Fuel Tank Temperature Profile Development for Highway Driving

Final Report

United States Environmental Protection Agency

Fuel Tank Temperature Profile Development for Highway Driving

Final Report

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
SGS-Environmental Testing Corporation (SGS-ETC)
Eastern Research Group (ERG)
EPA Contract No. EP-C-12-017
Work Assignment No. 1-05

NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

EPA United States Environmental Protection Agency

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Glossary of Terms and Acronyms

CDPHE	Colorado Department of Public Health and the Environment
CFR	Code of Federal Regulations
CRADA	Cooperative Research and Development Agreement
CRC	Coordinating Research Council
DAQ	Data Acquisition System
DTF	Ford's Driveability Test Facility
ECU	Engine Control Unit
EPA	US Environmental Protection Agency
ERG	Eastern Research Group
FTTP	Fuel Tank Temperature Profile
HC	Hydrocarbon
LA-92	LA92 "Unified" Dynamometer Driving Schedule
MOVES	Motor Vehicle Emissions Simulator
NREL	National Renewable Energy Laboratory
OBDII	Second-Generation On-Board Diagnostic System
OEM	Original Equipment Manufacturer
PZEV	Partial Zero-Emissions Vehicle
QAPP	Quality Assurance Project Plan
RVP	Reid Vapor Pressure
SGS-ETC	SGS- Environmental Testing Corporation
US-06	US-06 Supplemental Federal Test Procedure
VECI	Vehicle Emissions Control Information
VIN	Vehicle Identification Number

Executive Summary

This study, performed by Eastern Research Group (ERG) and subcontractor SGS-Environmental Testing Corporation (SGS-ETC), under contract to the US Environmental Protection Agency (EPA), was designed and conducted by EPA to develop fuel tank temperature profiles that could be used for running loss emissions testing and/or modeling to represent highway driving. Additional tests were performed to determine the repeatability of certification temperature profiles developed by manufacturers and used in previous test programs. This work builds on prior evaporative emissions test programs performed to determine the prevalence and emission rates of diurnal and hot soak emissions in US vehicles[1].

The testing for this program took place at Ford's Driveability Test Facility (DTF) in Allen Park, Michigan under contract to ERG and subcontractor SGS-ETC. Five vehicles supplied by EPA were tested using fuel with an RVP between 8.0 and 8.7 psi and an ethanol volume content of 10 +/- 0.2. The test cell simulated the following conditions of ambient air temperature of 95 °F, solar loading of 1000 W/m^2, with a thermal mat to simulate pavement temperature of 125 ° Fahrenheit. Each vehicle was driven over three different drive cycles of similar length. The first cycle was the standard running loss cycle (FTTP) consisting of one Urban Dynamometer Driving Schedule (UDDS), a 2-minute idle, two New York City Cycles, another 2-minute idle, another UDDS, and then a final 2-minute idle (see §86.115). The second cycle was three LA-92 cycles run back to back. The third sequence consisted of two US-06 cycles, a 70 mph highway cruise, and two final US-06 cycles. Fuel tank temperature, vapor temperature, fuel tank pressure, and OBDII commanded purge (or purge solenoid voltage when OBDII commanded purge was not available) were recorded throughout testing.

Results from the study showed the following:

- In general, higher-speed, more aggressive drive cycles result in lower final tank temperatures, possibly due to higher wind speeds under the vehicle (and thus higher amounts of convective cooling from the fuel tank)
- Fuel tank temperature profiles are strongly influenced by experimental conditions and vehicle setup. Highly-controlled road surface temperatures with known set points are necessary in order to replicate previously-developed tank temperature profiles for specific drive cycles
- Although not performed for this study, it may be possible to use mathematical models to "normalize" empirically-derived fuel tank temperature profiles in order to approximate profiles developed under different, or unknown, conditions

1.0 Objectives and Background

Over the past decade, the Environmental Protection Agency (EPA) and others have been conducting studies to characterize real world evaporative emissions on aging newer technology vehicles and their effects on the hydrocarbon (HC) inventory. The E-77 test program[1] recently performed by the Coordinating Research Council (CRC), the EPA and the Department of Energy's National Renewable Energy Laboratory (NREL) collected emission rates of aging enhanced evaporative emissions control and partial zero-emissions vehicle (PZEV) technology vehicles at various temperatures using different fuels both with and without 0.020" diameter leaks implanted at different locations over various evaporative test procedures including the static permeation test, the diurnal test and the dynamic permeation test. A 0.020" leak diameter was selected because this is the smallest size required to be detectable by vehicle OBDII systems. In addition, recent studies of vehicles with high evaporative emissions in Denver, Colorado were performed as part of a Cooperative Research and Development Agreement (CRADA) between the EPA and the Colorado Department of Public Health and the Environment (CDPHE) over three summers (2008-2010)[2]. These studies provided information on the prevalence of evaporative emissions leaks and the emission rates of those leaks in the real world fleet.

Work Assignment 1-08 under this contract also built on this work in order to simulate real-world evaporative emissions leak rates during transient operation and static tests[3]. The leak rates were collected using fuels with high and low RVPs on vehicles with various implanted leak sizes and locations in order to determine running loss, hot soak and static emissions from induced leaks on newer technology vehicles with enhanced evaporative emissions control systems. Prior to that, EPA completed a multi-day diurnal test program to evaluate diurnal emissions of vehicles which sit for more than the three days required in the certification test cycle[4]. During this multi-day diurnal test program, nine vehicles were tested over a fourteen day cycle with two fuels of varying RVPs.

EPA is accumulating this information to more accurately model evaporative emissions in their Motor Vehicle Emissions Simulator (MOVES) emissions model. It has become apparent through these studies that real world loading of the canister and purge strategies for on and off-cycle emissions can have a significant impact on evaporative emissions. CRC's E-77-2 programs showed that running loss emissions with leaks can vary by orders of magnitude with temperature, fuel volatility, and even leak location[5]. EPA is interested in appropriately applying these large swings across the vehicle miles traveled in MOVES, and therefore is seeking temperature profiles for different modes of highway driving which tend to be cooler than the certification running loss cycle for which emissions data were collected in WA 1-08.

This current work assignment (WA 1-05) was performed to develop evaporative emissions testing tank temperature profiles for a different drive cycle than that used for certification testing. In this work, the ERG / SGS team collected data in an environmentally controlled test cell in order to develop fuel tank temperature profiles on a set of five vehicles over non-standard drive cycles developed for this study. Internal tank pressure and OBDII commanded purge (or purge solenoid voltage when OBDII commanded purge was not available) were also collected during the drive cycle.

2.0 Study Equipment and Preparation

2.1 Test Vehicles

The EPA provided 5 vehicles to be tested in this study. The vehicles were chosen from available vehicles that had previously been used in prior EPA test programs. The five vehicles provided for the test program are listed in Table 1, and details regarding the selected vehicles and test parameters are listed in Table 2.

Table 1. Test Vehicle Summary

Vehicle Make and Model	Model Year	Approx. Odo	Emissions Standard	Canister Cap[1] (g)	Tank Vol (gal)	Canister/Tank Ratio[2]
Dodge Caravan	2007	117k	Tier 2 / Bin 5	177	20.00	8.85
Toyota Corolla	2009	121k	Tier 2 / Bin 5	115	13.25	8.68
Ford Focus PZEV	2010	29k	SULEV II PZEV	110	13.00	8.46
Honda Accord	2007	124k	Tier 2 / Bin 5	140	17.00	8.24
Chevrolet Silverado	2006	112k	Tier 2 / Bin 8	177	26.00	6.81

1 Canister Cap = canister working capacity, in grams
2 Canister working capacity (g) / Tank volume (gal)

Table 2. Test Vehicle Details

Vehicle	Model Year	Inertia Weight	Tank Capacity	Road Load A	Road Load B	Road Load C	Engine Family	Evap Family
Caravan	2007	4750	20.00	15.32	0.0948	0.02662	7CRXT03.8NEO	7CRXR0177GHA
Corolla	2009	3250	13.25	11.93	0.0068	0.02276	9TYXV01.8BEA	9TYXR0115P12
Focus	2010	3000	13.00	4.01	0.5575	0.01269	AFMXV02.0VZX	AFMXR0110GCX
Accord	2007	3500	17.00	9.76	0.2918	0.01602	7HNXV02.4KKC	7HNXR0140BBA
Silverado	2006	5500	26.00	1.44	1.2678	0.02258	6GMXT05.3379	6GMXR0176820

2.2 Laboratory and Test Equipment Overview

All testing was performed at Ford's DTF. The Ford DTF operates 24 hours per day, 7 days a week on a three shift per day schedule with reduced staffing on the weekends. The Ford DTF has six vehicle labs equipped with a variety of features including chassis dynamometers, extreme environmental and thermal simulation, wind simulation, heated road simulation and barometric pressure simulation. The Ford DTF has the ability to operate light to medium-duty two-wheel drive vehicles (2,000 to 32,000 lbs. GVWR) under normal to extreme ambient environmental conditions. All test cells are equipped with single 63" roll diameter electric dynamometers. The test cell used to develop the fuel tank temperature profiles required for this study can simulate a hot road surface. Ford DTF is not currently ISO accredited, but follows quality standards developed during a former period of accreditation. To verify compliance with the Tank Temperature Profile Development procedure defined in 40 CFR §86.129-94, SGS-ETC provided an on-site technical lead at the DTF throughout the study to supervise the tests performed by the DTF. The maintenance, calibration and verification of the measurement equipment used in this study conformed to requirements defined in the work plan and quality assurance project plan (QAPP) developed for this project.

