United States Environmental Protection Agency

Air and Radiation

EPA420-R-01-026
April 2001
M6.EVP.004

Update of Hot Soak Emissions

EPA420-R-01-026
April 2001

Update of Hot Soak Emissions

M6.EVP.004

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

Preapred for EPA by:
ARCADIS Geraghty & Miller, Inc.
EPA Contract No. 68-C6-0068
Work Assignment No. 1-01

I. INTRODUCTION

The U.S. Environmental Protection Agency's (EPA) highway emission factor model, currently MOBILE5a, calculates in-use emission factors for exhaust and evaporative emissions using national average values as supplemented by user-supplied input (e.g., temperature, fuel volatility, etc.). EPA is currently working to develop a new version of the model (MOBILE6) to further improve its accuracy and include more "real world" data.

Evaporative "hot soak" (trip-end) emissions represent one area where data now exist to better characterize conditions observed during "real world" driving conditions. A hot soak is defined as the evaporative losses produced as fuel evaporates from the carburetor and fuel tank in carbureted vehicles, or from the fuel tank in fuel injected vehicles, as a result of heating of the fuel tank and fuel system above ambient temperatures. Average temperatures that occur during a hot soak event are shown in Figure 1. As can be seen from this figure, fuel system temperatures greatly exceed ambient temperatures during a hot soak event.

Hot soak emissions generally occur during the one-hour period[1] after the engine is shut down and are measured in a sealed housing for evaporative emission determination (SHED). Results from SHED tests are in grams per one-hour test (g/test). Level of emissions during a hot soak is a function of fuel volatility (Reid Vapor Pressure [RVP]) and ambient temperature, as well as other variables.

In previous versions of the MOBILE model, hot soak emissions were characterized using data derived from laboratory testing of light-duty vehicles and trucks. Testing was conducted under EPA-derived fuel RVP and temperature criteria. These criteria stem from the EPA certification test procedure, and specifically consisted of a certification test fuel with a fuel volatility level of 9.0 psi, a fuel tank fill level of 40%, and an ambient temperature of approximately 82°F. Two additional fuels with RVP levels of 10.4 and 11.7 psi were also used during testing performed in 1984 through 1989. In 1990, data from testing in Hammond, Indiana was also added to the emission factor database. This test program involved the procurement of vehicles tested in Indiana Inspection and Maintenance (I/M) program lanes, where vehicles were driven on an IM240 transient test cycle, and testing of the evaporative emissions control systems was performed to see if either failures existed due to improper pressure and/or improper purging of vapors. This testing is known as pressure/purge tests. Some vehicles that failed either test were also tested for their diurnal and hot soak emissions, in an attempt to assess whether failure of pressure/purge testing could be correlated to high diurnal and hot soak emissions.

The MOBILE model contains correction factors for the effects of RVP and temperature on hot soak emissions that allow the user to adjust these conditions to correspond to local values. These correction factors have been developed though statistical analysis of the EPA hot soak emissions data.

---

[1] The majority of hot soak emissions occur within 10 minutes after engine shut-off, but are measured during a hot soak test for a 1 hour period.

Since the development of the latest version of MOBILE, EPA has recognized the need to incorporate additional hot soak data into its modeling efforts. The data used to generate hot soak curve fits for MOBILE5a did not incorporate low RVP fuels, which are now regulated in various parts of the country. Furthermore, the data did not fully represent "real world" conditions, as "real world" vehicles never have certification fuel in their fuel tanks and are operated under a wide range of ambient temperature conditions.

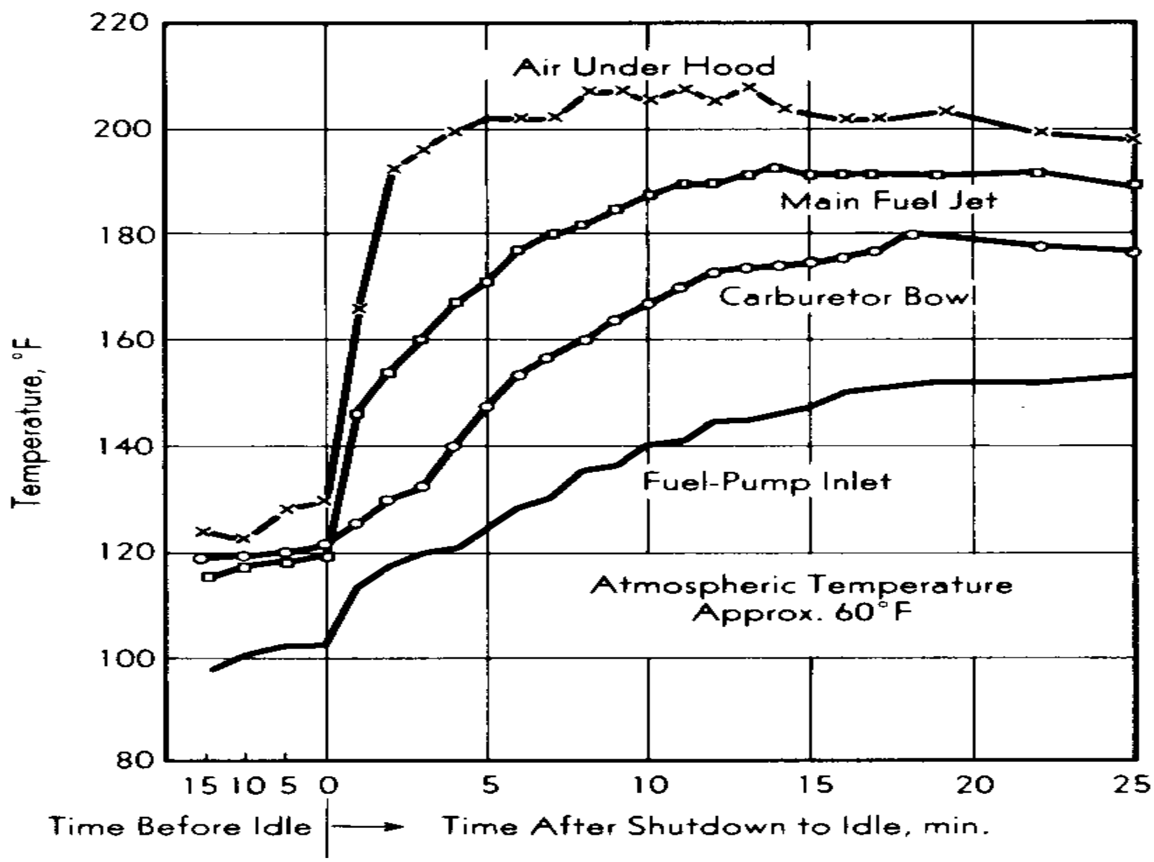


Figure 1. Temperatures occurring during a hot soak event

To this end, several studies have recently been conducted characterizing hot soak emissions at higher ambient temperatures and over a wider range of fuel RVPs than those contained in previous EPA testing. The two most significant studies were conducted by the Auto/Oil Air Quality Improvement Research Program (AQIRP) and by EPA, both under contract with the Automotive Testing Laboratories (ATL). Both studies recruited vehicles from Arizona Inspection and Maintenance (I/M) testing lanes, and the testing was performed under comparable conditions. Table 1 lists the testing conditions and average results of emissions testing for both studies. In addition, two other EPA work assignments (Contract 68-C3-0006, Work Assignments 0-07 and 0-11) contain hot soak testing on smaller numbers of vehicles. This report details an analysis of these "real world" databases and develops correction factors for RVP and ambient temperature based upon this data.

These databases encompass vehicles with "real world" gasolines in their fuel tanks, have a variety of tank fill levels, are tested as received and at a variety of ambient temperatures.

Table 1. Comparison of testing criteria for "real world" hot soak studies

	Auto/Oil	**EPA**
Testing dates	June 15, 1993 to September 15, 1993	July 7, 1995 to September 29, 1995
Number of test vehicles	299	181
Type of vehicles	In-use LDVs and LDTs	In-use LDVs and LDTs
Model years represented	1983 - 1993	1981 - 1994
Location of Testing	Automotive Testing Laboratory, Mesa, Arizona	Automotive Testing Laboratory, Mesa, Arizona
Daytime temperature range	82°F to 112°F	at least 80°F
Hot soak cut-point	2.0 grams/test	2.0 grams/test
As-received average HC emissions across fleet	1.53 grams/test	1.76 grams/test
Range of emissions	0.04 to 49.39 grams/test	0.06 to 46.95 grams/test
No. of high emitters	46 out of 299	28 out of 181
Percent high-emitters	15.3%	15.6%

The approach described below, developed under direction by EPA, attempts only to replace the existing MOBILE5 estimates for adjustment of hot soak emissions for RVP levels below 9 pounds per square inch (psi) with new estimates based on the new data. The baseline estimates of hot soak emissions and the effects of RVP values above 9 psi would be retained for MOBILE6.

II. DATA ANALYSIS

There are several variables which directly affect hot soak emissions. Hot soak emissions in vehicles (with newer evaporative emissions control systems) are usually due to small leaks in the evaporative emission control system (joints, lines, valves) and permeation of the fuel hoses and tank. These fuel vapor leaks are generally driven by the heating of the fuel system above ambient conditions during a hot soak event As seen in Figure 1, fuel system temperatures greatly exceed ambient temperatures during a hot soak event. Fuel tank temperature is usually close to ambient but can increase in fuel injected vehicles due to fuel returning from the hot engine compartment. Typically, tank temperatures in fuel injected vehicles can exceed ambient temperatures by 5 to 15°F. Thus hot soak emissions are not a direct function of ambient temperature.

