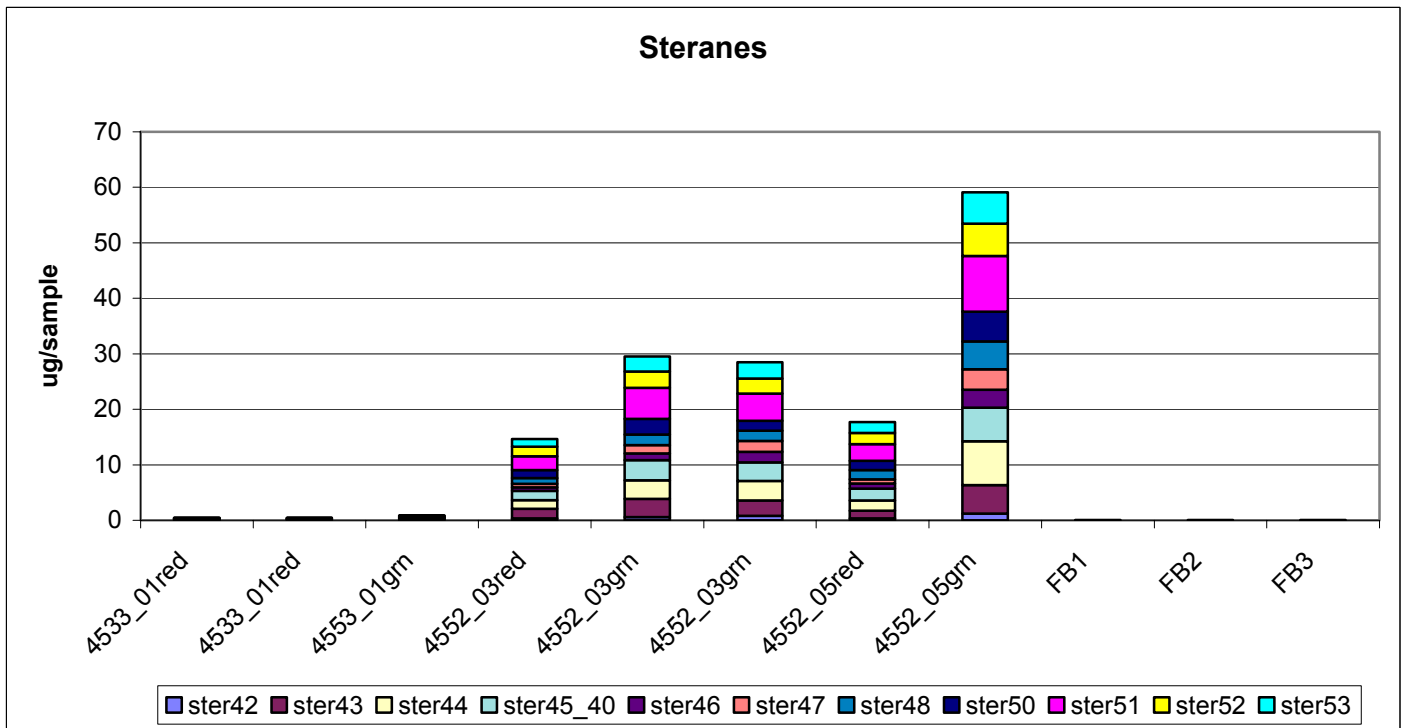


Figure A 2: : Mass of sterane compounds on crankcase blow-by filters determined by DRI.

APPENDIX B – SHORT REPORTS FROM INDIVIDUAL WVU TEST RUNS

Test Sequence Number: 4552**WVU Test Reference Number: WVU-Peterbilt-D2-TEST_D**

Fleet Owner Full Name West Virginia University
 Fleet Address MAE Dept.
 Fleet Address (City, State, Zip) Morgantown WV 26506