2.3 Fuel Procurement and Preparation

SGS-ETC used a fuel provided by the Ford DTF which conformed with requirements set forth in 40 CFR§86.113-04(a)(1) for fuel tank temperature profile development. This fuel had an RVP between 8.0 and 8.7 psi and an ethanol volume content of 10 +/- 0.2. Additional fuel specifications are provided in Appendix A.

2.4 Vehicle Preparation

SGS-ETC took the following steps to prepare each vehicle for tank temperature profile development:

1. Create and prepare log books for recording and noting vehicle specifications and process chronology

2. Check vehicles to verify safe operation on dynamometer

3. Document vehicle information (VIN, year, make, model, engine and evaporative families); take pictures of the vehicles, VIN plate and the emissions control system (VECI) labels

4. Read and record all OBDII diagnostic trouble codes and readiness codes

5. Perform pressure test of evaporative emissions system using the Snap-On leak detection unit (supplied by EPA) and record results

6. Install a fuel drain for changing fuel

7. Install two (2), type J, fuel tank thermocouples (one in the liquid and one in the vapor space at a 40% fill)

8. Install tank pressure monitoring equipment and an induced pressurization port.

9. Fit ports on the fuel tank and in the vapor collection canister inlet for installing induced leak orifices

10. Photograph the locations of the modifications to the vehicles' OEM configuration

11. Perform pressure test of evaporative emissions system using a Snap-On leak detection unit (supplied by EPA) and record results

12. Check and adjust fluid levels and filters

13. Derive the appropriate vehicle road load for dynamometer testing

3.0 Test Program

3.1 Testing Overview

Test procedures conformed to the following steps.

Step 1) Drain and Refuel: An external pump connected to the fuel tank drain quick connect was used to completely drain the tank. The tank was then fueled to 40% of tank capacity with the specified fuel, and the vehicle was then placed into soak.

Step 2) Soak: The vehicle was soaked in a temperature-controlled environment to stabilize fuel temperatures to 95 ±3 °F. Fuel temperatures were held at 95 ±3 °F for a minimum of one hour before the beginning of a tank temperature profile development test.

Step 3) Tank Temperature Profile Development Test: A test was then performed employing the following steps and procedures:

1. The test vehicle was moved onto the dynamometer. This process involved turning the engine on and operating the vehicle for less than 60 seconds per the allowance in §86.129-94(d)(4)(iv), "Fuel Temperature Profile, Profile Determination Procedure". The vehicle engine compartment cover and any windows, doors, and luggage compartments were closed.

2. Fans were positioned as described in §86.135–90(b) and §86.107–96(d), "Sampling and Analytical Systems; Evaporative Emissions, Fuel Temperature Control System".

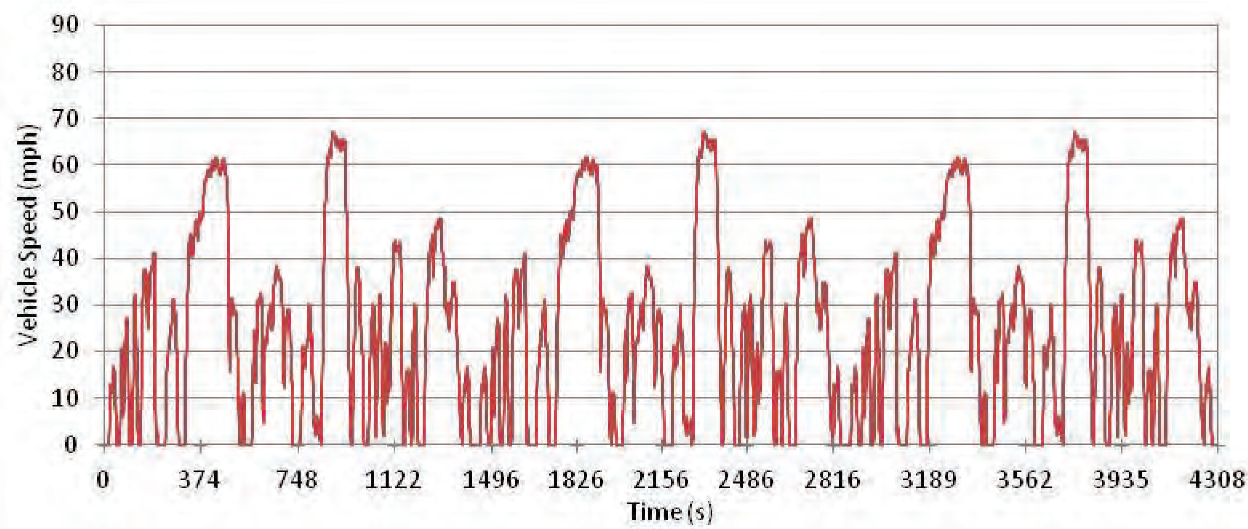
3. The vehicle air conditioning system (if so equipped) was set to the "normal" air conditioning mode and adjusted to the minimum discharge air temperature and high fan speed. Vehicles equipped with automatic temperature controlled air conditioning systems were set to operate in "automatic" temperature and fan modes with the system set at 72 °F as described in §86.129-94(d)(4)(iii).

4. The temperature of the liquid fuel was monitored and recorded at least every 1 second with the temperature recording system specified in §86.107–96(e). The vapor temperature was monitored for reference only and was not used as a process variable for controlling tank temperature.

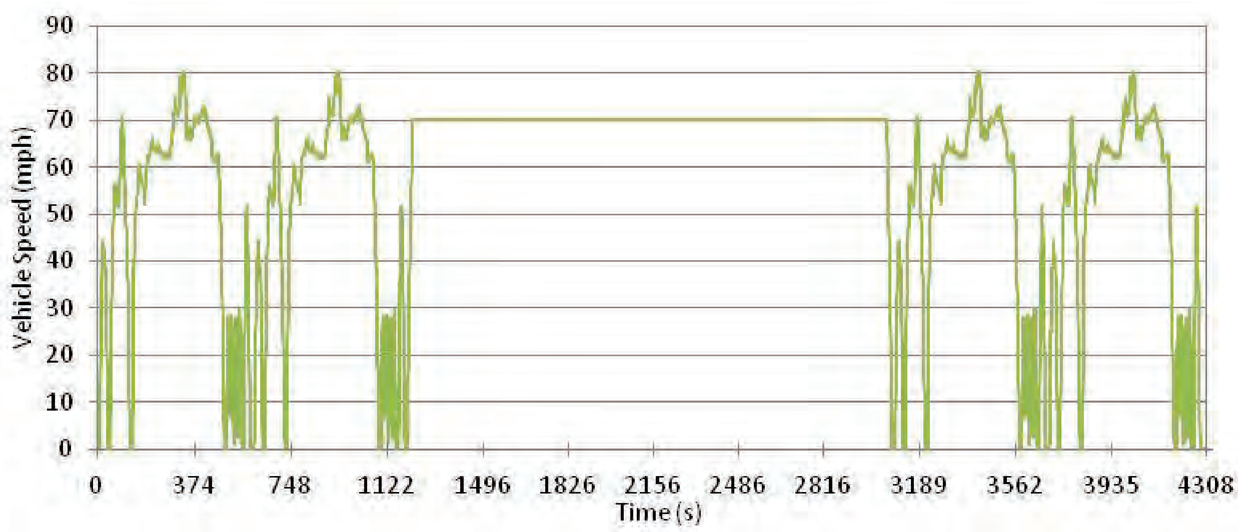
5. When the ambient temperature was at least 95 °F (35 °C) and the fuel tank temperature was 95±3 °F, the tank temperature profile development test was started.

6. The tank temperature profile development test was conducted by operating the test vehicle through two different drive cycles – repeating this entire procedure for each cycle. The transmission was operated according to the specifications of §86.128, "Transmissions", during the driving cycles. The driving cycles specified were three LA92 cycles run back to back, then a US06, thirty minutes of 70 mph highway cruise, followed by another US06. These are shown in the following diagrams;

    (a) Three LA92 cycles run back to back



(b) US06, thirty minutes of highway cruise at 70 mph, another US06.



7. The ambient temperature was maintained at 95 °F during the tank temperature profile development test and no more than a 2 °F drop was allowed during the procedure.