Data from the "real world" data set are characterized in Table 2. In addition to the categories of the data used in MOBILE5a, two new strata were added. The first is "gross liquid leaker." This refers to vehicles which produce abnormally high evaporative emissions as a result of a fuel leak and which have hot soak emissions of over 10 grams per test. The second is the addition of two new model year groupings (1981-1985, and 1986 and newer) for vehicles that passed both the pressure and purge tests. This stratification of model year groups was used to capture the significant improvement of evaporative emissions systems in most automobiles that occurred beginning with the 1986 model year. Other strata used in MOBILE5a were continued, i.e., hot soak data from vehicles that passed both the pressure and purge tests were stratified by fuel system type (carbureted [Carb], throttle body fuel injected [TBI], and port fuel injected [PFI]) and by vehicle type classification (passenger cars [LDV] and light-duty trucks [LDT]).

Hose permeation can also be a large source of hot soak emissions, particularly in fuel injected vehicles. PFI systems typically run at pressures of 40-50 psi, while TBI systems run around 10 psi. Permeation of fuel through elastomers in the fuel and evaporative control system can be very temperature sensitive and can be a large source of hot soak emissions in newer vehicles. Injector leaks in fuel injected systems can result in very high hot soak emissions (liquid leakers).

A further factor in real world hot soak emissions is the different molecular weight of the fuel vapor. Because different fuels have different light ends and there is some weathering (loss of light ends over time) of fuel components in fuel tanks, hot soak emissions can vary in molecular weight by up to 50%. In the Auto/Oil Air Quality Improvement Research Program (AQIRP), over 50 current vehicles were tested on a variety of fuels. Hot soak emission molecular weight varied from 65.6 g/g mole to 92.3 g/g mole with an average molecular weight of 84.1 g/g mole. These large fluctuations in molecular weight can significantly affect the mass of emissions emitted during a hot soak event.

With these factors in mind, it was not surprising to find significant scatter in the real world hot soak data. Furthermore, most of the data represented RVPs of 5 to 7 psi. Extrapolation of this data past 9 psi is not recommended due to the narrow range of RVPs in the data set. Therefore curve fits using real world data were only generated up to 9 psi RVP. For RVPs over 9 psi, previous MOBILE5a curves were used. This presented an additional challenge to the regression analyses, making sure that the two curves met at 9 psi RVP at all temperatures. This required that the functional form of the equation be identical to those presently used in MOBILE5a and that the temperature coefficient in those equations be the same. Thus regression analyses were performed only on RVP using the real world data.

In some cases, the data produced a negative coefficient with regard to RVP (i.e. as RVP increased, predicted hot soak emissions decreased). As this is intuitively incorrect, additional data points were generated using the MOBILE5a curve fits at 9 psi RVP and added to the data sets that produced a negative RVP coefficient until the resulting curve produced by regression analysis had a positive RVP coefficient. Further discussion is found in each of the sections below.

The following sections describe the stratification of the hot soak data sets, the methodology used to determined curve fits of that data, and a discussion of the results of the curve fits.

III. GROSS LIQUID LEAKERS

Liquid fuel leaks from fuel systems can result in very high hot soak emissions. This is particularly true for fuel injection systems that operate at high pressure (40-45 psi). If an injector is leaking due to damage or incorrect position, pressure built up in the fuel system will bleed off through that injector. Liquid leaks can also exist in carbureted fuel systems as a result of leaking carburetor gaskets or a defective fuel shut off at the carburetor bowl. The real world data set included 17 liquid leakers, 9 of which fell into the gross liquid leaker category. Gross liquid leakers were defined as those vehicles with liquid fuel leaks that were measured at over 10 grams per test of hot soak emissions. Since the set of liquid leaker data was so small, all that could be defined was an average value for two different fuel systems, namely carbureted (Carb) and port fuel injected (PFI). Carb vehicles had an average gross liquid leaker hot soak value of 14.60 g/test, while PFI vehicles had an average liquid leaker hot soak value of 57.79 g/test. It is reasonable that fuel injected systems would have much higher liquid leak emissions as they are usually under higher fuel pressure. While there is no data on TBI liquid leakers in the data sets, Bernoulli's equation indicates that the leak rate for TBI systems would be about one half that for PFI systems (the square root of the ratio of operating pressures). Therefore, without further data, the author suggests assuming that TBI liquid leakers might emit approximately half the emissions of PFI systems. These estimates are further revised in the report, "Evaporative Emissions of Gross Liquid Leakers in MOBILE6," (M6.EVP.009).

IV. PRESSURE TEST FAIL VEHICLES

Of the 630 vehicles tested, 80 vehicles that did not fall into the gross liquid leaker category failed the pressure test. Data within this strata had significant scatter and in several cases there was not enough data to support further stratification by fuel system type, so all pressure fail data were aggregated together similar to what was done for MOBILE5a. The MOBILE5a curve fit for pressure failed vehicles was in the form of :

$$\text{Hot Soak} = \exp(A*(RVP-9.0) + B*(Temp - 82) + C) \qquad (IV.1)$$

Since the data was at various ambient temperatures, each hot soak test value was adjusted to 95°F using the MOBILE5a temperature correction as shown below:

$$\text{Adjusted Hot Soak} = \text{Hot Soak} * \exp(1.774+0.05114*(95-82))/\exp(1.774+0.05114*(Temp-82)) \qquad (IV.2)$$

In addition, to be consistent with MOBILE5a, all fuel injected test data (TBI and PFI) were divided by 0.88, the fuel system adjustment factor in MOBILE5a (in MOBILE5a, this factor is multiplied by all fuel injected vehicle results to adjust for the difference between in-use and FTP fuel tank levels). A regression analysis was run on the adjusted hot soak versus RVP data to determine coefficient B in equation IV.1 above. A t-statistic of 2.88 resulted for the coefficient with a P-value of 0.0051. The coefficient C was determined so that the calculated hot soak results using the real world curve fit matched the MOBILE5a curve fit at 9 psi RVP at all temperatures. This still resulted in a P-value of 0.0195 for coefficient C. The equation for all pressure fail vehicles for less than 9 psi RVP is:

$$\text{Hot Soak} = \exp(0.413356*(\text{RVP} - 9.0) + 0.05114*(\text{Temp} - 82) + 1.774) \qquad \text{(IV.3)}$$

This may be compared to the MOBILE5a equation for RVP less than 9.0 psi, which is:

$$\text{Hot Soak} = \exp(0.4443*(\text{RVP} - 9.0) + 0.05114*(\text{Temp} - 82) + 1.774) \qquad \text{(IV.4)}$$

For fuel injected vehicles, the fuel system adjustment factor of 0.88 should be multiplied by both equations IV.3 and IV.4 to obtain hot soak emission results.

Predicted hot soak emissions calculated using equation IV.3 are shown in Table 3 for pressure fail vehicles before application of the fuel system adjustment factor. MOBILE5a estimates calculated using equation IV.4 are also included for reference. Figure 2 shows the real world and MOBILE5a curve fits as well as the real world data for TBI vehicles. Figure 3 shows the real world and MOBILE5a curve fits as well as real world data for PFI vehicles. Figure 4 shows the real world and MOBILE5a curve fits as well as real world data for Carb vehicles. Figures 2 and 3 show both real world and MOBILE5a curve fits with the fuel system adjustment factor applied. While the curve fits are the same in all three figures (except for application of the fuel system adjustment factor), real world data were shown divided by fuel system type in Figures 2 through 4 so that the reader could see how the real world data compared against the new and MOBILE5a curve fits.

As seen in Table 3 and Figures 2, 3 and 4, the new pressure fail curve fits predict slightly higher emissions in the 5 to 7 psi RVP range than the previous MOBILE5a curve fits. This indicates that real world pressure test fail data shows slightly higher levels of hot soak emissions than previously estimated from the laboratory data used to generate the curve fits for MOBILE5a.

V. PURGE TEST FAIL VEHICLES

Of the 630 vehicles tested, 47 vehicles that did not fall into the gross liquid leaker category failed the purge test. Data within this strata had significant scatter and in several cases there were not enough data to support further stratification by fuel system type, so all purge fail data were aggregated together similar to what was done for MOBILE5a. The MOBILE5a curve fit for purge failed vehicles was in the form of :

$$\text{Hot Soak} = \exp(A*(RVP-9.0) + B*(Temp - 82) + C) \quad (V.1)$$

Since the data was at various ambient temperatures, each hot soak test value was adjusted to 95°F using the MOBILE5a temperature correction as shown below:

$$\text{Adjusted Hot Soak} = \text{Hot Soak} * \exp(1.76223+0.05114*(95-82))/\exp(1.76223+0.05114*(Temp-82)) \quad (V.2)$$

In addition, to be consistent with MOBILE5a, all fuel injected test data were divided by 0.88, the fuel system adjustment factor in MOBILE5a. A regression analysis was run on the adjusted hot soak versus RVP data to determine coefficient B in equation V.1 above. A t-statistic of 2.37 resulted for the coefficient with a P-level of 0.0222. The coefficient C was determined so that the calculated hot soak results using the real world curve fit matched the MOBILE5a curve fit at 9 psi RVP at all temperatures. This coefficient resulted in a P-value of 0.0261. The equation for all purge fail vehicles for less than 9 psi RVP is:

$$\text{Hot Soak} = \exp(0.552175*(RVP - 9.0) + 0.05114*(Temp - 82) + 1.76223) \quad (V.3)$$

This may be compared to the MOBILE5a equation for RVP less than 9.0 psi, which is:

$$\text{Hot Soak} = \exp(0.4443*(RVP - 9.0) + 0.05114*(Temp - 82) + 1.76223) \quad (V.4)$$

For fuel injected vehicles, the fuel system adjustment factor of 0.88 should be multiplied by both equations V.3 and V.4 to obtain hot soak emission results.

Predicted hot soak emissions calculated using equation V.3 are shown in Table 4 for purge fail vehicles before application of the fuel system adjustment factor. MOBILE5a estimates calculated using equation V.4 are also included for reference.