Vehicle Type Tractor
 Vehicle ID Number (VIN) 1XP5DB8X0TN363654
 Vehicle Manufacturer Peterbilt
 Vehicle Model Year 1996
 Gross Vehicle Weight (GVW) (lb.) 46000
 Vehicle Total Curb Weight (lb.) 18530
 Vehicle Tested Weight (lb.) 56000
 Odometer Reading (mile) 427724
 Transmission Type Manual
 Transmission Configuration 18 speed
 Number of Axles 3

Engine Type Caterpillar 3406E
 Engine Model Year 1996

Engine Displacement (Liter) 14.6
 Number of Cylinders 6
 Engine Rated Power (hp) 550

Primary Fuel D2
 Test Cycle TEST_D
 Test Date 12/7/05

Engineer Barnett, Ryan
 Driver England, Gary

Emissions Results (g/mile)**Fuel Economy**

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	PM	CO ₂	mile/gal	BTU/mile	Miles
4552-3	7.69	18.2	18.1	0.42	0.71	2638	3.78	34842	5.45
4552-4	6.99	17.8	16.5	0.44	0.60	2559	3.90	33793	5.46
4552-5	7.05	18.4	17.0	0.44	0.63	2613	3.82	34496	5.50
4552 Average	7.24	18.2	17.2	0.43	0.65	2603	3.83	34377	5.47
Std. Dev.	0.39	0.3	0.9	0.01	0.06	40	0.06	534	0.03
CV%	5.3	1.6		2.4	9.1	1.5	1.6	1.6	0.5

x-Not Reportable, a-Outlier, b-HC Not Reportable(Residual HC), c-missing component, d-Coefficient of Variation Too Large, e-below detectable limit

Test Purpose:

Baseline testing with crankcase sampling of Peterbilt without New Condensate system

Test Sequence Number: 4555**WVU Test Reference Number: WVU-Peterbilt-D2-TEST_D**

Fleet Owner Full Name West Virginia University
 Fleet Address MAE Dept.
 Fleet Address (City, State, Zip) Morgantown WV 26506

Vehicle Type Tractor
 Vehicle ID Number (VIN) 1XP5DB8X0TN363654
 Vehicle Manufacturer Peterbilt
 Vehicle Model Year 1996
 Gross Vehicle Weight (GVW) (lb.) 46000
 Vehicle Total Curb Weight (lb.) 18530
 Vehicle Tested Weight (lb.) 56000
 Odometer Reading (mile) 427724
 Transmission Type Manual
 Transmission Configuration 18 speed
 Number of Axles 3

Engine Type Caterpillar 3406E
 Engine Model Year 1996

Engine Displacement (Liter) 14.6
 Number of Cylinders 6
 Engine Rated Power (hp) 550

Primary Fuel D2
 Test Cycle TEST_D
 Test Date 12/8/05

Engineer Barnett, Ryan
 Driver England, Gary

Emissions Results (g/mile)**Fuel Economy**

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	PM	CO ₂	mile/gal	BTU/mile	Miles
4555-1	7.49	18.6	18.5	0.54	0.56	2725	3.66	35987	5.50
4555-2	7.37	17.9	16.5	0.46	0.52	2622	3.80	34627	5.49
4555-3	7.78	18.2	16.8	0.48	0.56	2650	3.76	35008	5.50
4555 Average	7.55	18.2	17.3	0.49	0.54	2666	3.74	35207	5.50
Std. Dev.	0.21	0.4	1.1	0.04	0.02	53	0.07	702	0.00
CV%	2.8	2.0		8.5	3.7	2.0	2.0	2.0	0.1

x-Not Reportable, a-Outlier, b-HC Not Reportable(Residual HC), c-missing component, d-Coefficient of Variation Too Large, e-below detectable limit

Test Purpose:

Baseline testing with crankcase sampling of Peterbilt with the New Condensator system installed

Test Sequence Number: 4611**WVU Test Reference Number: WVU-Peterbilt-D2-TEST_D**

Fleet Owner Full Name West Virginia University
 Fleet Address MAE Dept.
 Fleet Address (City, State, Zip) Morgantown WV 26506

