

Effects of 7, 9, and 10 psi Vapor Pressure Fuels on Multi-Day Diurnal Evaporative Emissions of Tier 2 and LEV II Vehicles

Johanna Dolch
Ford Motor Co

Aaron Reek and Gerard Glinsky
SGS Environmental Testing Corp

Dominic Diccico
Ford Motor Co

Valerie Ughetta
Alliance of Automobile Manufacturers Inc

ABSTRACT

In order to meet more stringent evaporative emissions requirements, multiple advancements in vehicle fuel system and carbon canister technologies have been made. Regardless of technological advancements, the vapor pressure of the fuel remains a vital property in controlling evaporative emissions. A series of tests were performed to explore the effects of vapor pressure on multiday diurnal evaporative emissions for 9 and 10 psi Reid Vapor Pressure (RVP) 10% ethanol (E10) gasoline-blend fuels, followed by tests with 7 psi RVP E10 gasoline on a subset of the same vehicles. A test procedure was developed to monitor evaporative emissions, canister loading profiles and breakthrough emissions for each of the fuels. A total of five vehicles were tested on all 3 fuels, blended to represent 7, 9, and 10 psi at sea level. Tests were run over 14 days using the United States (U.S.) Federal Diurnal Cycle (72°F to 96°F) in a Sealed Housing for Evaporative Determination (SHED) at a test facility in Colorado. Two of the five vehicles had evaporative emissions systems that met the California Air Resources Board (CARB) requirements for a Partial Zero Emission Vehicle (PZEV), while the other three vehicles were certified to U.S. Tier 2 evaporative emissions standards. The data collected throughout the testing provide a correlation between the hydrocarbon slip from the vehicle canister and the fuel vapor pressure. The data indicate that achieving lower evaporative emissions can be accomplished through the use of decreased vapor pressure fuels.

CITATION: Dolch, J., Reek, A., Glinsky, G., Diccico, D. et al., "Effects of 7, 9, and 10 psi Vapor Pressure Fuels on Multi-Day Diurnal Evaporative Emissions of Tier 2 and LEV II Vehicles," *SAE Int. J. Fuels Lubr.* 6(2):2013, doi: 10.4271/2013-01-1057.

INTRODUCTION

Hydrocarbon (HC) emissions are known to contribute to the formation of photochemical smog [1]. Furthermore, hydrocarbon emissions from vehicles may also contain human carcinogens such as benzene, furthering the importance for the control of hydrocarbon emissions by regulatory bodies such as the U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB). It is known that hydrocarbon emissions are not limited to exhaust emissions.

Hydrocarbons can escape via evaporation from the fuel system not only during vehicle operation, but also during periods of increasing ambient temperatures while the vehicle is at rest. As air quality standards continue to become more stringent, more emphasis for the control of vehicle emissions is being placed on original equipment manufacturers (OEMs) to produce vehicles that meet tighter and tighter exhaust and evaporative emissions standards. Studies of evaporative emissions began in the 1970s. Throughout the subsequent decades, testing has shown that the vapor pressure of the fuel has a profound effect on the amount of HC evaporative emissions [2,3,4,5].

In order to monitor and analyze evaporative emissions of HC, federal regulations require vehicles to be tested on the Federal Diurnal Cycle, which is a 3-day diurnal test conducted according to 40 Code of Federal Regulations (CFR) Part 86.1233[6] in which the ambient temperature cycles between 72°F and 96°F. The use of carbon canisters on vehicles was generally adopted by OEMs as a means to meet stricter evaporative emissions standards beyond the initial 6 grams HC per test requirement introduced in 1970-71 in the United States. Carbon canisters contain activated carbon that adsorbs excess HC vapors emitted from the fuel tank. These vapors are contained in the canister until the canister undergoes a regeneration event in which air is drawn back through the canister and into the fuel tank, purging the canister of the HC it has captured. These regenerations occur while the engine is running, and to a lesser and incomplete extent during the cooling portion of the diurnal cycle (when the engine is not running). When vehicles are at rest for extended periods of time, the canister does not have the opportunity to undergo complete regeneration and excess hydrocarbons that are beyond the canister's working capacity are emitted directly into the atmosphere. In order to meet increasingly stringent evaporative emissions standards for Tier 2 and LEV II (see [Table 1](#)) vehicles were equipped with advanced carbon canister technologies which mitigate evaporative emissions from the fuel system. Therefore, in order to determine the effect of fuel vapor pressure on evaporative emissions, a test procedure which goes beyond the amount of time to which vehicles are typically certified was needed. Additionally, although there had been considerable work done on vehicles meeting older emissions standards, available information related to the effect of vapor pressure on evaporative emissions from newer technology vehicles, including those certified to the most stringent emissions standard from CARB, partial zero emission vehicles (PZEVs), was relatively sparse. With the further decrease in evaporative emissions standards on the horizon with California's LEV III program and pending Federal Tier 3 standards, the stringency of standards will continue to increase.