Figure 5 shows the real world and MOBILE5a curve fits as well as the real world data for TBI vehicles. Figure 6 shows the real world and MOBILE5a curve fits as well as real world data for PFI vehicles. Figure 7 shows the real world and MOBILE5a curve fits as well as real world data for Carb vehicles. Figures 5 and 6 show both real world and MOBILE5a curve fits with the fuel system adjustment factor applied. Again, real world data have been stratified by fuel system type in Figures 5 through 7 for comparison purposes only.

As seen by Table 4 and Figures 5, 6 and 7, the new purge fail curve fits predict slightly lower emissions in the 5 to 7 psi RVP range than the previous MOBILE5a curve fits. This indicates that real world purge test fail data shows slightly lower levels of hot soak emissions than previously estimated from the laboratory data used to generate the curve fits for MOBILE5a.

VI. PASSING VEHICLES

Of the 630 vehicles tested, 494 vehicles which did not fall into the gross liquid leaker category passed both the pressure and purge tests. The hot soak data set of vehicles that passed both the pressure and purge tests allow some disaggregations, although some of the disaggregations did not produce statistically significant curves due to large data scatter. In some cases, the data even produced negative coefficients for RVP and additional data calculated from MOBILE5a curve fits at 9 psi RVP had to be added to produce reasonable trends over the RVP range (5 to 9 psi). The functional form of current MOBILE5a pass/pass vehicle equations and strata were used to perform regression analyses of the real world data. An additional stratification was added to each set, however. The data were divided into two model year groupings for each vehicle type. Since manufacturers became more aware of the need to 'fine tune' evaporative emission systems during the 1981 through 1985 model years, the data was stratified into two model year groupings, namely 1981-1985 and 1986+. Discussion of the methodology used and the results of the regression analysis are contained within each subsection below.

A. TBI

Of the 494 vehicles that passed both the pressure and purge tests, 102 vehicles had TBI fuel systems. A curve fit similar to that used in MOBILE5a for TBI vehicles was used:

$$\text{Hot Soak} = (A + B*RVP)*(C + D*Temp^2)/E \qquad \text{(VI.1)}$$

Since the data were at various ambient temperatures, each hot soak test value was adjusted to 95°F using the temperature correction factor defined in MOBILE5a curve fits for TBI pass/pass vehicles:

$$\text{Adjusted Hot Soak} = \text{Hot Soak} * (-2.4636+0.00056161*95^2))/(-2.4636+0.00056161*Temp^2) \qquad \text{(VI.2)}$$

In addition, to be consistent with MOBILE5a, all fuel injected test data were divided by 0.88, the fuel system adjustment factor used in MOBILE5a. A regression analysis was run on the adjusted hot soak versus RVP data to determine coefficients A and B in equation VI.1 above for each strata.

Of the 102 TBI tests, 17 corresponded to LDVs with model years between 1981 and 1985, 56 were LDVs model years 1986+, and 29 were LDTs model years 1986+. There were no test data for LDTs model years 1981-1985.

For the TBI LDVs with model years (MY) between 1981 and 1985, t-statistics of -0.44 and 0.87 and P-values of 0.666 and 0.396 resulted for coefficients A and B, respectively, indicating that neither produced statistically significant curves due to significant data scatter. It did, however, produce a reasonable trend with regard to RVP. For TBI LDVs with MY 1986+, t-statistics of -0.44 and 0.65 and P-values of 0.661 and 0.516 resulted for coefficients A and B, respectively, indicating that neither produced statistically significant curves due to significant data scatter. It did, however, also produce a reasonable trend with regard to RVP. For TBI LDTs with MY 1986+, t-statistics of

-3.96 and 6.76 and P-values of 4.9E-04 and 3.0E-07 resulted for coefficients A and B, respectively, indicating that these coefficients were statistically significant. Coefficients C and D were retained from the MOBILE5a curve fits for TBI pass/pass vehicles and coefficient E was determined so that the calculated hot soak results using the real world curve fits matched the MOBILE5a curve fits at 9 psi RVP at all temperatures.

The equations for the two model year groupings of LDVs are as follows:

1981-1985 MY LDVs

$$\text{Hot Soak} = (-0.52111 + 0.159322*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/1.898 \qquad \text{(VI.3)}$$

1986+ MY LDVs

$$\text{Hot Soak} = (-1.27508 + 0.28853*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/2.748 \qquad \text{(VI.4)}$$

For comparison, the MOBILE5a equation for MY 1981+ LDV TBI vehicles that pass both the pressure and purge tests is:

$$\text{Hot Soak} = (0.258327 + 0.041297*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/1.31 \qquad \text{(VI.5)}$$

As explained in Section IV, equations VI.3, VI.4, and VI.5 should be multiplied by the fuel system adjustment factor of 0.88 to obtain hot soak emission results.

Predicted hot soak emissions for TBI LDVs calculated using equations VI.3 and VI.4 are shown in Table 5 (with the fuel system adjustment factor applied) along with MOBILE5a TBI LDV estimates (calculated using equation VI.5). Plots of hot soak emissions at 95°F are shown in Figure 8. Curves shown in Figure 8 also have the fuel system adjustment factor applied.

As seen in Table 5 and Figure 8, the new TBI LDV curve fits predict slightly lower emissions in the 5 to 7 psi RVP range than the previous MOBILE5a curve fits. While no conclusions can be drawn from these curve fits (as they are not statistically significant), one might assume that the real world vehicle set used to define these curve fits had lower hot soak emissions in the 5 to 7 psi RVP range than that estimated from MOBILE5a (which was produced from an extrapolation of higher laboratory data). Furthermore, curve fits for MY 86+ vehicles showed lower hot soak emissions than the MY 81-85 group, which is reasonable assuming an improvement in evaporative control system design.

The equation for LDTs derived from the real world data is:

1986+ MY LDTs

$$\text{Hot Soak} = (-0.71055 + 0.17803*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/2.596 \qquad \text{(VI.6)}$$

The MOBILE5a equation for MY 1981+ LDT TBI vehicles that pass both the pressure and purge tests is:

$$\text{Hot Soak} = (0.078327 + 0.041297*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/1.31 \quad \text{(VI.7)}$$

Equations VI.6 and VI.7 should be multiplied by the fuel system adjustment factor of 0.88 to obtain hot soak emission results.

Predicted hot soak emissions for TBI LDTs calculated using equation VI.6 are shown in Table 6 along with MOBILE5a TBI LDT estimates (calculated using equation VI.7) with the fuel system correction factor applied in both cases. Plots of hot soak emissions for TBI LDT pass/pass vehicles at 95°F are shown in Figure 9 with the fuel system correction factor applied to the curve fits.

Predicted hot soak emissions using the real world curve fits are lower in the 5 to 7 psi RVP range than predicted using previous MOBILE5a curve fits. The real world data shows lower levels of hot soak emissions in this region than previously extrapolated from the laboratory data at higher RVPs used to generate the curve fits for MOBILE5a.

B. PFI

Of the 494 vehicles that passed both the pressure and purge tests, 279 vehicles had PFI fuel systems. A curve fit similar to that used in MOBILE5a for PFI vehicles was used:

$$\text{Hot Soak} = (A + B*\text{RVP})*(C*\text{Temp})/D \quad \text{(VI.8)}$$

Since the data was at various ambient temperatures, each hot soak test value was adjusted to 95°F using the temperature correction factor defined in MOBILE5a curve fits for PFI pass/pass vehicles:

$$\text{Adjusted Hot Soak} = \text{Hot Soak} * 95/\text{Temp} \quad \text{(VI.9)}$$

In addition, as explained in Section IV, to be consistent with MOBILE5a, all fuel injected test data were divided by 0.88, the fuel system adjustment factor in MOBILE5a. A regression analysis was run on the adjusted hot soak versus RVP data to determine coefficients A and B in equation VI.8 above for each strata.

Of the 279 PFI tests, 15 corresponded to LDVs with model years between 1981 and 1985, 225 were LDVs model years 1986+, and 39 were LDTs model years 1986+. There were no test data for LDTs model years 1981-1985.

For the PFI LDVs with model years (MY) between 1981 and 1985, the first regression analysis resulted in a negative B coefficient, implying a decrease in emissions with increasing fuel RVP, which is intuitively incorrect. To correct this situation, 15 additional data points calculated using the MOBILE5a curve fit at 9 psi RVP and 95°F were added to the 15 real world data points. This produced a positive B coefficient with a t-statistic of 2.02 with a P-value of 0.0528. Real world data for PFI LDVs with MY 1986+ also produced a negative B coefficient. By adding 25 MOBILE5a calculated data points at 9 psi RVP and 95°F to the 223 real world data points, a positive

B coefficient resulted with a t-statistic of 1.74 and a P-value of 0.084. For PFI LDTs with MY 1986+, a positive B coefficient was achieved without addition of MOBILE5a points, but the t-statistic and P-value were only 0.29 and 0.77, respectively, indicating that it was not statistically significant. Coefficient C was retained from the MOBILE5a curve fits for PFI pass/pass vehicles and coefficient D was determined so that the calculated hot soak results using the real world curve fits matched the MOBILE5a curve fits at 9 psi RVP at all temperatures.

The equations for the two model year groupings of LDVs are as follows:

1981-1985 MY LDVs

$$\text{Hot Soak} = (-0.058967 + 0.100658*\text{RVP})*(0.0055541*\text{Temp})/0.749 \qquad \text{(VI.10)}$$

1986+ MY LDVs

$$\text{Hot Soak} = (-0.0097563 + 0.082809*\text{RVP})*(0.0055541*\text{Temp})/0.651 \qquad \text{(VI.11)}$$

For comparison purposes, the MOBILE5a equation for MY 1981+ LDV PFI vehicles that pass both the pressure and purge tests is:

$$\text{Hot Soak} = (-0.40673 + 0.10297*\text{RVP})*(0.0055541*\text{Temp})/0.46 \qquad \text{(VI.12)}$$

Equations VI.10, VI.11, and VI.12 should be multiplied by the fuel system adjustment factor of 0.88 to obtain hot soak emission results.

