Supplemental Chapter D: Repair Durability Supplemental Testing Information

I. Introduction

Vehicles participating in this project were first baseline tested using a data logger, a portable emission measurement system (PEMS), or a Constant Volume Sampling (CVS) chassis dynamometer to confirm either the malmaintenance status of a vehicle. Repaired vehicles were returned to their owners and recaptured after a 12-month period or sooner, if required (e.g., abnormal diesel particulate filters (DPF) regeneration frequency or MILs activated), and emissions tested and repaired again as needed.

II. Experiment

(i) Vehicle preparation, test weight, and test fuel

Vehicle preparation for dynamometer tests included proper vehicle mounting, pre-test safety inspection, and pre-test vehicle operations. Examples of sampler and analyzer connections are shown in figures 1 through 5. Prior to emission testing, a forced DPF regeneration was performed, if necessary, to prevent regeneration during a test. This was done since a "self-regeneration" that occurs during a test would result in the data from that test being deemed invalid, forcing the test to be repeated once the regeneration has completed.

Figure 1. Sampling pores on exhaust elbow (left) for "engine out" exhaust emissions, and exhaust pipe for "tail-pipe" exhaust emissions (right)

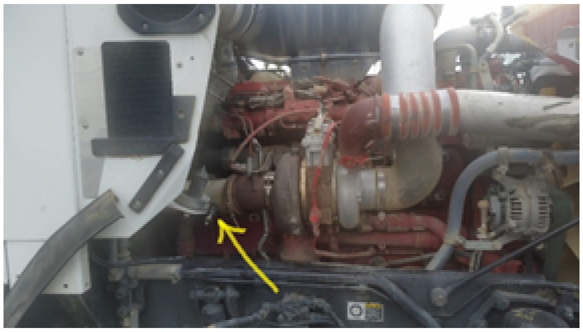

Figure 2. Exhaust elbow is located between the turbocharger outlet and one-box aftertreatment systems inlet.

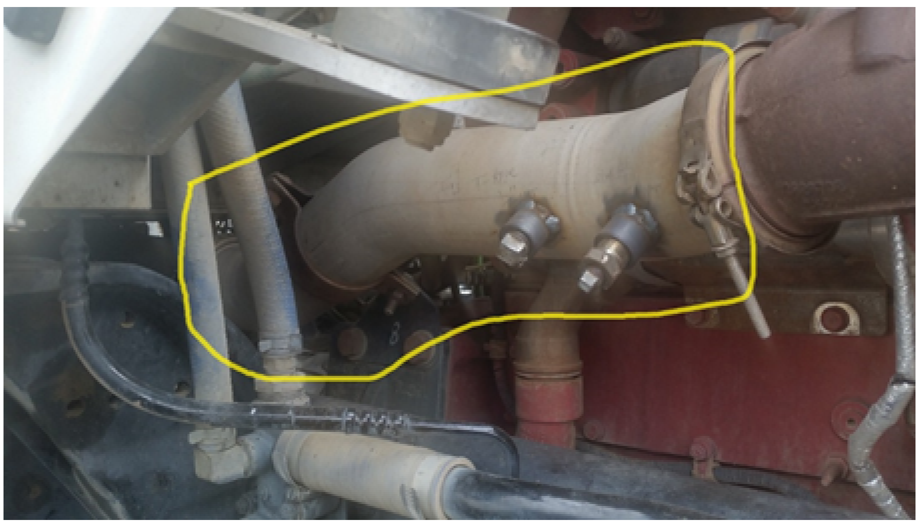

Figure 3. Sampling pores on exhaust elbow

Figure 4. Exhaust pipe with sampling pores on a horizontal type exhaust

Figure 5. Exhaust pipe with sampling pores on a vertical type exhaust

All vehicles were tested with a fixed 65,000 (±1,000) pounds simulated test weight. Previously determined dynamometer coefficients of a vehicle similar to the test vehicle were used for testing. Commercially available ultra-low sulfur diesel fuel purchased was used.

(ii) Test cycles, preconditioning, and test sequence

Each vehicle tested on a CVS chassis dynamometer had two test cycles performed: the heavy-duty urban dynamometer driving schedule (HD-UDDS), and the CARB-heavy heavy-duty diesel truck (HHDDT) cruise cycle. The characteristics of each test cycle are provided in Table 1, and Figures 6 and 7 show the instantaneous speed points for the HD-UDDS and CARB-cruise test cycles, respectively.