8. The following parameters were measured and recorded during tank temperature profile development

(a) Date and time of vehicle fueling

(b) Odometer reading at vehicle fueling

(c) Date and time car was parked, parking location

(d) Odometer reading at vehicle parking

(e) Date and time engine was started

(f) Time of initiation of selected cycle

(g) Time of completion of selected cycle

(h) Ambient temperatures throughout the period of the selected cycle

(i) Simulated wind speed throughout the period of the selected cycle

(j) Simulated surface temperature throughout the period of the selected cycle

(k) Trace Speed

(l) Actual Speed

(m) Fuel Liquid Temperature

(n) Fuel Vapor Temperature

(o) Fuel Vapor Pressure

3.2 Data Collection Process

Various data files were collected during this study and have been provided to EPA as separate deliverables to this study (Appendix D). All data files are in either tab delimited, or comma separated variable format and consist of the following:

- Ambient temperatures, fuel liquid and vapor temperatures, and purge valve voltages recorded by the Omega DAQ used during testing;
- Test dates, times, trace and vehicle speeds, wind speeds, surface temperatures and fuel vapor pressures recorded by Ford DTF's data acquisition system; and
- OBD test data (including commanded purge, when available) recorded by the HEM Data OBD Mini Logger

As described in the Appendix D data description, data files have been provided for the FTTP, LA92 and US06 tests conducted during the study.

3.3 Data Validation and Analysis

Data was validated by ensuring the road surface mat temperatures did not fall beneath 125 °F and by ensuring the ambient temperatures did not fall beneath 93 °F during testing. The trace was checked for driver violations.

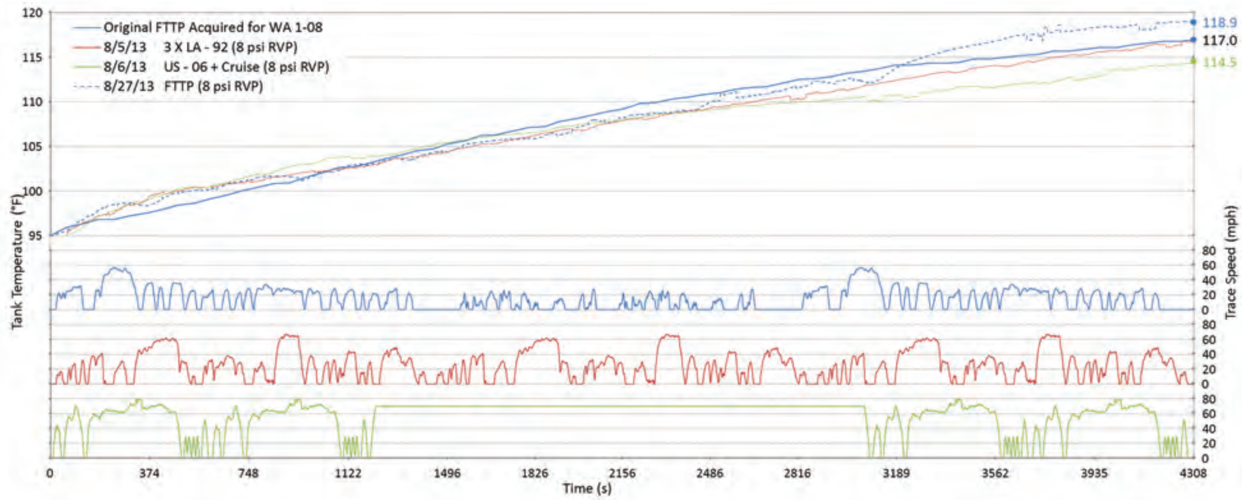
Nonlinear regression was performed on the data to improve understanding of the interaction of the final tank temperature with the mat temperatures, the proximity of the fuel tank to the road surface, and the surface area of the fuel tank exposed to the road surface. Even though a statistical model with a high coefficient of determination was developed with the aforementioned variables, the influence of many other parameters, such as underbody wind, exhaust system configuration, fuel tank materials and volume of fuel in the tank on tank temperatures were not available for consideration. For these reasons, use of this model would not be appropriate across broad ranges of inputs, and this model was, therefore, not included in this report.

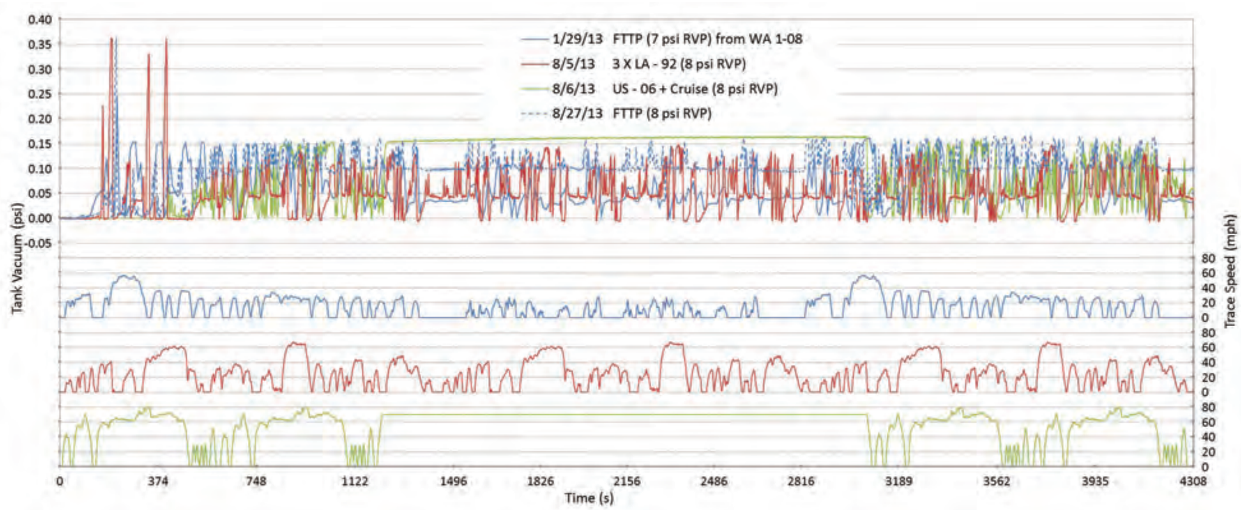
Additional issues encountered during the study were investigated and resolved as described in Appendix B, Issues Encountered and Solutions.

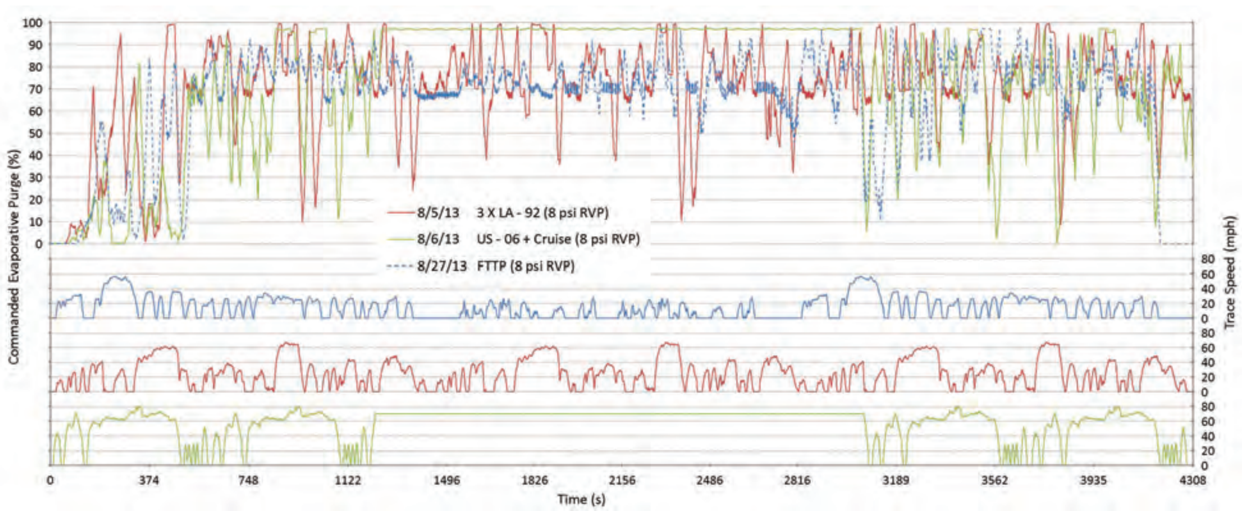
3.4 Results

The following subsections provide results for the LA-92/US-06 testing and the FTTP testing. Results presented include separate graphs of fuel tank temperatures, fuel tank vacuum, and commanded purge (based on a running 20-second average of the OBD datastream (or purge solenoid voltage) versus time. Speed of each of the three traces is plotted on each of the graphs for reference.