Predicted hot soak emissions for PFI LDVs calculated using equations VI.10 and VI.11 are shown in Table 7 (with the fuel system adjustment factor applied) along with MOBILE5a PFI LDV estimates (calculated using equation VI.12). Plots of hot soak emissions at 95°F are shown in Figure 10. Curves shown in Figure 10 also have the fuel system adjustment factor applied.

Predicted hot soak emissions using the real world curve fits are generally higher in the 5 to 7 psi RVP range than predicted using previous MOBILE5a curve fits. While this could indicate that real world data shows higher levels of hot soak emissions in this region than previously estimated from the laboratory data used to generate the curve fits for MOBILE5a, it could also be a artifact of the significant data scatter.

The equation for LDT hot soak emissions derived from the real world data is:

1986+ MY LDTs

$$\text{Hot Soak} = (0.3456+0.04906*\text{RVP})*(0.0055541*\text{Temp})/0.805 \qquad \text{(VI.13)}$$

For comparison purposes, the MOBILE5a equation for MY 1981+ LDT PFI vehicles that pass both the pressure and purge tests is:

$$\text{Hot Soak} = (0.078327 + 0.041297*\text{RVP})*(0.0055541*\text{Temp})/0.46 \qquad \text{(VI.14)}$$

Equations VI.13 and VI.14 should be multiplied by the fuel system adjustment factor of 0.88 to obtain hot soak emission results.

Predicted hot soak emissions for PFI LDTs calculated using equation VI.13 are shown in Table 8 along with MOBILE5a PFI LDT estimates (calculated using equation VI.14) with the fuel system correction factor applied in both cases. Plots of hot soak emissions for PFI LDT pass/pass vehicles at 95°F are shown in Figure 11 with the fuel system correction factor applied to the curve fits.

Predicted hot soak emissions using the real world curve fit are only slightly higher than previous MOBILE5a estimates in the 5 to 7 psi RVP range.

C. Carb

Of the 494 vehicles that passed both the pressure and purge tests, 113 vehicles had Carb fuel systems. A curve fit similar to that used in MOBILE5a for Carb vehicles was used:

$$\text{Hot Soak} = (A + B*RVP)*(C + D*Temp^2)/E \qquad \text{(VI.15)}$$

Since the data was at various ambient temperatures, each hot soak test value was adjusted to 95°F using the temperature correction factor defined in MOBILE5a curve fits for Carb pass/pass vehicles:

$$\text{Adjusted Hot Soak} = \text{Hot Soak} * (-2.4636+0.00056161*95^2))/(-2.4636+0.00056161*Temp^2) \qquad \text{(VI.16)}$$

A regression analysis was run on the adjusted hot soak versus RVP data to determine coefficients A and B in equation VI.15 above for each disaggregation.

Of the 113 Carb tests, 45 corresponded to LDVs with model years between 1981 and 1985, 38 were LDVs model years 1986+, 14 were LDTs with model years between 1981 and 1985 and 16 were LDTs model years 1986+.

For Carb LDVs with MYs 1981-1985, the first regression analysis resulted in a negative B coefficient. To correct this situation, 4 additional data points were calculated using the MOBILE5a curve fit at 9 psi RVP and 95°F and added to the 43 real world data points. This produced a positive B coefficient with a t-statistic of 2.29 and a P-value of 0.0266. Real world data for LDVs with MYs 1986+ also produced a negative B coefficient. An additional 4 MOBILE5a calculated points at 9 psi RVP and 95°F were added to the 38 real world points. This gave a positive B coefficient with a t-statistic of 1.56 and a P-value of 0.127, indicating that it was not statistically significant at a 95% confidence level but produced a reasonable trend. For Carb LDTs, a similar trend was found. Twelve MOBILE5a data points (at 9 psi and 95°F) had to be added to the 11 real world data points for MYs 1981-1985 and 15 MOBILE5a calculated data points had to be added to the 16 real world data points for the MYs 1986+ to obtain a positive B coefficient. The t-statistic for the MY 1981-1985 B coefficient was 0.56 indicating that is was not statistically significant (P-value of 0.57), but the MY 1986+ B coefficient t-statistic was 5.16 indicating it was statistically significant (P-value of

1.6E-05). Coefficients C and D were retained from the MOBILE5a curve fits for Carb pass/pass vehicles and coefficient E was determined so that the calculated hot soak results from using the real world curve fits matched the MOBILE5a curve fits at 9 psi RVP and all temperatures.

The equations for the two model year groupings of LDVs are as follows:

1981-1985 MY LDVs

$$\text{Hot Soak} = (-1.13591 + 0.39098*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/2.081 \qquad \text{(VI.17)}$$

1986+ MY LDVs

$$\text{Hot Soak} = (-1.7318 + 0.45214*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/2.041 \qquad \text{(VI.18)}$$

For comparison purposes, the MOBILE5a equation for MY 1981+ LDV Carb vehicles that pass both the pressure and purge tests is:

$$\text{Hot Soak} = (0.25593 + 0.13823*\text{RVP})*(-2.4636+0.00056161*\text{Temp}^2)/1.31 \qquad \text{(VI.19)}$$

Predicted hot soak emissions for Carb LDVs calculated using equations VI.17 and VI.18 are shown in Table 9 along with MOBILE5a Carb LDV estimates (calculated using equation VI.19). Plots of hot soak emissions at 95°F are shown in Figure 12.

Predicted hot soak emissions using the real world curve fits are lower than the previous MOBILE5a estimates in the 5 to 7 psi RVP range. While no conclusions can be drawn from these curve fits (as additional data needed to be added to make the curves show a positive trend with RVP), one might assume that the real world vehicle set used to define these curve fits had lower hot soak emissions in the 5 to 7 psi RVP range than that estimated from MOBILE5a (which was produced from an extrapolation of higher laboratory data). Furthermore, curve fits for MY 86+ vehicles showed lower hot soak emissions than the MY 81-85 group, which is reasonable assuming an improvement in evaporative control system design.

The equations for LDTs derived from the real world data are:

1981-1985 MY LDTs

$$\text{Hot Soak} = (1.29368+0.08904*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/2.541 \qquad \text{(VI.20)}$$

1986+ MY LDTs

$$\text{Hot Soak} = (-1.8687+0.43908*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/2.527 \qquad \text{(VI.21)}$$

For comparison purposes, the MOBILE5a equation for MY 1981+ LDT Carb vehicles that pass both the pressure and purge tests is:

$$\text{Hot Soak} = (-0.164070 + 0.13823*\text{RVP})*(-2.4636+0.00056161*\text{Temp}^2)/1.31 \qquad \text{(VI.22)}$$

Predicted hot soak emissions for Carb LDTs calculated using equations VI.20, and VI.21

are shown in Table 10 along with MOBILE5a Carb LDT estimates (calculated using equation VI.22). Plots of hot soak emissions for Carb LDT pass/pass vehicles at 95°F are shown in Figure 13.

As can be seen from Figure 13 and Table 10, real world data for Carb LDTs with MYs 81-85 predict higher hot soak emissions than MOBILE5a and MYs 86+ predict lower hot soak emissions than MOBILE5a. It would be expected that newer model Carb LDTs would have significantly lower emissions than older model LDTs due to improvements in the evaporative emission control system.

VII. DISCUSSION OF RESULTS

The new "real world" curve fits provided reasonable trends in hot soak emissions relative to RVP and temperature. For RVPs between 5.0 and 9.0, the "real world" curve fits provided a more accurate picture of "real world" hot soak emissions for MY 1986+ vehicles. However, the data sets analyzed contained no data over 9.0 RVP and thus extrapolations beyond 9 psi RVP could not be developed. This created some dilemma as to meeting the MOBILE5a curves at 9 psi RVP. The methodology used in this report provides a better real world curve fit for lower RVPs and still allows using MOBILE5a curve fits above 9 psi RVP without a discontinuity.

In most cases the curve fits provided reasonable agreement with previous data. The addition of a liquid leaker category adds better definition of the real world conditions. In addition, the additional stratification of model year groups provides a better picture of hot soak emissions as technology improves.

To improve the curve fits developed in this report, additional data are needed, particularly in the 9 psi RVP range and higher. Previous data in this region were generated using laboratory tests and may not be indicative of real world conditions. Furthermore, new vehicles now entering the market have significantly improved evaporative emission control systems. These vehicles should also be tested to give a more accurate picture of in-use emissions from the current and future U.S. vehicle fleet.

VIII. HIGH ALTITUDE AND HEAVY DUTY VEHICLES

High altitude hot soak emissions are determined by a multiplicative adjustment to the low altitude estimates. The adjustment factor (1.3) is the same as was used in MOBILE5.

No heavy duty vehicles were tested to measure hot soak emissions for MOBILE6. MOBILE6 will use the same technique for calculating hot soak emissions trucks with a GVWR over 8,500 pounds (all heavy duty classes and busses) as was used in MOBILE5. This technique assumes that the difference between the evaporative emission standards for heavy duty vehicles and light duty vehicles reflects a difference in the actual uncontrolled emission rates of these vehicles. This has been determined to be a factor of 1.5 for heavy duty trucks up to 14,000 pounds GVWR and a factor of 2.0 for heavy duty trucks over 14,000 pounds GVWR. These adjustments are the same as were used in MOBILE5.

The resulting heavy duty truck hot soak emissions will also be affected by the differences in the distribution of fuel delivery systems and any differences in the rate of pressure/purge failures. These base hot soak emission rates are further adjusted by the effects of the new evaporative test procedure and the introduction of new emission standards, such as Tier 2. These effects are discussed in the report, "Modeling Diurnal and Resting Loss Emissions from Vehicles Certified to Enhanced Evaporative Standards, Including OBD Assumptions," (M6.EVP.005, EPA420-P-99-009).