Table 1. Comparison of United States Evaporative Emissions Standards for Passenger Cars (PC)

	Model Years (PC Only)	3-Day Diurnal (g/test)	2-day Diurnal (g/test)
Federal Tier 1	1994 - 2006	2.0	2.5
Federal Tier 2	2004 - 2008	0.95	1.2
Federal Tier 2 MSAT*	2009+	0.50	0.65
California LEV I	1994 - 2006	2.0	2.5
California LEV II	2004+	0.50	0.65
California LEV II PZEV	2004+	0.35	0.35
California LEV III	2018+	0.300	0.300

*MSAT - Mobile Source Air Toxics

In the summer of 2011, a test program was developed to monitor evaporative emissions, canister loading profiles and breakthrough emissions from extended multiday diurnal testing using two different vapor pressure fuels. The two fuels used for the original study were a 9.0 psi Reid Vapor Pressure (RVP) at sea level (equivalent to 7.8 psi in Denver, see [Appendix A](#)) and 10.0 psi RVP at sea level (equivalent to 9.0 psi in Denver, see [Appendix A](#)). The Federal Diurnal Cycle was run in a Sealed Housing for Evaporative Determination (SHED) over a period of 14 consecutive days. The original study tested 9 vehicles at Environmental Testing Corporation (ETC, now a part of SGS) in Denver, Colorado [7].

In order to provide a more comprehensive data set the Alliance of Automobile Manufacturers and the Association of Global Automakers sponsored a follow-on testing program with a 7.4 psi fuel at sea level (equivalent to 6.4 psi in Denver, see [Appendix A](#)) in the spring of 2012, with a total of five of the original vehicles from the 9 and 10 psi tests (four of the original vehicles had already been deployed for other projects). After the completion of the original testing on the 9 psi and 10 psi RVP fuels, modifications were made to the original test procedure to allow for more accurate canister hydrocarbon slip measurements. For the purposes of this report, the descriptions of the test fuels will be abbreviated as follows: 7.4 psi RVP will be referred to as 7 RVP, 9.0 psi RVP as 9 RVP, and 10.0 psi RVP as 10 RVP. These represent the Reid Vapor Pressures of each test fuel at sea level.

EXPERIMENTAL SETUP

SGS-ETC tested five of the same vehicles on 7 RVP fuel as were used for the previous study on 9 and 10 RVP fuel. The five vehicles used for the 7 RVP testing are identified in [Table 2](#). Two of these five vehicles (Ford Focus, Toyota Prius) were certified as Partial Zero Emission Vehicles (PZEVs), and are shaded in [Table 2](#). The remaining three vehicles were certified to meet EPA Tier 2 evaporative emissions standards.

The vehicles were configured for testing in the same manner as the previous study (further described below), with the intention that the vapor pressure of the fuel would be the only test parameter change from the earlier 9 RVP and 10 RVP tests. There were various improvements made to the SHED setup and sampling system, which are detailed below in the Test Configuration and Sampling Method section of this report. The vehicles had received no modifications or additional mileage accumulation between the completion of the 9 RVP and 10 RVP testing and the beginning of the 7 RVP study. Between the study with the 9 and 10 RVP fuel and the 7 RVP testing, the vehicles were stored indoors with the 9 RVP fuel in the fuel tanks and the canisters returned to their original locations. Two of the vehicles, the 2009 Saturn Outlook and the 2010 Ford Focus, were used for correlation testing while developing the new SHED setup and sampling system.

An additional step that was added to this round of testing was an initial canister purge to minimum mass. This was done by continuously purging the vehicle canister with air on a canister conditioning stand until the rate of change of the canister mass was less than 2 grams in 2 hours. This ensured that the initial state of the canister was the same for all vehicles, and that all canisters began the preconditioning procedure in their empty state.

Table 2. Vehicles Tested

Make	Model	MY	Odometer	VECI Labels		Canister WC* (g)	Tank Vol. (gal)
				Engine	Evap		
Saturn	Outlook	2009	120,403	9GMXT03.6151	9GMXR0197972	197	22.0
Toyota	Camry	2009	121,187	9TYXV02.4BEA	9TYXR0130A12	130	18.5
Ford	Focus	2010	28,390	AFMXV02.0VZX	AFMXR0110GCX	110	14.5
Ford	Taurus	2008	115,599	8FMXV03.5VEP	8FMXR0145K8K	145	20.0
Toyota	Prius	2010	27,789	ATYXV01.8HC3	ATYXR0110P42	110	11.9