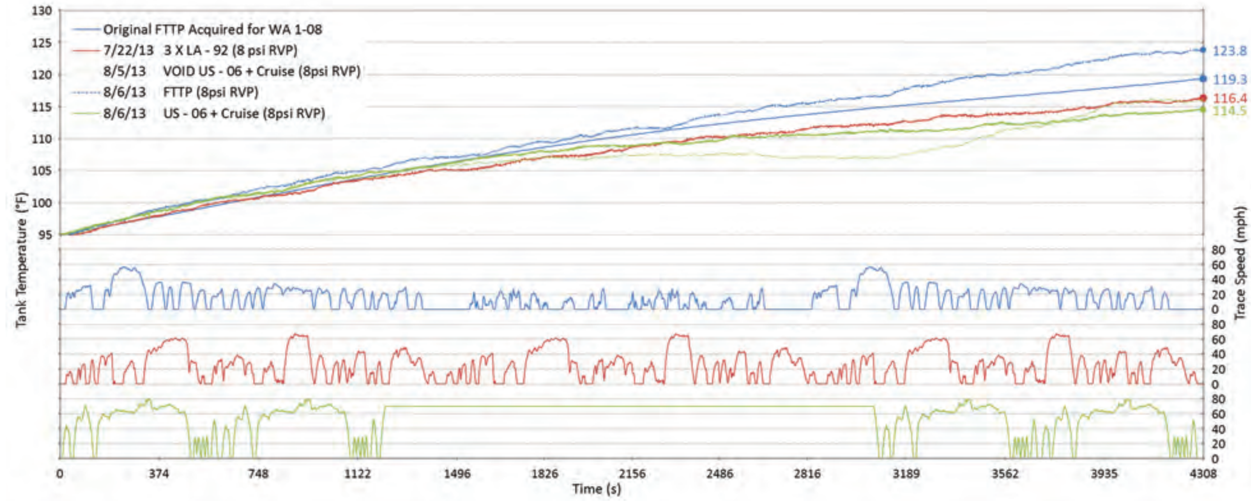
3.4.1 Honda Accord Test Results

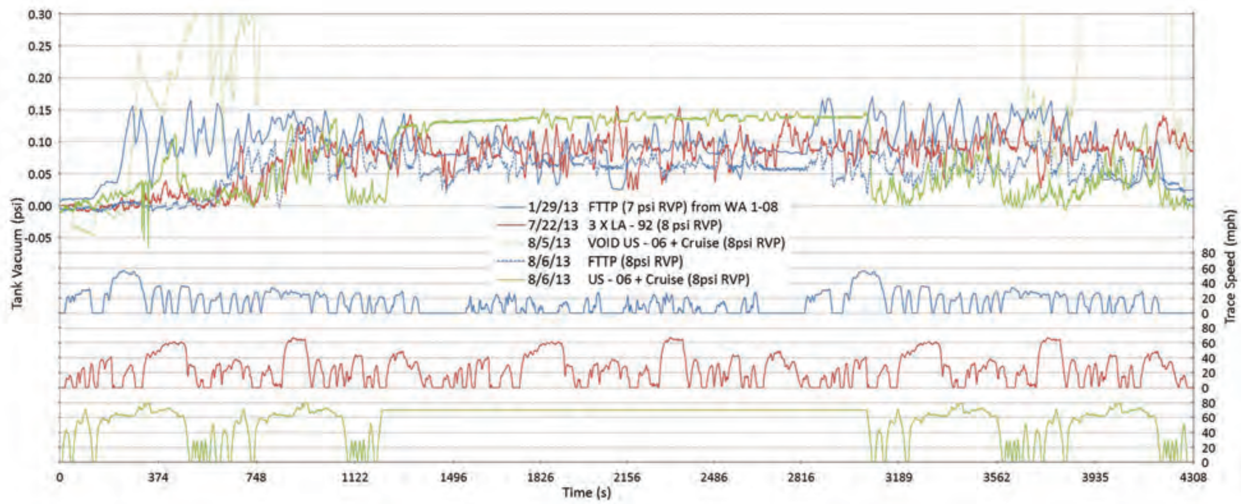


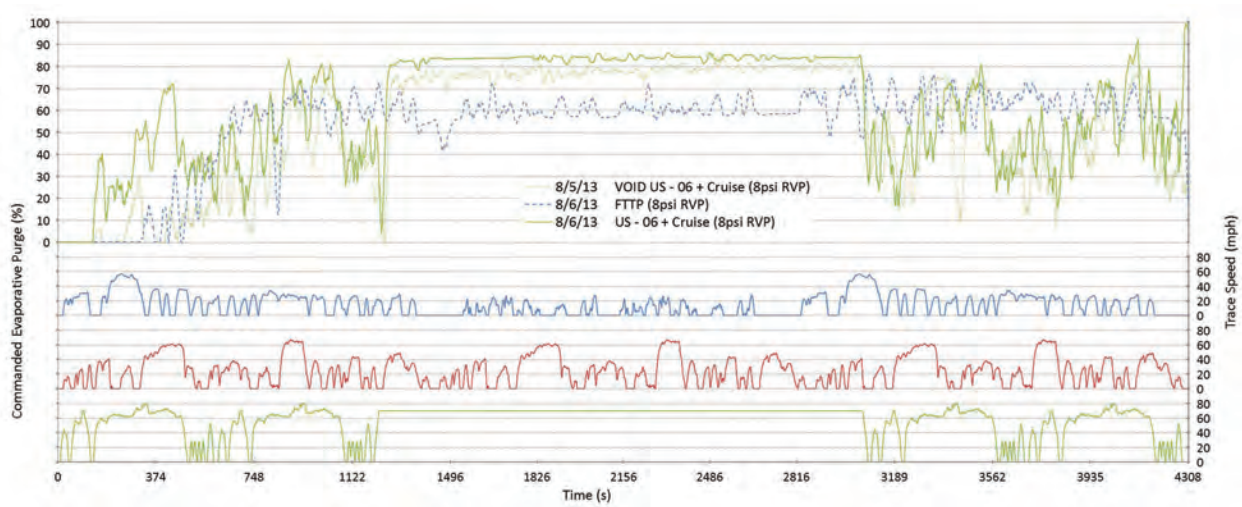




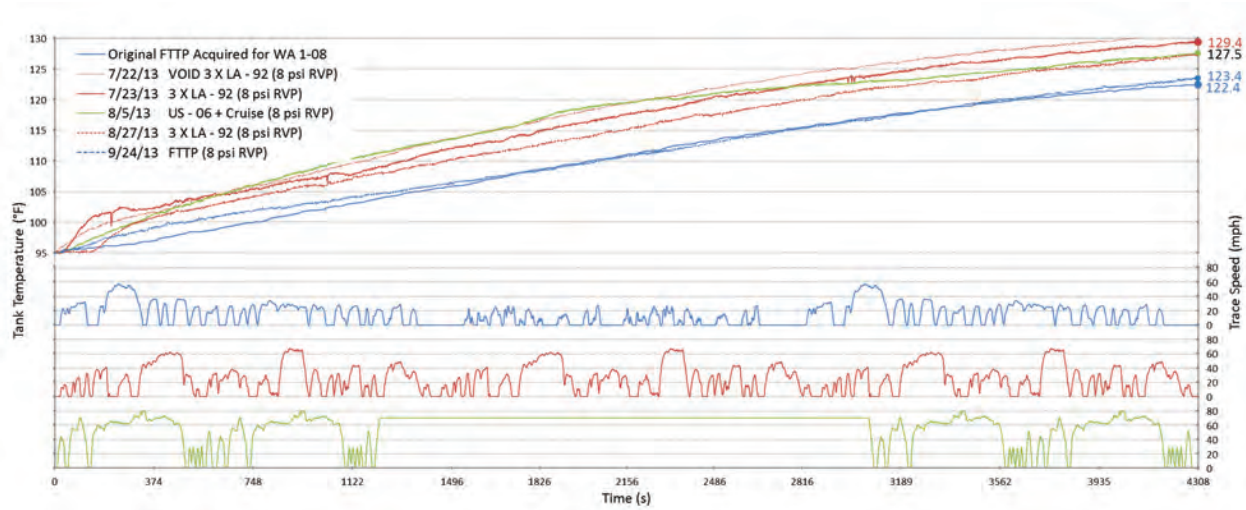
3.4.2 Dodge Caravan Test Results

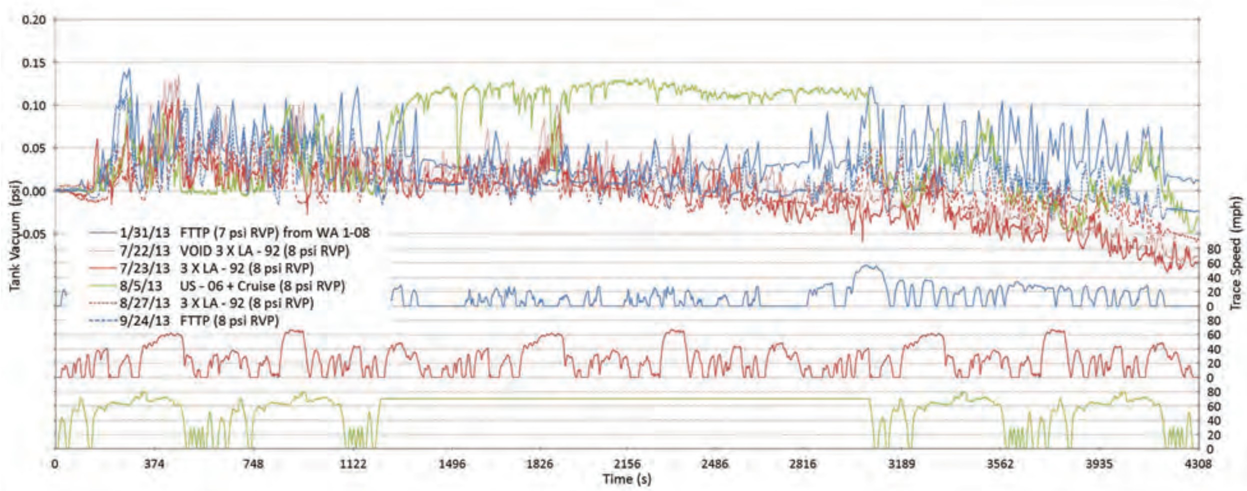


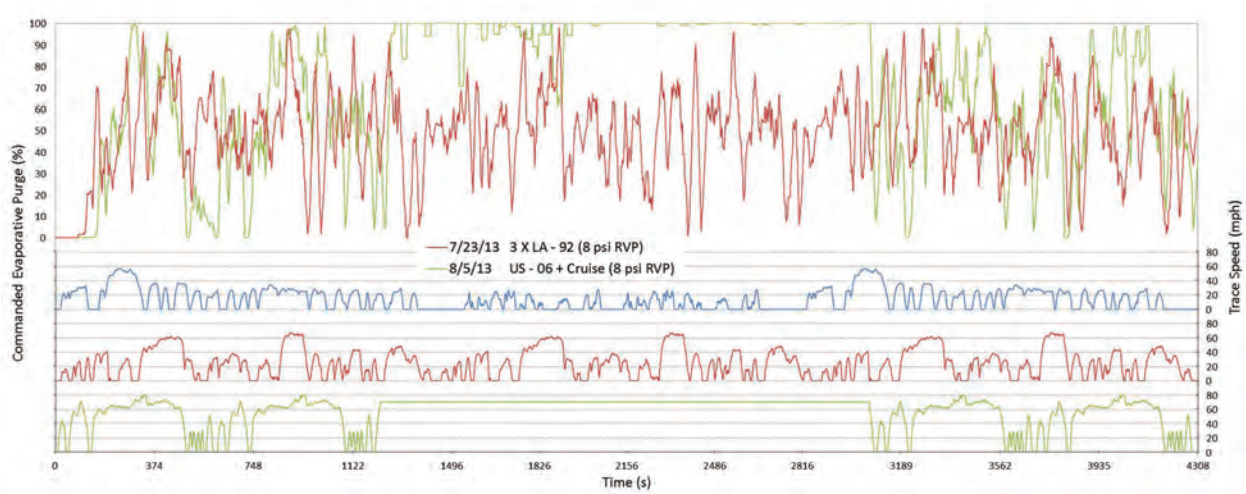




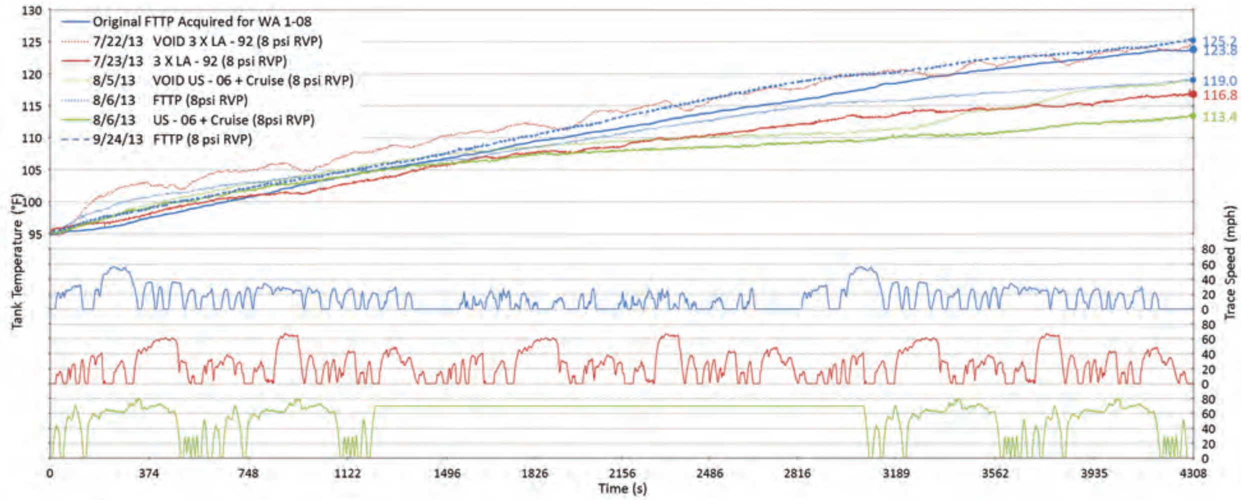
3.4.3 Toyota Corolla Test Results

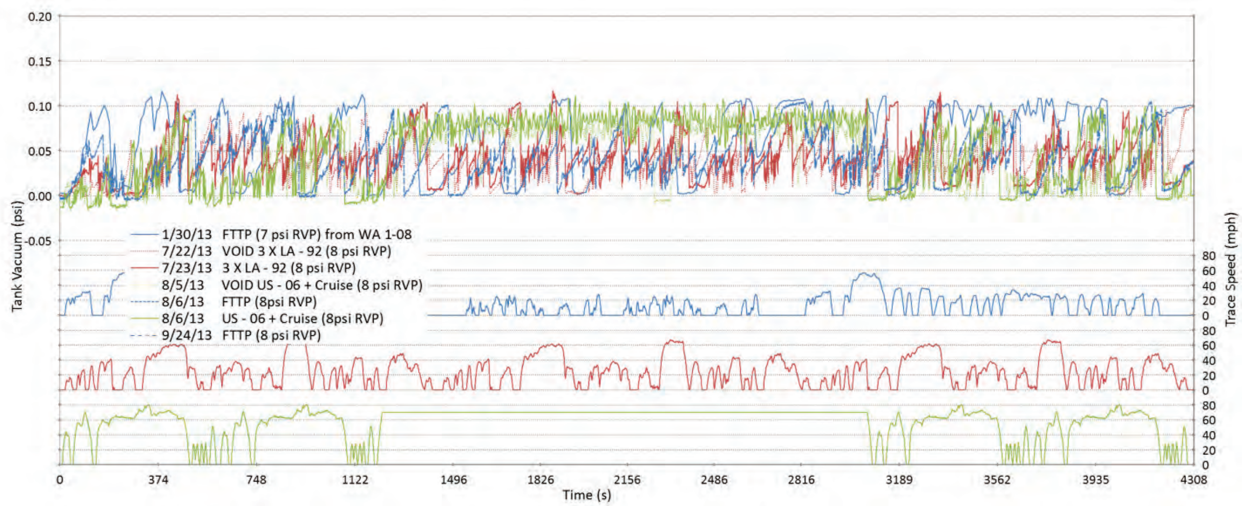


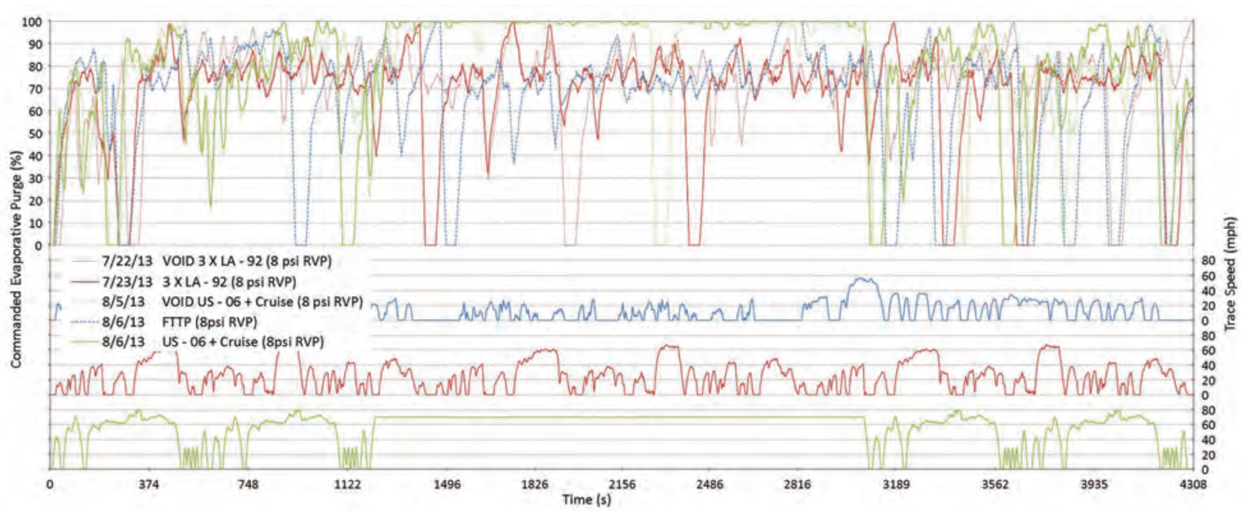




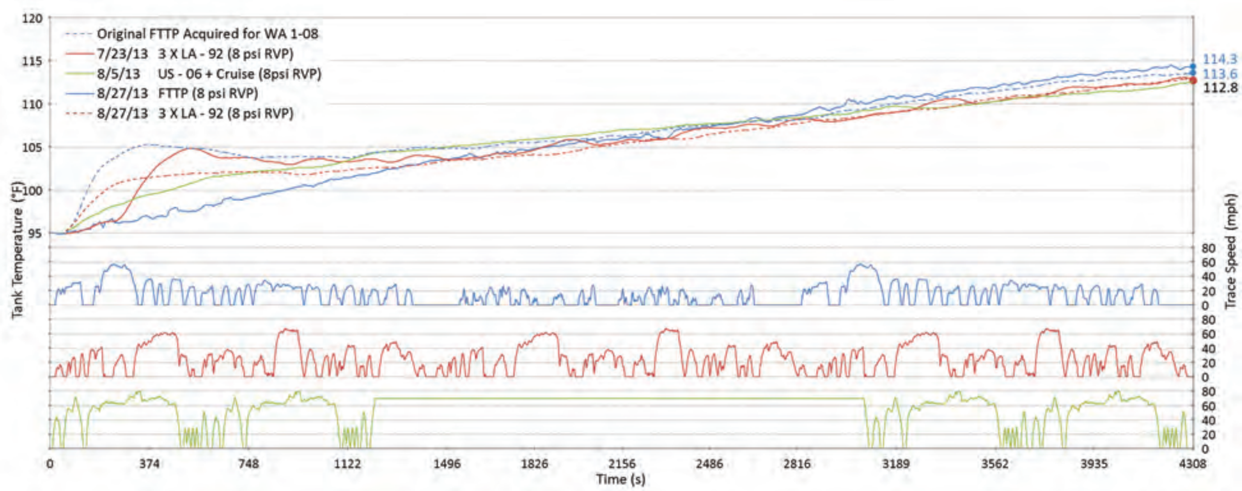
3.4.4 Ford Focus Test Results

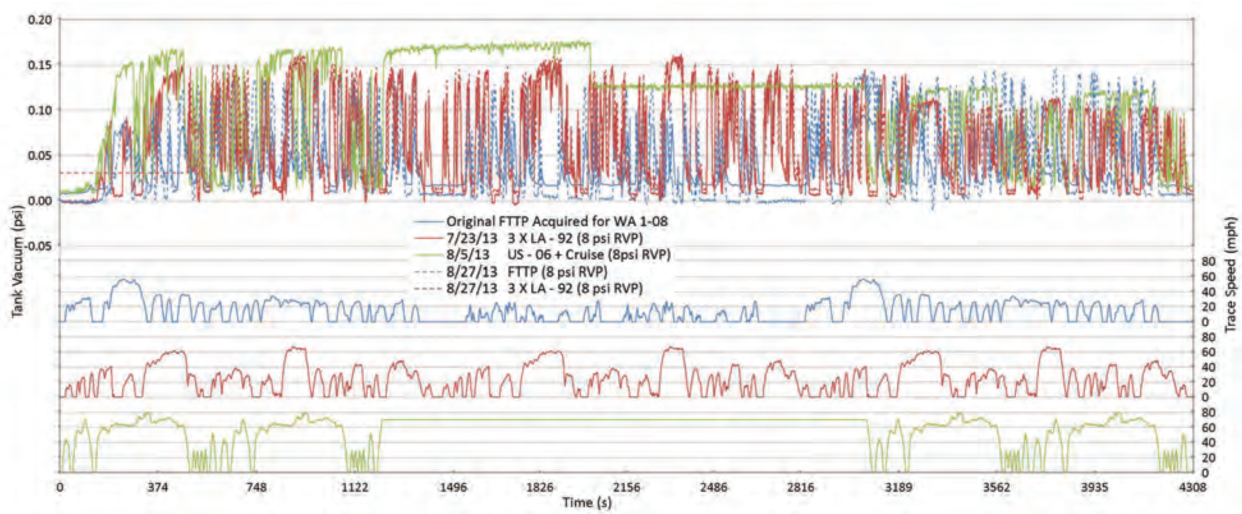


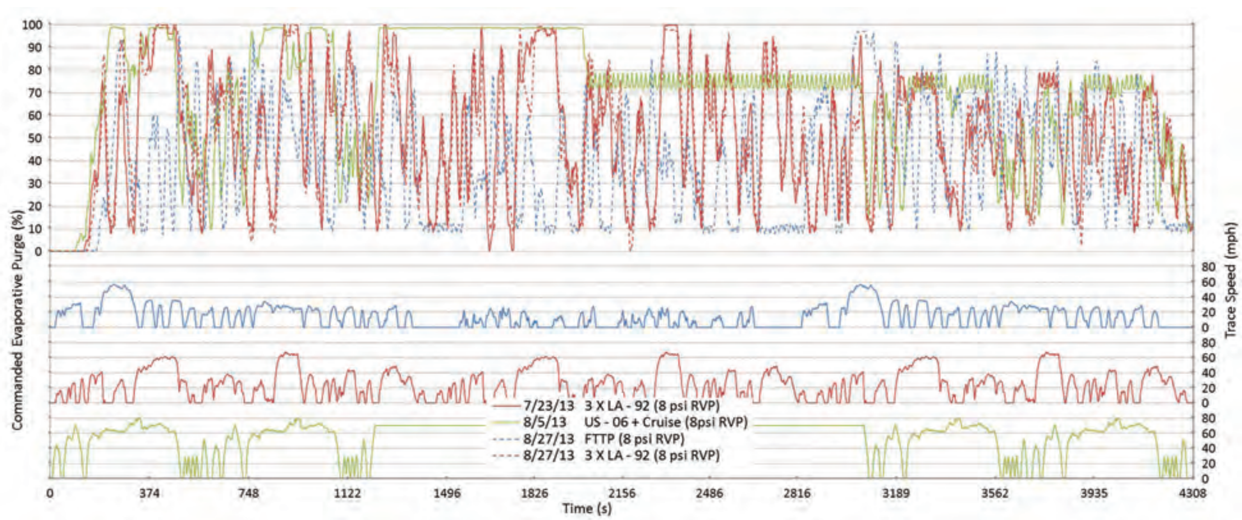




3.4.5 Chevrolet Silverado Test Results







3.4.6 Observations and Conclusions

Fuel tank temperature profile is influenced by a number of factors, such as the following:

- road surface temperature (or heated mat / simulated road surface temperature)
- distance from road surface to tank
- spatial arrangement, including exposed area of fuel tank to heated road surface
- fuel tank material and associated heat transfer properties
- volume of fuel in tank
- rate of heat generation from in-tank fuel pump
- proximity of exhaust to fuel tank
- arrangement of associated heat shielding, and
- volume and speed of air flowing under tank (which influences convective cooling)

Although many of these parameters are fixed based on the vehicle type, the volume and speed of air flowing under the tank will vary based on the drive cycle (speed of vehicle) while the road surface temperature can vary from test to test.