Table 2. Data strata

Fuel System	Pressure Test	Purge Test	Leaker Category	Vehicle Type	Model Year	Sample Size	Average Hot Soak (g/test)	Standard Deviation (g/test)
Carb	All	All	Liquid	All	All	2	14.60	0.09
FI	All	All	Liquid	All	All	7	57.79	26.71
TBI	Fail	All	Vapor	All	All	19	5.30	9.52
PFI	Fail	All	Vapor	All	All	40	2.50	2.80
Carb	Fail	All	Vapor	All	All	21	6.39	3.93
TBI	All	Fail	Vapor	All	All	12	1.71	2.48
PFI	All	Fail	Vapor	All	All	23	10.69	9.90
Carb	All	Fail	Vapor	All	All	12	4.52	2.95
TBI	Pass	Pass	Vapor	LDV	81-85	17	0.54	0.37
TBI	Pass	Pass	Vapor	LDV	86+	56	0.61	1.24
TBI	Pass	Pass	Vapor	LDT	81-85	0	-	-
TBI	Pass	Pass	Vapor	LDT	86+	29	0.48	0.35
PFI	Pass	Pass	Vapor	LDV	81-85	15	0.51	0.43
PFI	Pass	Pass	Vapor	LDV	86+	225	0.66	2.37
PFI	Pass	Pass	Vapor	LDT	81-85	0	-	-
PFI	Pass	Pass	Vapor	LDT	86+	39	1.17	2.54
Carb	Pass	Pass	Vapor	LDV	81-85	45	2.27	3.50
Carb	Pass	Pass	Vapor	LDV	86+	38	1.35	1.67
Carb	Pass	Pass	Vapor	LDT	81-85	14	3.68	4.18
Carb	Pass	Pass	Vapor	LDT	86+	16	1.29	1.42
Total Vehicles/Average Emissions						630	2.50	2.99

Table 3. Pressure fail hot soak emission estimates*
(g/test)

RVP psi	Temp °F	New Curve Fit	MOBILE5a Curve Fit
5.0	75	0.79	0.70
	90	1.70	1.50
	105	3.66	3.23
	120	7.88	6.96
6.0	75	1.19	1.09
	90	2.57	2.34
	105	5.53	5.04
	120	11.91	10.85
7.0	75	1.80	1.69
	90	3.88	3.65
	105	8.36	7.86
	120	18.00	16.92
8.0	75	2.73	2.64
	90	5.87	5.69
	105	12.64	12.25
	120	27.22	26.39
9.0	75	4.12	4.12
	90	8.87	8.87
	105	19.11	19.11
	120	41.15	41.15

* unadjusted for fuel system

Figure 2. Estimated TBI Pressure Fail Hot Soak Emissions and Real World Data

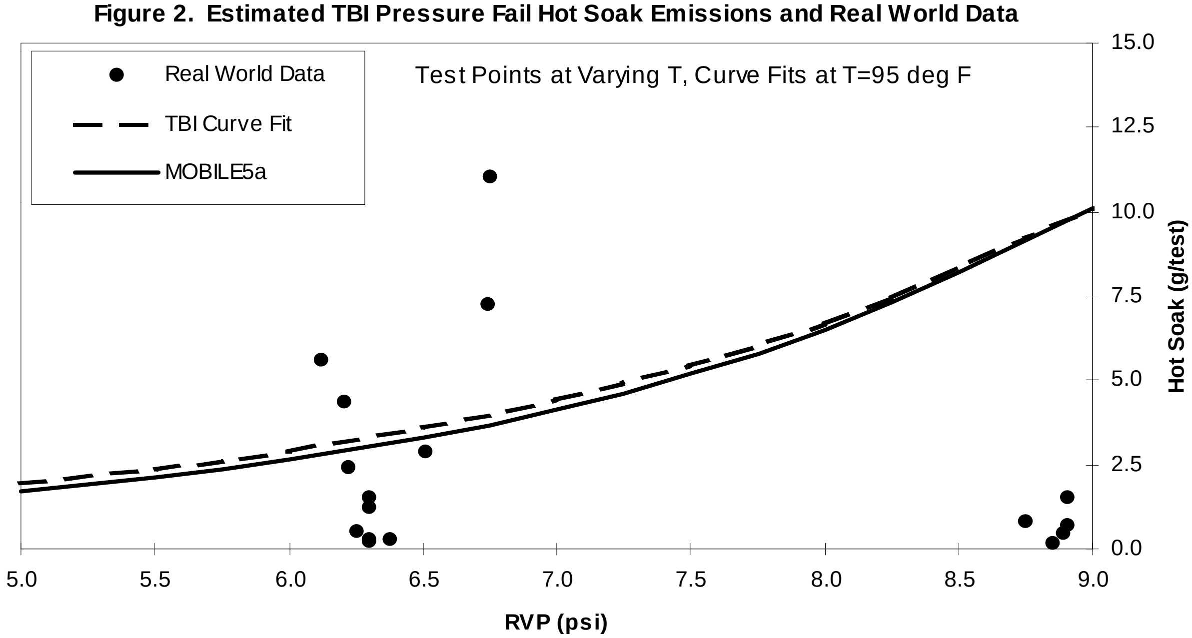


Figure 3. Estimated PFI Pressure Fail Hot Soak Emissions and Real World Data

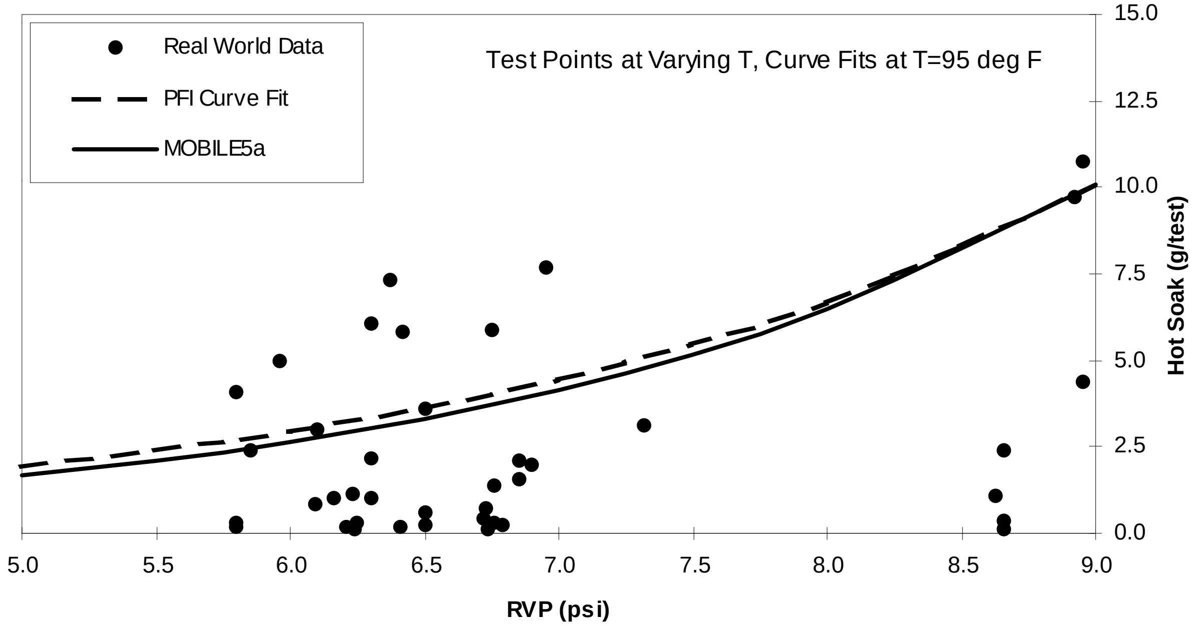


Figure 4. Estimated Carb Pressure Fail Hot Soak Emissions and Real World Data

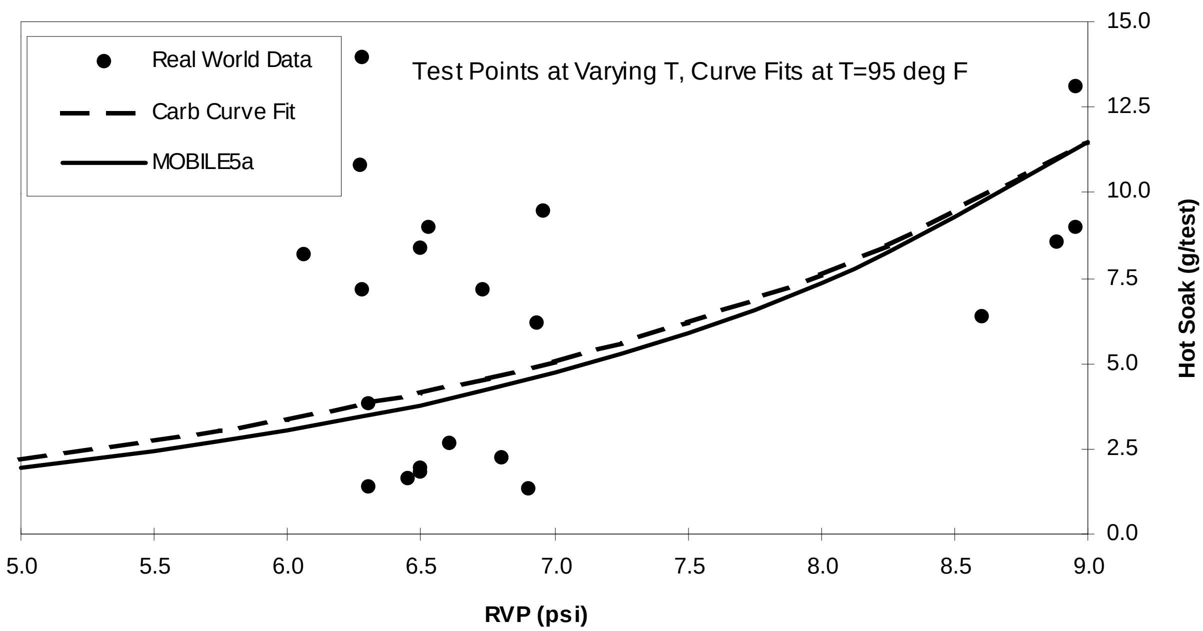


Table 4. Purge fail hot soak emission estimates*
(g/test)