Table 1. Description of Test Cycles

Test Cycle	Time (sec)	Average Speed (mph)	Distance (mi)
HD-UDDS	1,060	18.9	5.55
CARB-HHDDT Cruise	2,083	39.9	23.1

For the test cycles, either both cold-start and hot-start emissions were collected or only the hot-start emissions were be collected. The vehicles went through the daily test sequence (see Table 2, Daily Test Sequence) for each cycle, as applicable, with associated preconditioning cycles and designated number of replicates.

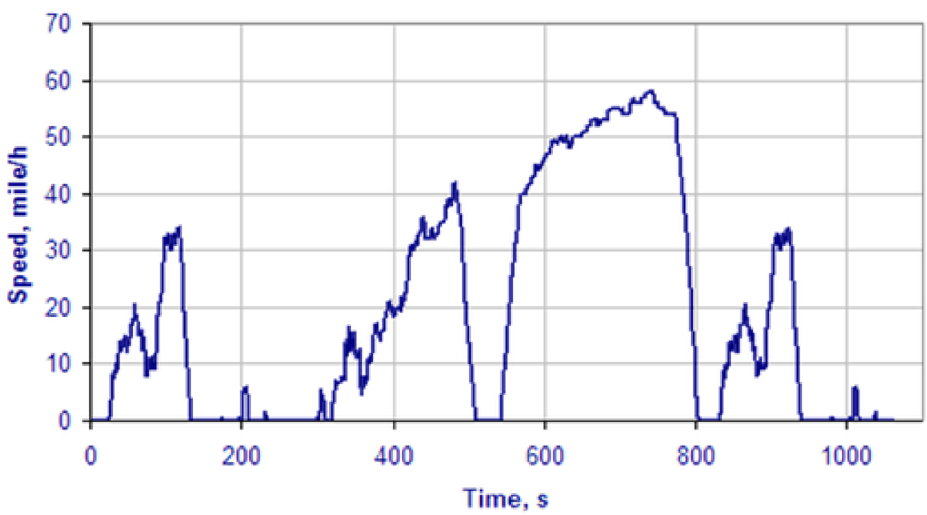

Figure 6. HD-UDDS Chassis-Dynamometer Cycle

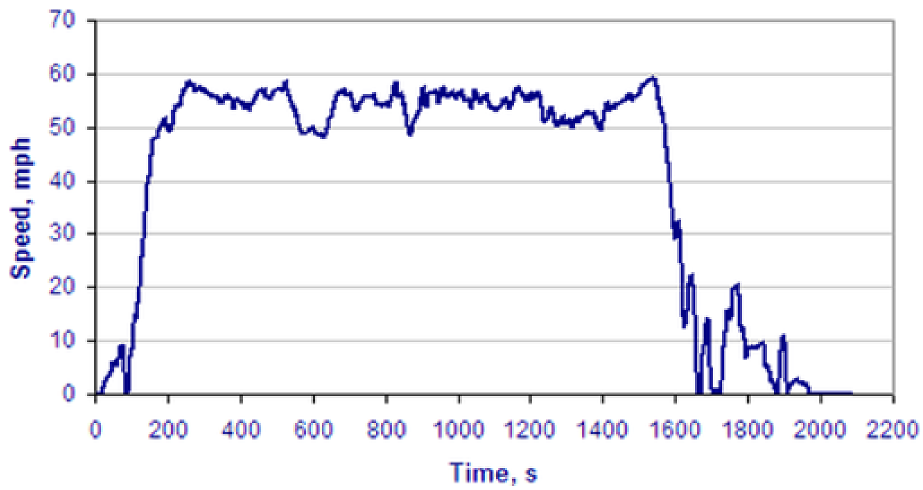

Figure 7. CARB-Cruise Chassis-Dynamometer Cycle

Before the vehicle was mounted on the chassis dynamometer, a snap-idle test will be done to measure the opacity. HD-UDDS cycles were repeated back-to-back (HD-UDDS×2) to collect enough PM mass for gravimetric analysis, while the CARB-HHDDT cruise cycle was tested only once (CARB-Cruise×1). Prior to hot tests, all test vehicles were driven at 45 mph for 15 minutes (30 minutes hot soak). This was done to ensure that the vehicle's engine and aftertreatment systems were in the same state for each repeat of a test cycle, and that the exhaust emissions were not influenced by conditions other than that encountered during the test cycle.