This study demonstrated the difficulties in replicating the generation of OEM fuel tank temperature profiles through an in-lab simulation, in particular without knowledge of actual road surface temperatures and wind conditions from the original on-road temp profile development work. It's also possible that the OEM fuel tank temperature profiles were numerically modified (smoothed) before use in evaporative certification testing.

Further complications such as limited laboratory control of the road surface mat temperature and potential temperature gradients in the laboratory flow tunnel resulted in additional deviations between fuel tank temperature profiles developed during this study and those originally developed by the original vehicle manufacturers.

As described in Appendix B, the Toyota Corolla showed increased temperatures for the more aggressive drive cycles, an effect unique to this vehicle. All other vehicles demonstrated a decrease in the tank temperature for the more aggressive cycles, likely due to the increased air flow (and thus convective cooling) at the underside of the fuel tank. Further investigation revealed the exhaust heat shields for the Corolla had been removed during a prior study, resulting in exhaust system radiation heating of the fuel tank. This likely caused the tank temperature profiles from the more aggressive traces to show increases above the original certification profile. After new heat shields were acquired and installed, testing showed very good agreement between this study's temperature profile and the original certification temperature profile. Figure 3.4.3 shows a corresponding increase in fuel tank pressure (reduction in tank vacuum) due to the purge being overwhelmed from the excessive heating.