RVP psi	Temp °F	New Curve Fit	MOBILE5a Curve Fit
5.0	75	0.45	0.69
	90	0.96	1.48
	105	2.07	3.19
	120	4.47	6.88
6.0	75	0.78	1.07
	90	1.67	2.31
	105	3.60	4.98
	120	7.76	10.73
7.0	75	1.35	1.67
	90	2.91	3.61
	105	6.26	7.77
	120	13.48	16.73
8.0	75	2.34	2.61
	90	5.05	5.62
	105	10.87	12.11
	120	23.41	26.08
9.0	75	4.07	4.07
	90	8.77	8.77
	105	18.89	18.89
	120	40.67	40.67

* unadjusted for fuel system

Figure 5. Estimated TBI Purge Fail Hot Soak Emissions and Real World Data

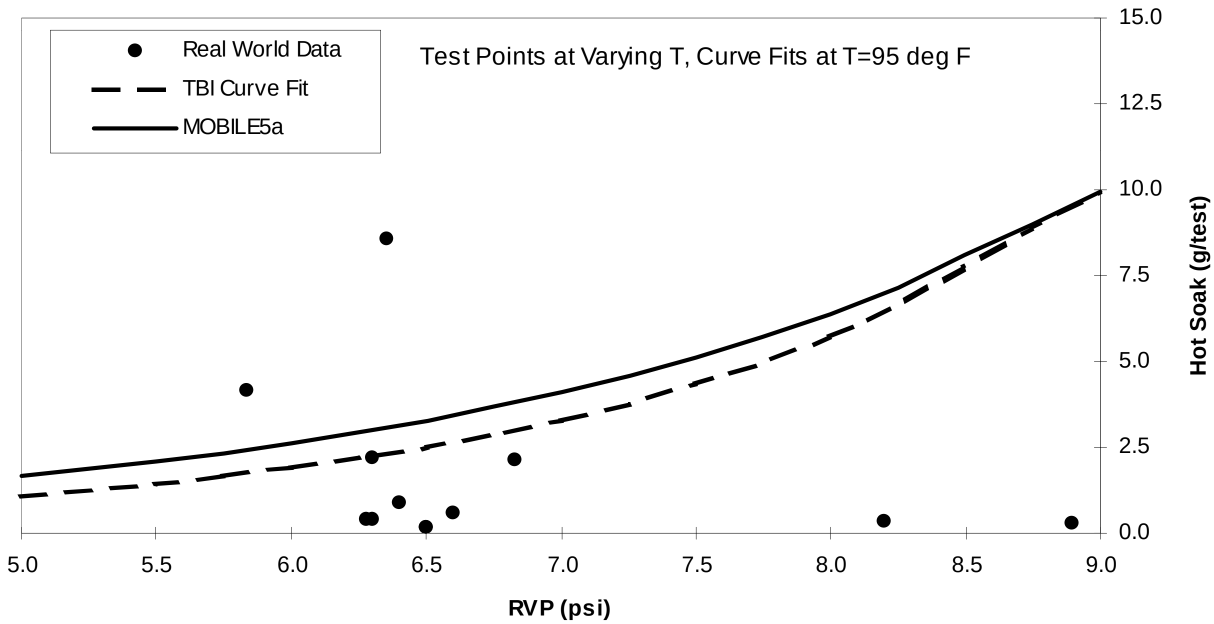


Figure 6. Estimated PFI Purge Fail Hot Soak Emissions and Real World Data

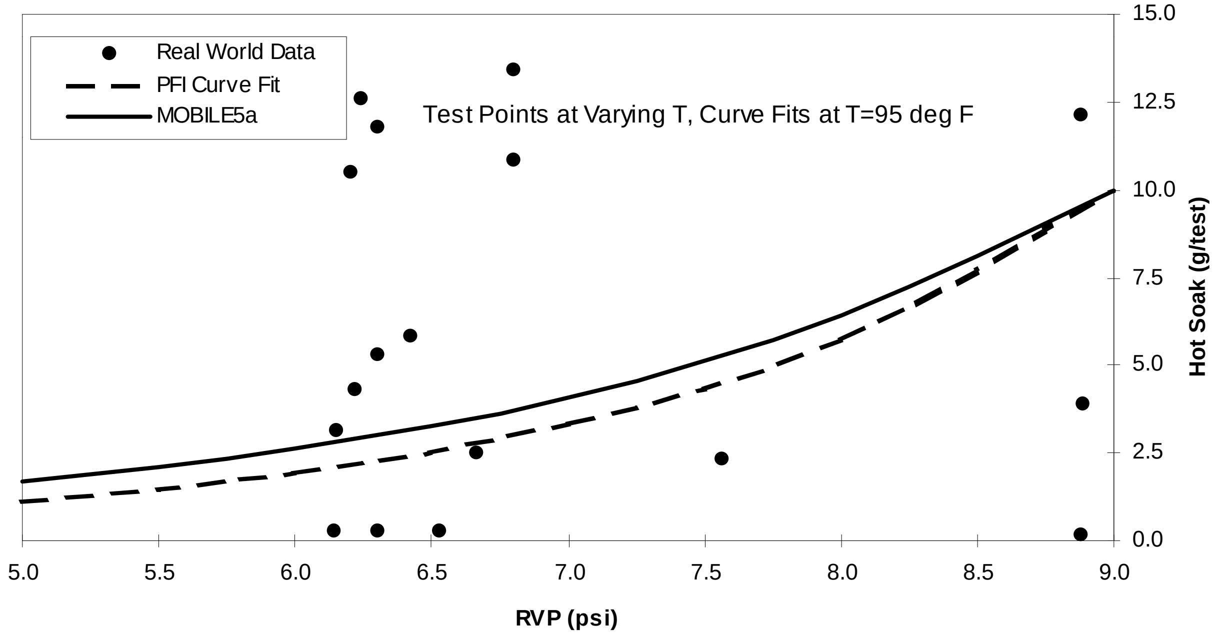


Figure 7. Estimated Carb Purge Fail Hot Soak Emissions and Real World Data

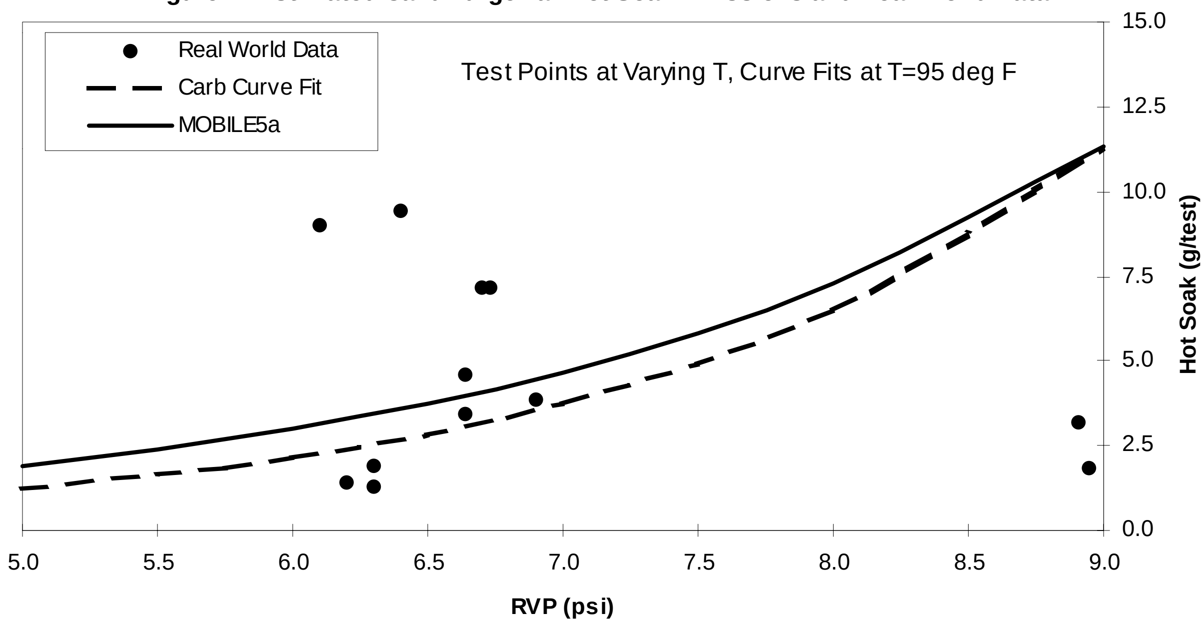


Table 5. TBI LDV pass/pass hot soak emission estimates* (g/test)

RVP psi	Temp °F	MY 81-85 LDV	MY 86+ LDV	MY 81+ LDV MOBILE5a
5.0	75	0.09	0.04	0.22
	90	0.27	0.11	0.65
	105	0.48	0.20	1.16
	120	0.72	0.30	1.76
6.0	75	0.14	0.10	0.24
	90	0.42	0.30	0.71
	105	0.75	0.54	1.27
	120	1.13	0.82	1.91
7.0	75	0.19	0.17	0.26
	90	0.57	0.50	0.77
	105	1.03	0.89	1.37
	120	1.55	1.34	2.07
8.0	75	0.24	0.23	0.28
	90	0.73	0.69	0.82
	105	1.30	1.23	1.47
	120	1.96	1.86	2.22
9.0	75	0.29	0.29	0.29
	90	0.88	0.88	0.88
	105	1.58	1.58	1.58
	120	2.38	2.38	2.38