(iii) Emissions measurements

CVS chassis dynamometer emissions testing measured the following criteria pollutants carbon dioxide (CO2), carbon monoxide (CO), total hydrocarbons (THC), NOx, and PM, in the dilute vehicle engine out and tail-pipe exhaust emissions, according to the test procedures in Title 40, Code of Federal Regulations (CFR) Part 1065.

Table 2. Daily Test Sequence (if Cold-Start cycles are included)

Week	Mon	Tue	Wed	Thu	Fri
1				Vehicle Check-in Vehicle Mounting, and Test prep	Vehicle Mounting, and Test prep
2	PEMS emissions testing	PEMS emissions testing	PEMS emissions testing	PEMS emissions testing	PEMS emissions testing Test vehicle has to be delivered to MTA by noon
3	QA/QC, Vehicle Mounting, and Test prep (UDDS×2)	Cold-UDDS×2 15 min @ 45 mph 30 min Hot soak Hot-UDDS×2	Cold-UDDS×2 15 min @ 45 mph 30 min Hot soak Hot-UDDS×2	Cold-UDDS×2 15 min @ 45 mph 30 min Hot soak Hot-UDDS×2 Test prep (CARB Cruise×1)	Cold-CARB Cruise×1 15 min @ 45 mph 30 min Hot soak Hot-CARB Cruise×1
4	QA/QC	Cold-CARB Cruise×1 15 min @ 45 mph 30 min Hot soak Hot-CARB Cruise×1	Cold-CARB Cruise×1 15 min @ 45 mph 30 min Hot soak Hot-CARB Cruise×1	Back-up test day	Vehicle dismounting

PM filter speciation

Integrated filter sample analysis was conducted in the laboratory. Teflon and quartz fiber filters were used for water soluble ions, trace elements, and organic carbon/elemental carbon (OC/EC) analysis. 47mm Teflon and quartz fiber filters (2500QAT-UP 47mm, Pall Corp) pre-fired at 900˚C for a minimum of four hours were used. Filter requirements from chassis dynamometer testing were 28 Teflon and 14 quartz fiber filters. A summary of filter requirements is provided in Table 3.

Dilute Exhaust Bag speciation

Dilute exhaust and background air were collected in Tedlar bags for subsequent analysis. Twenty-four (24) bags for N_2O analysis were collected for each test set. A summary of Tedlar bag requirements is provided in Table 3.

Real-Time Measurements

A semi-continuous OC/EC sampler was operated in parallel for comparison. Pre- and post-DPF soot concentrations (as a PM surrogate) in undiluted exhaust were measured using two real-time micro soot sensors. A Fourier transform infrared (FTIR) spectrometer was used for measuring engine-out gaseous concentrations of CO_2, CO, NO_x, ammonia (NH_3), and N_2O, along with several hydrocarbons. The FTIR data was used for diagnostic purposes.

(iv) PEMS testing

Vehicles selected to participate in this project were baseline tested using PEMS to confirm their malmaintenance status. The PEMS emissions testing measured the criteria pollutants CO_2, CO, THC, NO_x, and PM, in dilute vehicle engine-out and tail-pipe exhaust emissions, according to the test procedures in Title 40, CFR Part 1065, Subpart J – Field Testing and Portable Emission Measurement Systems. The testing was performed on test vehicles to assess these vehicles' level of "noncompliance" with respect to in-use NTE requirements. Additionally, the vehicles that were sent to repair facilities for emission control system and/or engine problem diagnosis and repair were PEMS tested upon return to determine the level of in-use NTE compliance, as well as to measure their engine-out emissions.

Table 3. Sample Media Requirements

Cycle	Replicate	Teflon Filters for Ions(1)	Teflon Filters for Elements(1)	Quartz Fiber Filters for OC/EC(1)	Tedlar Bags for N_2O(2)
Cold UDDSx2	3	3	3	3	6
Hot UDDSx2	3	3	3	3	6
Cold CARB Cruise	3	3	3	3	6
Hot CARB Cruise	3	3	3	3	6
Tunnel Blank	3	3	3	3	0
Trip Blank	1	1	1	1	0
Total		**16**	**16**	**16**	**24**

(v) Data logger

Vehicle emissions data was collected by a data logger. A data logger with a SAE J1939/J1979 splitter cable was connected to the HD OBD ports in vehicles as shown in Figure 8, and thus have access to the extensive operations data by various systems such as the engine, emissions aftertreatment systems, and chassis.