Shaded vehicles are certified PZEVs

*Canister working capacity in grams

The vehicles tested on 7 RVP fuel were configured in the same manner as the previous study with minimal modification. An attempt to relocate each vehicle canister from its native environment for placement on a scale located in the SHED was made using the original hoses from the vehicle. If the original hoses would not accommodate the canister relocation to the scale then a minimal amount of non-permeable extension hose was added to connect the vehicle canister to the SHED scale. If the hoses were in need of modification, additional leak checks were performed on the system. The vehicle canister was placed on the scale in an orientation as if it were in its native environment when it was installed in the vehicle. Maintaining this native orientation is critical as canisters fill with HC vapor as if the HC vapor were a liquid; therefore, a non-native orientation can influence the canister's ability to absorb hydrocarbons per its design.

In addition to relocating the canister, hoses were added to the canister vent to allow bleed emissions to be measured outside the SHED and fresh air supplied for canister back purge. Back purge occurs when the vapors in the fuel tank contract and the fuel vapor pressure decreases as a result of a decreasing temperature. If fresh air is not supplied at the canister vent, it is possible for hydrocarbon vapors to be drawn back into the canister from the vent line. To enable fuel temperature measurement, a thermocouple was adhered to the fuel tank skin and insulated. This was done because the fuel tank temperature generally lags behind changes in the SHED ambient temperature; therefore, in order to properly time-align the vehicle canister weight gain, the fuel temperature must be known.

Fuels

SGS purchased the base fuel with 10% ethanol from a local source in the Denver area. The RVP of the base fuel was then adjusted to a sea level equivalent of 7 psi (actual

RVP in Denver of 6.4 psi). The RVP was adjusted by weathering the fuel by bubbling nitrogen through the fuel in a 300 gallon fuel tote until it reached the target RVP and was then transferred into 55 gallon drums for storage. The drums were sealed, labeled and stored in SGS's fuel storage room for the duration of the project. The RVP was confirmed throughout this process using SGS's Petrolab Minivap VPS RVP instrument. SGS used its on-site infrared spectrometer which is capable of measuring ethanol content in gasoline to an accuracy of 0.19% to determine the actual ethanol content in each fuel batch. This was done to ensure that the ethanol content of the 7 RVP fuel matched that of the 9 and 10 RVP fuels used in the previous study, which was also 10% nominal. This assured that the vapor pressure, not the ethanol content, was varied between tests. Additionally, other fuel parameters, such as the distillation curve and HC composition (olefins, aromatics and saturates) as per 40 CFR 86.113, were measured by an outside laboratory, Southwest Research Institute. A complete table of measured fuel properties is located in [Appendix A](#).

Figure 1 shows the distillation curves for the three test fuels 7 RVP, 9 RVP and 10 RVP. A brief review of the distillation curves, as well as the other tested parameters, found the three fuels to meet the Standard Specification for ASTM Automotive Spark-Ignition Engine Fuel (D4814-11b [8]). This verified that the weathering process from the base fuel (also compliant to ASTM D4814-11b) did not materially affect the other volatility characteristics of the fuel. Although the scope of the project was the study of the effects of RVP, the distillation curve is also an important measure of volatility of the fuel. Minor adjustments to the distillation curve, concentrated at the front end, can lead to large changes in evaporative emissions.

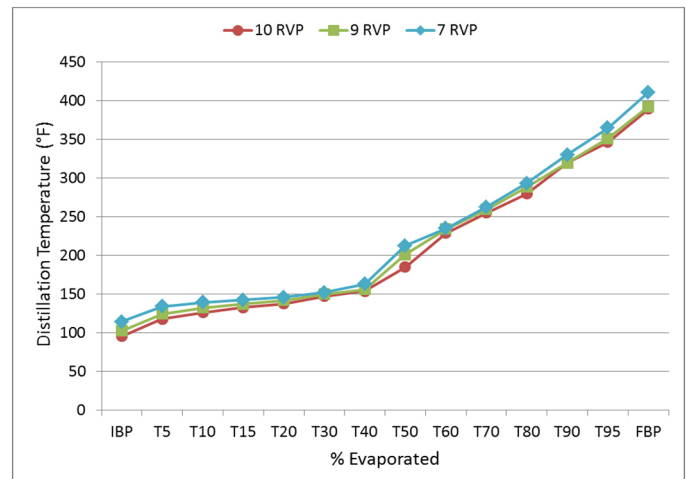


Figure 1. Distillation Curve for 7, 9 and 10 RVP Fuels

Test Configuration and Sampling Method

The measurement method from the previous study utilized a small air pump to drive the bleed emissions from the



Documents

Document Sharing Hub

canister vent to a trap canister located outside the SHED and then supply fresh air for canister back purge during the declining temperature periods of the diurnal cycle. In this method the pump moved a small amount of ambient air (3 liters per hour) through a "T" located at the canister vent to the trap canister where the vapors were collected and measured gravimetrically on a scale. This set up is depicted in Figure 2.