* adjusted for fuel system

Figure 8. Estimated TBI LDV Pass/Pass Hot Soak Emissions and Real World Data

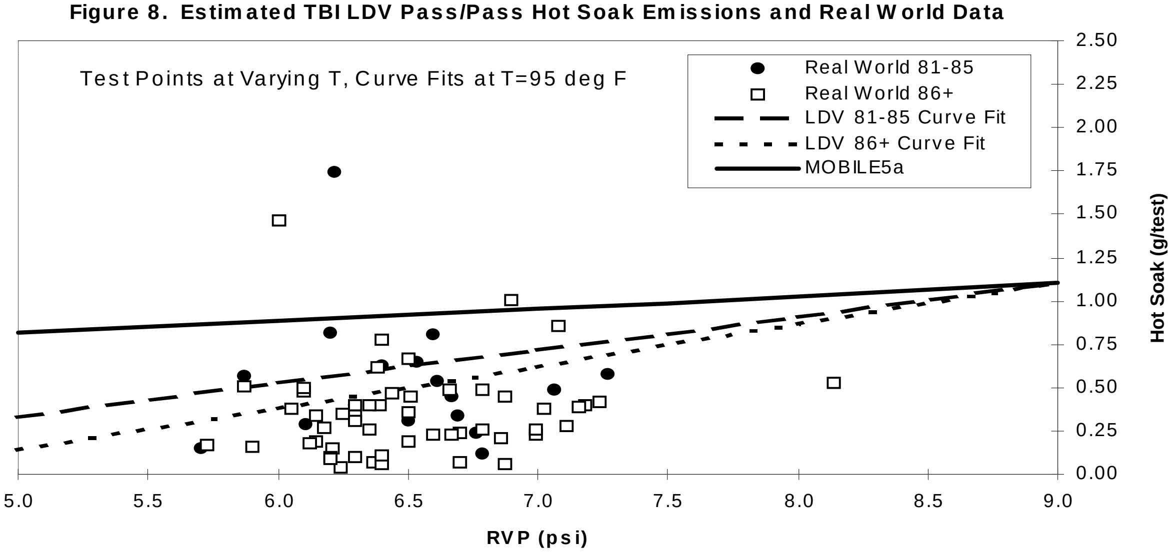


Table 6. TBI LDT pass/pass hot soak emission estimates*
(g/test)

RVP psi	Temp °F	MY 86+ LDTs	MY 81+ LDTs MOBILE5a
5.0	75	0.04	0.13
	90	0.13	0.40
	105	0.23	0.71
	120	0.34	1.08
6.0	75	0.08	0.15
	90	0.25	0.46
	105	0.45	0.82
	120	0.68	1.23
7.0	75	0.13	0.17
	90	0.38	0.51
	105	0.68	0.92
	120	1.02	1.39
8.0	75	0.17	0.19
	90	0.50	0.57
	105	0.90	1.02
	120	1.36	1.54
9.0	75	0.21	0.21
	90	0.63	0.63
	105	1.13	1.13
	120	1.70	1.70

* adjusted for fuel system

Figure 9. Estimated TBI LDT Pass/Pass Hot Soak Emissions and Real World Data

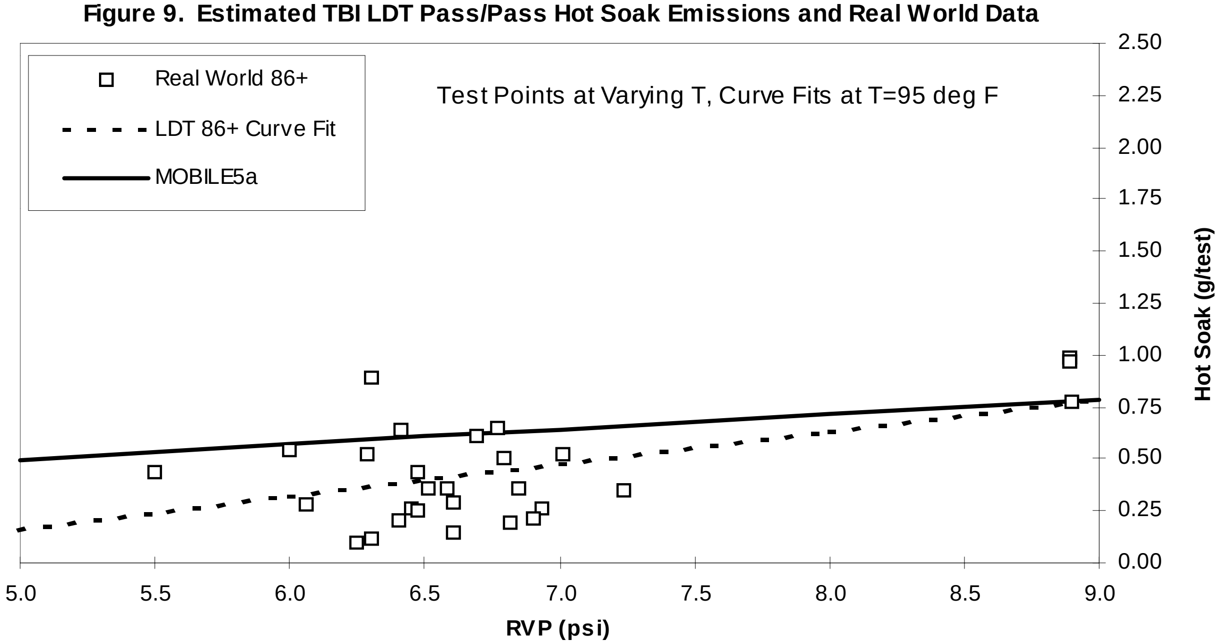


Table 7. PFI LDV pass/pass hot soak emission estimates* (g/test)

RVP psi	Temp °F	MY 81-85 LDVs	MY 86+ LDVs	MY 81+ LDVs MOBILE5a
5.0	75	0.22	0.23	0.09
	90	0.26	0.27	0.10
	105	0.30	0.32	0.12
	120	0.35	0.36	0.14
6.0	75	0.27	0.27	0.17
	90	0.32	0.33	0.20
	105	0.37	0.38	0.24
	120	0.43	0.44	0.27
7.0	75	0.32	0.32	0.25
	90	0.38	0.39	0.30
	105	0.44	0.45	0.35
	120	0.51	0.51	0.40
8.0	75	0.37	0.37	0.33
	90	0.44	0.44	0.40
	105	0.51	0.51	0.47
	120	0.58	0.59	0.53
9.0	75	0.41	0.41	0.41
	90	0.50	0.50	0.50
	105	0.58	0.58	0.58
	120	0.66	0.66	0.66

* adjusted for fuel system

Figure 10. Estimated PFI LDV Pass/Pass Hot Soak Emissions and Real World Data

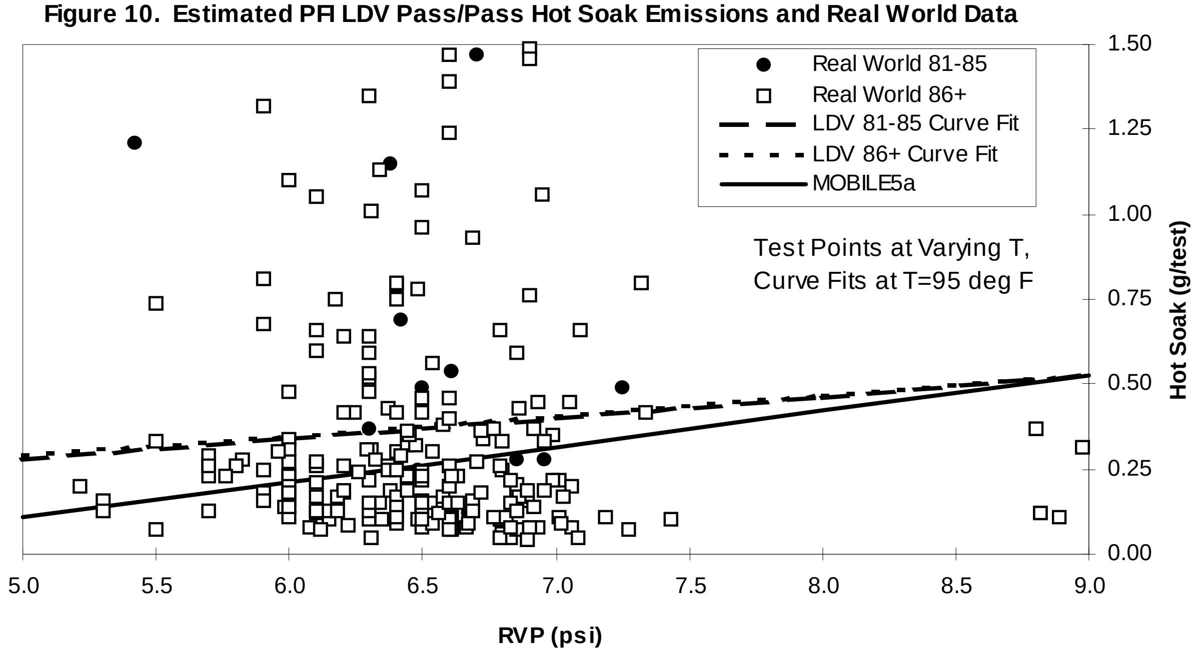


Table 8. PFI LDT pass/pass hot soak emission estimates* (g/test)

RVP psi	Temp °F	MY 86+ LDTs	MY 81+ LDTs MOBILE5a
5.0	75	0.27	0.23
	90	0.32	0.27
	105	0.38	0.32
	120	0.43	0.36
6.0	75	0.29	0.26
	90	0.35	0.31
	105	0.41	0.36
	120	0.47	0.42
7.0	75	0.31	0.29
	90	0.38	0.35
	105	0.44	0.41
	120	0.50	0.47
8.0	75	0.34	0.33
	90	0.40	0.39
	105	0.47	0.46
	120	0.51	0.52
9.0	75	0.36	0.36
	90	0.43	0.43
	105	0.50	0.50
	120	0.57	0.57