The Chevrolet Silverado (and to a lesser extent the Toyota Corolla) exhibited steep temperature rate increases near the beginning of temperature development tests. This was seen on all the Silverado tests, but was primarily limited to one of the LA-92 tests for the Corolla. Supplemental measurements of the flow tunnel ambient temperatures conducted by SGS-ETC suggested this could be due to ambient temperature gradients at the start of the tests (prior to adequate ambient air mixing), although it's not entirely clear why this occurred with these two vehicles and not the other test vehicles.

Exploratory testing conducted by SGS-ETC in order to determine the cause of differences between the FTTP profiles developed for this study and those used for original vehicle evaporative emissions certification testing did seem to indicate the original profiles could be obtained by adjusting the road surface mat temperature set point. Since the OEM mat set point was unknown in most cases, this would entail an iterative process in which the mat temperature was adjusted based on its predicted effect in order to match the OEM FTTP profile. Based on this testing, numerical strategies were developed to "normalize" drive trace temperatures to match the OEM FTTP profiles. These strategies are described in Appendix B, and sample calculations are provided electronically as Appendix C. However, the temperature profiles provided for this study have not been normalized using any of these strategies. Future work could be conducted to determine how best to apply adjustments to the profiles provided as part of this study, although care must be taken to apply the data corrections only to deviations resulting from systematic bias.