Vehicle Type Tractor
 Vehicle ID Number (VIN) 1XP5DB8X0TN363654
 Vehicle Manufacturer Peterbilt
 Vehicle Model Year 1996
 Gross Vehicle Weight (GVW) (lb.) 46000
 Vehicle Total Curb Weight (lb.) 18530
 Vehicle Tested Weight (lb.) 56000
 Odometer Reading (mile) 441097
 Transmission Type Manual
 Transmission Configuration 18 speed
 Number of Axles 3

Engine Type Caterpillar 3406
 Engine Model Year 1996

Engine Displacement (Liter) 14.6
 Number of Cylinders 6
 Engine Rated Power (hp) 550

Primary Fuel D2
 Test Cycle TEST_D
 Test Date 4/20/06

Engineer Barnett, Ryan
 Driver England, Jason

Emissions Results (g/mile)**Fuel Economy**

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	PM	CO ₂	mile/gal	BTU/mile	Miles
4611-2	5.48	20.6	20.7	0.35	0.50	2574	3.88	33946	5.54
4611-3	5.95	20.3	20.4	0.34	0.54	2550	3.92	33640	5.53
4611-4	5.71	20.1	19.1	0.31	0.57	2523	3.96	33287	5.51
4611-5	5.68	19.7	18.7	0.31	0.51	2475	4.03	32656	5.50
4611 Average	5.71	20.2	19.7	0.32	0.53	2530	3.95	33382	5.52
Std. Dev.	0.19	0.4	1.0	0.02	0.03	42	0.07	554	0.02
CV%	3.3	1.9		7.0	5.5	1.7	1.7	1.7	0.3

x-Not Reportable, a-Outlier, b-HC Not Reportable(Residual HC), c-missing component, d-Coefficient of Variation Too Large, e-below detectable limit

Test Purpose:

Post mileage-accumulation testing of the Peterbilt with the New Condensator system installed

Test Sequence Number: 4614**WVU Test Reference Number: WVU-Peterbilt-D2-TEST_D**

Fleet Owner Full Name West Virginia University
 Fleet Address MAE Dept.
 Fleet Address (City, State, Zip) Morgantown WV 26506

Vehicle Type Tractor
 Vehicle ID Number (VIN) 1XP5DB8X0TN363654
 Vehicle Manufacturer Peterbilt
 Vehicle Model Year 1996
 Gross Vehicle Weight (GVW) (lb.) 46000
 Vehicle Total Curb Weight (lb.) 18530
 Vehicle Tested Weight (lb.) 56000
 Odometer Reading (mile) 441097
 Transmission Type Manual
 Transmission Configuration 18 speed
 Number of Axles 3

Engine Type Caterpillar C15 3406
 Engine ID Number 3406E
 Engine Model Year 1996

Engine Displacement (Liter) 14.6
 Number of Cylinders 6
 Engine Rated Power (hp) 550

Primary Fuel D2
 Test Cycle TEST_D
 Test Date 4/21/06

Engineer Barnett, Ryan
 Driver England, Jason

Emissions Results (g/mile)**Fuel Economy**

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	PM	CO ₂	mile/gal	BTU/mile	Miles
4614-2	5.87	20.6	20.6	0.32	0.58	2598	3.84	34270	5.52
4614-3	5.83	19.4	19.4	0.34	0.58	2496	4.00	32929	5.54
4614-4	5.84	19.3	19.2	0.35	0.56	2755	3.62	36343	5.47
4614-5	5.98	18.6	17.3	0.38	0.58	2761	3.62	36416	5.51
4614 Average	5.88	19.5	19.1	0.35	0.57	2652	3.77	34990	5.51
Std. Dev.	0.07	0.8	1.4	0.03	0.01	129	0.19	1696	0.03
CV%	1.2	4.2		7.4	1.3	4.9	4.9	4.8	0.5

x-Not Reportable, a-Outlier, b-HC Not Reportable(Residual HC), c-missing component, d-Coefficient of Variation Too Large, e-below detectable limit

Test Purpose:

Post mileage-accumulation testing of the Peterbilt without the New Condensator system installed

Special Procedures:

Runs 2, and 3 are with the fan in auto mode. Runs 4 and 5 are with the fan in manual mode.