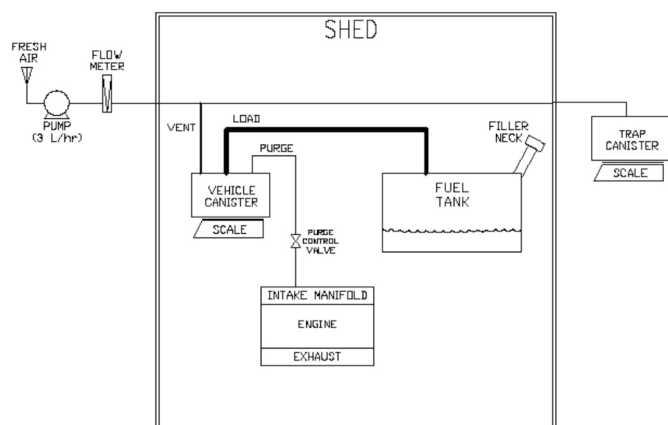


Figure 2. SHED Schematic - Gravimetric Method

Although this method was effective for measuring daily bleed emissions, the cumulative mass was not representative of the actual bleed mass over the entire test due to the small amount of mass lost from the trap canister each day during the natural diurnal back purge. Therefore, an improved measurement method was developed and utilized for the 7 RVP testing and is depicted in Figures 3, 4, 5.



Figure 3. SHED Setup for 7 RVP testing

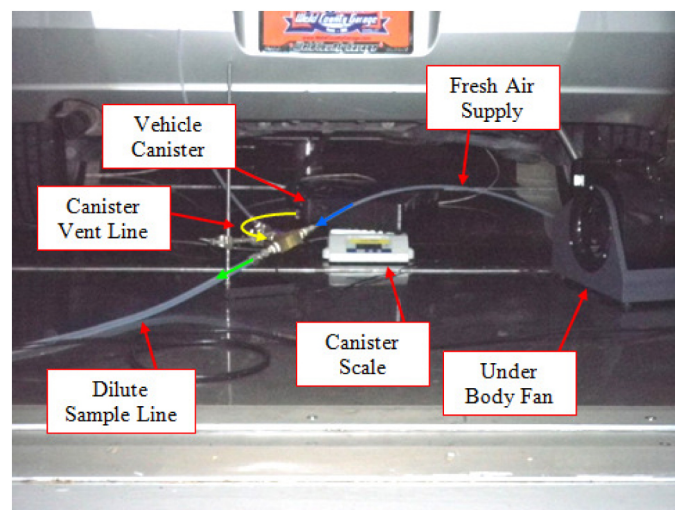


Figure 4. SHED Setup Detail - Direct Measurement Method

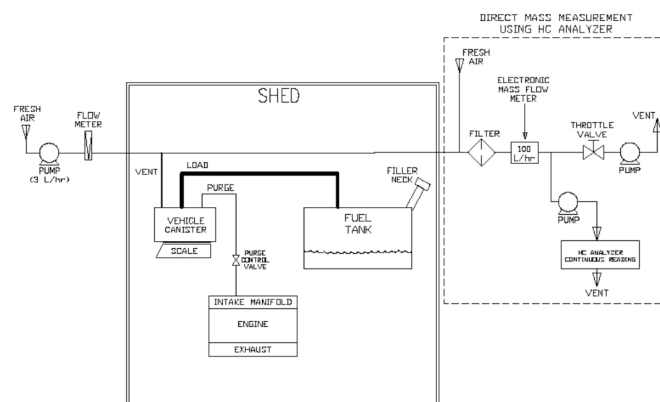


Figure 5. SHED Schematic - Direct Measurement Method

The new method replaced the external trap canister with a direct measurement configuration using a Flame Ionization Detector (FID) hydrocarbon analyzer and a dilute measured mass sampler. Hydrocarbons exiting the vehicle canister vent were diluted with fresh air from outside the SHED. The diluted sample was then drawn through a Mass Flow Meter and throttle valve by a high volume pump. The FID supply pump drew a sample from the dilute stream after the mass flow meter. The concentration vented from the vehicle canister was measured continuously throughout the 14-day test.

The concentration of the HC (in ppm) was converted to grams using the same calculation used for HC mass in exhaust emissions in 40 CFR 86.144. The equation, for reference, is provided in Eq. (1).

$$HC_{mass}(g) = V_{mix}(ft^3) \times Density_{HC} \left(\frac{g}{ft^3} \right) \times \frac{HC_{conc}(ppm)}{1,000,000}$$