Figure 8. A data logger with J1939/J1979 splitter cable

The on-board data storage allowed recorded data to be stored on the data logger, which was downloaded to a computer once the data loggers were retrieved at the end of the data collection period. The cellular modem function allowed recorded data to be sent wirelessly to the data server either periodically or in real-time. This wireless data transfer provided a way to quickly identify issues associated with the data loggers or the data quality.

A pre-configured data logger ensured that the OBD communication process and protocols transmitted the appropriate data from the HD OBD system to the data logger. OBD data was downloaded and converted into a spreadsheet including DPF differential pressure and NOx concentrations, which were key parameters to identify conversion and efficiency rates, as shown in Figure 9 and 10.

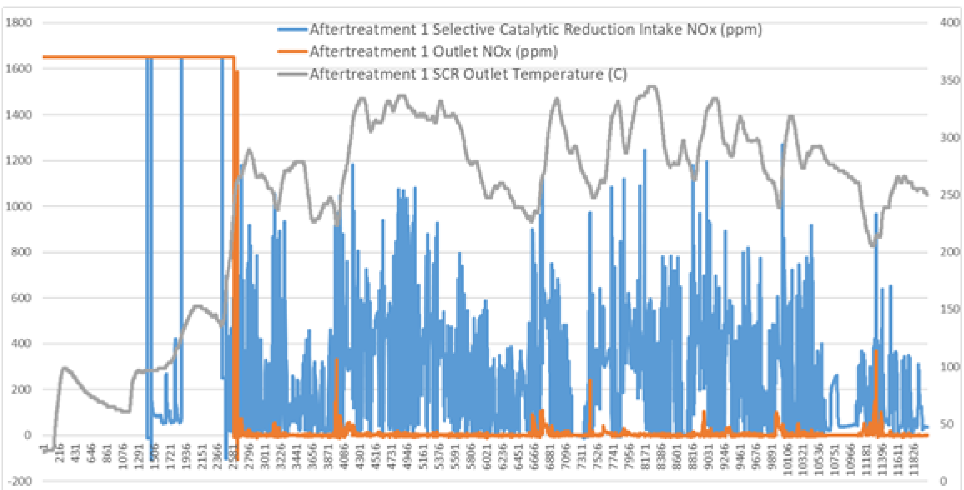

Figure 9. Comparison of NOx concentration before (intake) and after (outlet) SCR with reference temperature

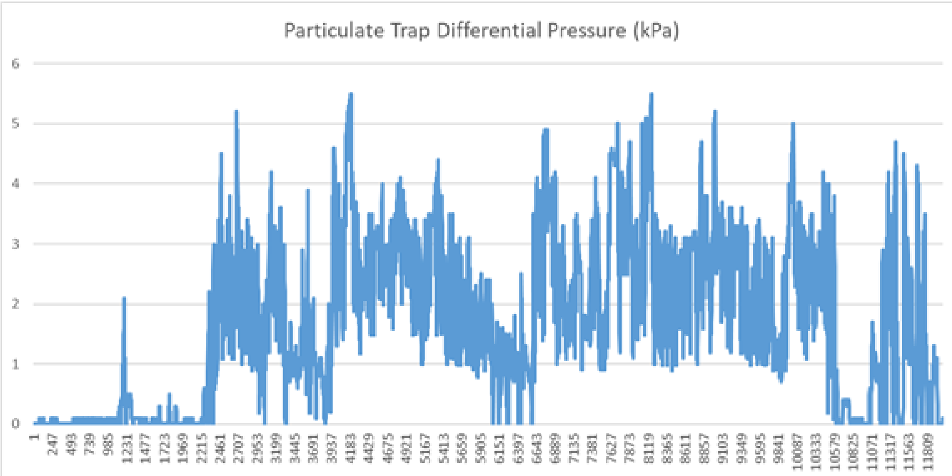

Figure 10. Particulate trap differential pressure (kPa)

(vi) Diagnose issues and perform repairs

Following baseline testing, the test vehicles were transferred to a repair facility for performing diagnostics and repairs, as needed. The repair facility provided all data related to the diagnosis and repairs performed on the vehicles, including recommended corrective actions, analysis reports, and cost estimates.

(vii) Emissions after repairs and recaptured vehicle testing

The repaired vehicles were retested using the OBD data logger, PEMS, or CVS chassis dynamometer testing. All of the tests performed for baseline testing were similarly repeated to confirm that the repairs performed resolved the "noncompliance" issues or low emissions conversion rates.

The test vehicles included in this test project were recaptured as feasible, preferably after a 6-to-12-month time period, or as needed, to monitor the vehicle performance, and effectiveness of the repairs.