4.0 References

1. CRC E-77 reports: Haskew, H., Liberty, T. (2008). Vehicle Evaporative Emission Mechanisms: A Pilot study, CRC Project E-77; Haskew, H., Liberty, T. (2010), Enhanced Evaporative Emission Vehicles (CRC E-77-2); Haskew, H., Liberty, T. (2010), Evaporative Emissions from In-Use Vehicles: Test Fleet Expansion (CRC E-77-2b); Haskew, H., Liberty, T. (2010), Study to Determine Evaporative Emission Breakdown, Including Permeation Effects and Diurnal Emissions Using E20 Fuels on Aging Enhanced Evaporative Emissions Certified Vehicles, CRC E-77-2c; DeFries, T., Lindner, J., Kishan, S., Palacios, C. (2011), Investigation of Techniques for High Evaporative Emissions Vehicle Detection: Denver Summer 2008 Pilot Study at Lipan Street Station; DeFries, T., Palacios, C., Weatherby, M., Stanard, A., Kishan, S.(2013) Estimated Summer Hot-Soak Distributions for Denver's Ken Caryl I/M Station Fleet

2. DeFries, T., Lindner, J., Kishan, S., Palacios, C. (2011), Investigation of Techniques for High Evaporative Emissions Vehicle Detection: Denver Summer 2008 Pilot Study at Lipan Street Station; DeFries, T., Palacios, C., Weatherby, M., Stanard, A., Kishan, S.(2013) Estimated Summer Hot-Soak Distributions for Denver's Ken Caryl I/M Station Fleet.

3. Sabisch, M., Kishan, S, Stewart, J, Glinsky, G. (2014), Running Loss Testing with Implanted Leaks.

4. Lindner, J., Sabisch, M., Glinsky, G, Steward, J., StDenis, M., Roeschen, J, (2012) Multi-Day Diurnal Testing, Contract CP-C-06-080, WA 5-11.

5. Haskew, H., Liberty, T. (2010), Enhanced Evaporative Emission Vehicles (CRC E-77-2); Haskew, H., Liberty, T. (2010), Evaporative Emissions from In-Use Vehicles: Test Fleet Expansion (CRC E-77-2b); Haskew, H., Liberty, T. (2010), Study to Determine Evaporative Emission Breakdown, Including Permeation Effects and Diurnal Emissions Using E20 Fuels on Aging Enhanced Evaporative Emissions Certified Vehicles, CRC E-77-2c.

5.0 Index of Appendices

The following is a list of the appendices to be provided with this report. As noted below, some appendices will be provided as separate electronic files.

Appendix A – Test Fuel Specifications
Appendix B – Issues Encountered and Solutions
Appendix C – Drive Trace Temperature Normalization Examples (electronic appendix, *.xlsx format)
Appendix D – Descriptions of Study Data (the following files will be provided electronically, by vehicle)

- DAQ Recording (*.csv)
- Ford DTF Data Recording (*.txt)
- OBDII Data (*.csv)
- Test Data (*.xlsx)

Appendix A
Test Fuel Specifications

Test fuel used for this study conformed to the following specifications:

Test Fuel Type	General Purpose and other DV
Test Fuel Specification Number	WW XE-M4CX560-A
Fuel Description/Application	E10 GASOLINE, Worldwide Driveability Sign-off, 91 RON E10 Summer Nominal (0°C and above)
RON	90 - 92
MON	82 - 84
Sulfur (ppm)	10 max
T10 (°C/F) or E70 (%v/v)	T10 = 50 - 60 C (122 - 140 F)
T50 (°C/F) or E100 (%v/v)	T50 = 90 - 100 C (194 - 212 F)
T90 (°C/F) or E150 (%v/v)	T90 = 160 - 170 C (320 - 338 F)
Vapor Pressure (kPa / psi)	55 - 60 kPa (8.0 - 8.7 psi)
Oxygenates (vol%) (e.g. ethanol, methanol, MTBE, ETBE, etc.)	10 +/- 0.2 %v/v Ethanol
Additives	Normal Commercial
Lead (g/L)	0.0025 max

Appendix B
Issues Encountered and Solutions

This appendix provides a summary of issues that were encountered during this study and a description of how each of those issues was addressed.

The study performed previously in Work Assignment 1-08, Running Loss Testing with Implanted Leaks, demonstrated difficulties in collecting the OBD commanded evaporative purge data stream. Only two of the vehicles from that study (which are the same as the vehicles in this study, the 2009 Toyota Corolla and the 2010 Ford Focus PZEV) broadcasted the OBD commanded evaporative purge. SGS-ETC measured and recorded the purge valve voltage to determine the commanded purge signal for the remaining vehicles, using an Omega multichannel portable data acquisition system (DAQ).

The Ford DTF did not have any viable means of measuring temperature data from the J-Type thermocouples which had been previously installed in the vehicle's sending units for vehicle fuel and fuel vapor temperature measurements, so SGS-ETC used the portable data acquisition system previously described in order to measure temperatures of the fuel liquid and vapor and also the ambient temperatures, in addition to the commanded evaporative purge.

Due to challenges with obtaining OBD data during Work Assignment 1-08, SGS-ETC made stronger efforts to collect OBD data from all tests during this study. While SGS-ETC was more successful in this endeavor than during Work Assignment 1-08, there are several instances of missing data. This is most notable with the Corolla data, where OBD data is missing from several tests. Since SGS-ETC expected to obtain the commanded evaporative purge from the OBD datastream, purge voltage was not collected, so for these tests, no purge rate signal (voltage or OBD) is available. Consequently, of the five tests performed on the Corolla, only two have commanded evaporative purge.

The Caravan does not have commanded purge data available for the LA-92 trace. This happened to be the first test performed using the DAQ system and it was not connected. This test did not demonstrate any other problems so it was decided to accept this test despite missing data.

Time alignment was handled by starting the DAQ recording as the test began. OBD data and pressure data (as measured by the Ford DTF) were aligned using vehicle speed and dynamometer roll speed, respectively.

During initial testing, the vehicle was moved into the wind tunnel while the wind tunnel was heating up, before the SGS-ETC technical supervisor arrived on-site. This would cause the liquid fuel temperature to fall below the 92 °F cutoff specified in 86.129-94(d)(4)(ii)(B), so test personnel would then wait until the fuel temperature reached 92 °F, plus an additional hour to allow the fuel temperature to stabilize prior to the start of testing on that vehicle.

During the first day of testing (July 22, 2013), the SGS-ETC technical supervisor noticed poor control of the thermal mat temperatures. The mat temperature was being controlled using a simple step control method and the simulated air speed of the more aggressive trace was causing large fluctuations in the mat temperature. Ford DTF improved the control by applying insulation over the surface thermocouple. However, the mat temperatures continued to swing, so SGS-ETC set the mat temperature to be greater than the minimum required 125 °F so that the temperature swings would not cause the mat temperatures to fall beneath the minimum temperature specified in the CFR.

At the beginning of testing, the air conditioning system in the Honda Accord was inoperable. The temperature inside the vehicle exceeded 110 °F during the first test performed on July 22, 2013 on this vehicle. This thermal extreme caused a problem with the data acquisition system inside the car, resulting in the data having a severe noise issue. To correct this problem, the vehicle was transported to SGS-ETC facilities in Jackson, MI, where the air conditioning system was repaired. The original test was voided and later successfully repeated.

On August 5, 2013, a failure in the DTF wind tunnel resulted in wind speed not being maintained for a portion of two of the US-06 tests performed on the Ford Focus and the Dodge Caravan. SGS-ETC technical oversight elected to continue testing and performed a repeat of the less aggressive 3 x LA-92 test cycle on the Accord to allow Ford DTF staff to make necessary repairs to the wind tunnel. After repairs, two subsequent US-06 tests were successfully completed on the Silverado and Corolla. The two tests on the Focus and Caravan were voided and repeated the following night.

During the US-06 test conducted on August 5, 2013 the vent line on the Caravan was clamped closed by one of the chain tie downs in the wind tunnel. This caused the amount of vacuum on the system to increase well beyond the typical amount of vacuum. This test had already been voided due to the previously-described wind tunnel malfunction. On subsequent tests, as part of the test process SGS-ETC technical oversight verified that the vent line was not pinched prior to test commencement.

The data acquisition computer crashed during the August 27, 2013 standard Fuel Tank Temperature Profile (FTTP) testing on the Corolla. Since SGS-ETC was not able to recover data from this experiment, this test was voided and repeated on September 24, 2012.

The Chevrolet Silverado's brakes failed during the US-06 test on August 6, 2013, causing a brief period of driver violations. The driver attempted to use the emergency brakes to slow the vehicle during this period. This was discussed with EPA and ERG personnel and it was decided that this was acceptable as the Silverado is an in-use vehicle.

Several vehicles, most notably the Silverado and the Corolla (prior to installing the heat shield as later described in this section), displayed a very rapid increase in liquid fuel temperature during the first ten minutes of testing, on occasion climbing as much as 10 °F during this period of time. This behavior was rigorously investigated through several techniques. SGS-ETC first performed a test in which the vehicle was parked in a shaded area and idled for at least 20 minutes. During this time, SGS-ETC measured the liquid fuel temperature to determine if the rapid increase in liquid fuel temperature was being induced by the vehicle. The temperature gains after 20 minutes were never greater than 5 °F. Results from additional data reviews suggested this temperature increase was caused by the facility's wind tunnel air temperature. Air temperature measurements collected in various locations by SGS-ETC showed the air temperature dipped during the first minutes of testing and the following air temperature increase coincided with the fuel temperature increase.

The Corolla showed greatly increased temperatures for the more aggressive cycles than for the previously obtained tank temperature profile. This effect was unique to this vehicle. All other vehicles demonstrated a decrease in the tank temperature for the newer cycles. During the latter stages of the project, it was discovered that the Corolla was missing the original manufacturer's fuel tank heat shield. A replacement shield was ordered and installed by SGS-ETC. The FTTP test performed after installing the heat shield showed very good agreement between the obtained temperature profile and the original certification temperature profile.

During the course of the study, the scope was expanded to include correlation testing to verify the each vehicle manufacturer's original certification tank temperature profile. The temperature profiles developed during this study using the FTTP drive trace did not match the manufacturer's original FTTP temperature profiles. The tank temperature profiles developed at the Ford DTF facility were consistently higher or lower than the OEM profiles. Additional testing was performed on the Ford focus, increasing the mat temperature above the 125 °F set point in an attempt to generate a matching temperature profile. This testing produced a good match, with the final test performed on the Corolla (with the heat shield installed) obtaining a superior match using the 125 °F mat temperature.

Based on results of this verification testing, EPA, ERG and SGS-ETC discussed whether or not the LA-92/US-06 tank temperature profiles that were developed during this study should be "normalized" to correct for the temperature discrepancies seen between this study's FTTP profiles and the vehicle manufacturer's original FTTP profiles. This would help ensure the LA-92/US-06 temperature profiles developed during this study are the same as if they had been developed by vehicle manufacturers using this study's drive cycles (manufacturer-equivalent, with all vehicle and test conditions equivalent to those at the manufacturer's test facility). Using "normalized" temperature profiles would help ensure running loss evaporative emissions measured using this study's LA-92/US-06 drive traces would not be biased by drive trace temperature discrepancies (which were shown in work assignment 1-08 to have a large influence on running loss emissions for vehicles with induced leaks).

Three different candidate strategies were developed for drive trace temperature "normalization". The first strategy (Final Temperature Correction of Original FTTP Profile) would scale the original (vehicle manufacturers') FTTP profile by the ratio of the final temperatures of the original FTTP profile to the recorded FTTP profile multiplied by the final drive trace temperature. This strategy is shown mathematically as follows:

$$T_{Corrected}(i) = \frac{T_{FTTP_{Original}}(i) - 95}{T_{FTTP_{Original}}(4308) - 95} \cdot \left(\frac{T_{FTTP_{Original}}(4308)}{T_{FTTP_{Recorded}}(4308)} \cdot T_{Recorded}(4308) - 95 \right) + 95$$

The second candidate strategy (Final Temperature Correction of the Recorded FTTP Profile) would scale the recorded FTTP profile by the ratio of the final temperatures of the original FTTP profile to the recorded FTTP profile multiplied by the final drive trace temperature. This strategy is shown mathematically as follows:

$$T_{Corrected}(i) = \frac{T_{Recorded}(i) - 95}{T_{Recorded}(4308) - 95} \cdot \left(\frac{T_{FTTP_{Original}}(4308)}{T_{FTTP_{Recorded}}(4308)} \cdot T_{Recorded}(4308) - 95 \right) + 95$$

The third candidate strategy (Continuous Correction) would provide a continuous correction of the recorded temperature by an ongoing ratio of the temperatures of the original FTTP profile to the recorded FTTP profile. This strategy is shown mathematically as follows:

$$T_{Corrected}(i) = \frac{T_{FTTP_{Original}}(i)}{T_{FTTP_{Recorded}}(i)} \cdot T_{Recorded}(i)$$

Examples of each of these strategies are provided electronically (Appendix C). None of the temperature profiles developed during this study have been corrected using any of these strategies.

Appendix C
Drive Trace Temperature Normalization Examples
(Note: This appendix will be provided electronically as a *.xlsx file)

Appendix D
Study Data

(Note: Descriptions of the data to be provided electronically follow)

Several files were obtained for each test performed during this study. These are described below, and the files are provided electronically as appendices. The file naming convention for these files is as follows:

[Date]_[Vehicle]_[Test Type]_[DAQ/DTF/OBD Data Set].csv

The date stamp is compressed into a six-digit number, the first two digits represent the year, the following two digits represent the month, and the last two digits are the day.

Date Stamp:YYMMDD so 130723 becomes 7/23/2013

The Test Type identifier designates the trace tested during a particular test. The following table coordinates the test type with the specific trace performed.

Table 3. Running Loss Testing Sequence

Test Type	Specific Trace	Duration (s)	Average Speed (mph)	Maximum Speed (mph)
FTTP	Standard Running Loss Trace	4308	14.4	56.7
LA92	3 X LA-92	4308	24.6	67.2
US06	2 X US-06 + 70 mph Cruise + 2 X US-06	4308	57.1	80.3

DAQ Recording (*.csv)

The DAQ recording is parsed into a csv. During experimentation additional instruments were added and removed from the configuration as necessary. The data presented in the DAQ files doesn't conform to a single standard output. There was some consideration as to adding a MFM to measure purge flow, however this instrument was never connected as it might interfere with proper purge behavior on the vehicle. The existence of such a channel within the data is erroneous, and reflects that nothing was measured using this device. The dataset contains the following measurements.

Start Time: Time and date the data recording was initiated.

Elapsed Time: Measured in seconds since Start Time.

Purge Valve: Measured in voltage. When converting this to voltage, the minimum voltage was assumed to correspond with a commanded purge of 0%, and the maximum voltage was assumed to correspond with a commanded purge of 100%.

Liquid Fuel Temperature: Measured in degrees Celsius, uses instrumentation installed for WA 1-08 Running Loss Testing with Implanted Leaks.

Vapor Fuel Temperature: Measured in degrees Celsius, uses instrumentation installed for WA 1-08 Running Loss Testing with Implanted Leaks.

Ambient Temperature/Ambient Top Temperature: Measured in degrees Celsius. A thermocouple was installed on the roof of the vehicle to verify ambient temperature simulation.

Ambient Front Temperature: Measured in degrees Celsius. A thermocouple was installed at the front of the vehicle extending downward so as to measure the temperature of the air before it passes under the vehicle. This was done to check for thermal stratification.

Ford DTF Data Recording (*.txt)

This tab delimited file is produced by Ford DTF data recording systems. The file begins with a row of header information containing the following data.

Vehicle: The test vehicle is identified.

Start Date: The date the test was performed.

Start Time: The time data recording began.

Operator: The technician responsible for controlling the wind tunnel during the test.

The file then produces several measurements of streaming data and test inputs. The recording frequency for these data are 1 Hz. Only a few of these data were used in the post-processing and quality analysis.

AID-Roll-Speed-F: Measured in miles per hour, this was used to align the individual data files for front wheel drive vehicles.

AID-Roll-Speed-R: Measured in miles per hour, this was used to align the individual data files for the one rear wheel drive vehicle, the Silverado.

AIRSPEED: Measured in miles per hour, this was checked against roll speed to verify proper operation of the wind tunnel

AIRHUMIDITY: Measured in percent relative humidity, this was checked to verify that the wind tunnel temperature and humidity controls were operating properly.

AIRTEMP: Measured in degrees Fahrenheit, this was checked against the ambient thermocouples installed on the vehicle and recorded using the DAQ.

MAT3_SUR: Measured in degrees Fahrenheit, this is the surface temperature of the forward pavement simulation mat.

MAT4_SUR: Measured in degrees Fahrenheit, this is the surface temperature of the middle pavement simulation mat.

MAT5_SUR: Measured in degrees Fahrenheit, this is the surface temperature of the rear pavement simulation mat.

MAT6_SUR: Measured in degrees Fahrenheit, this is the surface temperature of the rear pavement simulation mat used for the Silverado.

Fuel Vapor Pressure: Measured in inches of water, this is a measurement of positive pressure on the fuel system.

OBD2 Data (*.csv)

OBDII data was collected using a HEM Data mini logger provided by the EPA during the three driving portions (the FTP 72, the FTP 75, and the running loss test) of the test sequence. The OBDII data collection system was problematic and didn't consistently record data for all tests (as discussed above in the Issues Encountered and Solutions section). Data is stored in a binary file that is processed using the HEM Data's DawnEdit software. The data available varies for each vehicle as some vehicles use different communication standards and don't broadcast the same types of data. The data description in below describes only the data that was used during analysis. Also, per the discussion above in the Issues Encountered and Solutions section – OBDII data is not available for all driving tests.

Time: When the drive cycle began

VIN: The vehicle identification number for the unit under test

Vehicle Speed: The vehicle speed measured in miles per hour

Commanded Evaporative Purge: Measured in percent, this is how much purge was commanded by the vehicle while the vehicle was in operation

Test Data.xlsx

The three data files are collated, and then added to a single Excel workbook containing all test results and responsible for data visualization. Data from each vehicle is contained on a single sheet for that particular vehicle.