* adjusted for fuel system

Figure 11. Estimated PFI LDT Pass/Pass Hot Soak Emissions and Real World Data

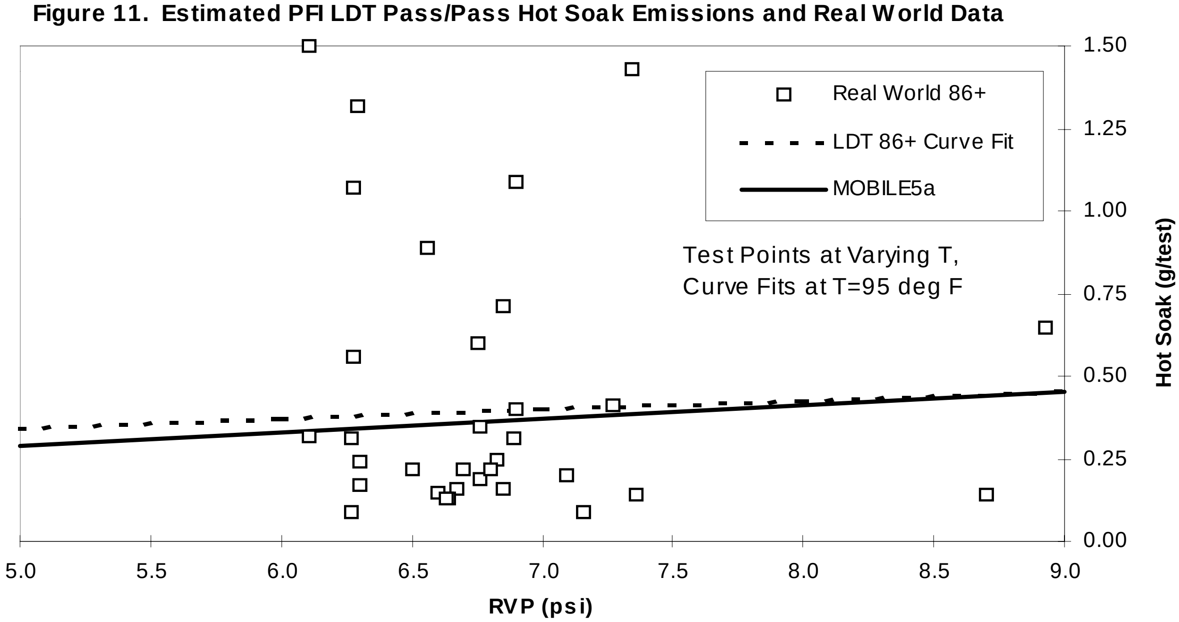


Table 9. Carb LDV pass/pass hot soak emission estimates (g/test)

RVP psi	Temp °F	MY 81-85 LDVs	MY 86+ LDVs	MY 81+ LDVs MOBILE5a
5.0	75	0.27	0.18	0.50
	90	0.82	0.54	1.51
	105	1.47	0.97	2.70
	120	2.21	1.46	4.07
6.0	75	0.40	0.33	0.58
	90	1.21	1.00	1.73
	105	2.17	1.79	3.09
	120	3.27	2.70	4.66
7.0	75	0.54	0.49	0.65
	90	1.60	1.46	1.95
	105	2.87	2.62	3.48
	120	4.33	3.95	5.25
8.0	75	0.67	0.64	0.72
	90	2.00	1.93	2.17
	105	3.57	3.44	3.88
	120	5.38	5.19	5.85
9.0	75	0.80	0.80	0.80
	90	2.39	2.39	2.39
	105	4.27	4.27	4.27
	120	6.44	6.44	6.44

Figure 12. Estimated Carb LDV Pass/Pass Hot Soak and Real World Data

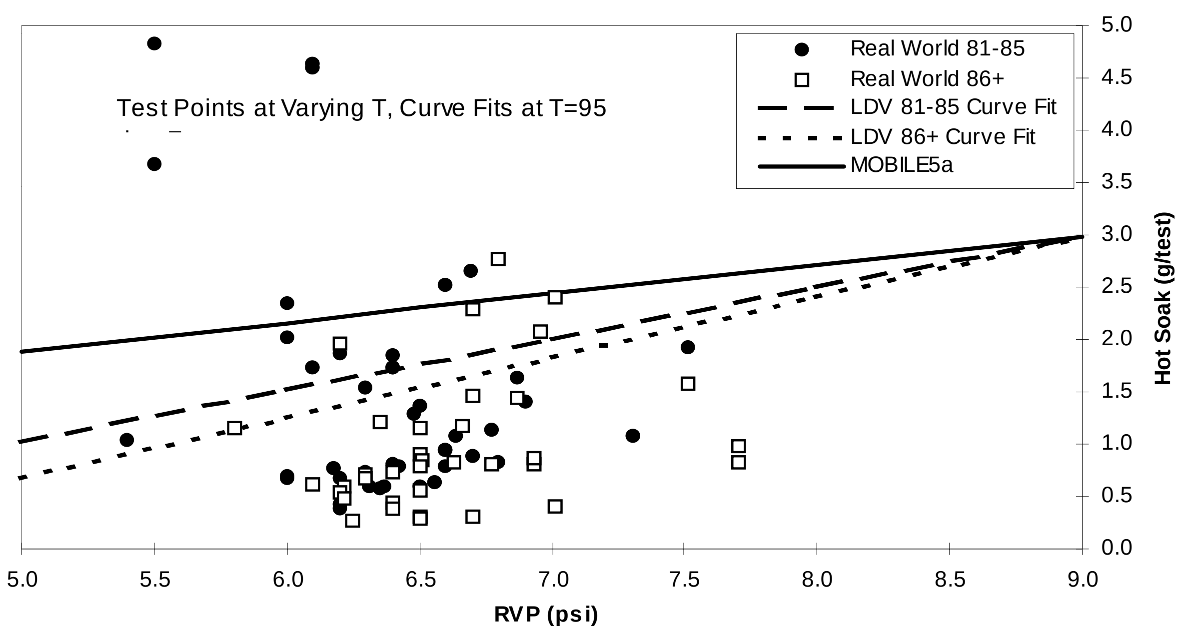
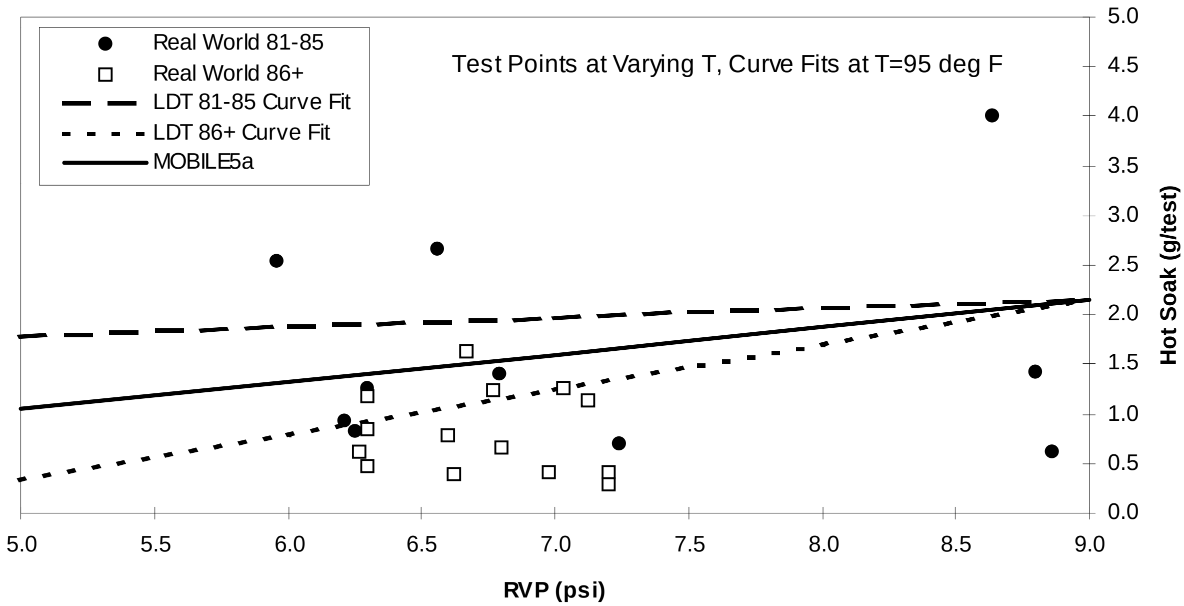


Table 10. Carb LDT pass/pass hot soak emission estimates (g/test)

RVP psi	Temp °F	MY 81-85 LDTs	MY 86+ LDTs	MY 81+ LDTs MOBILE5a
5.0	75	0.48	0.09	0.28
	90	1.43	0.27	0.84
	105	2.55	0.48	1.50
	120	3.85	0.73	2..26
6.0	75	0.50	0.21	0.35
	90	1.50	0.63	1.06
	105	2.68	1.13	1.89
	120	4.05	1.70	2.86
7.0	75	0.52	0.33	0.43
	90	1.57	0.99	1.28
	105	2.81	1.78	2.29
	120	4.24	2.68	3.45
8.0	75	0.55	0.45	0.50
	90	1.65	1.36	1.50
	105	2.94	2.43	2.68
	120	4.44	3.66	4.04
9.0	75	0.57	0.57	0.57
	90	1.72	1.72	1.72
	105	3.07	3.07	3.07
	120	4.64	4.64	4.64

Figure 13. Estimated Carb LDT Pass/Pass Hot Soak and Real World Data



Appendix
Response to Stakeholder Comments

API/Sierra Comments:

The American Petroleum Institute (API) and their contractor Sierra Research (Sierra) reviewed and commented on the analysis done by Arcadis Geraghty and Miller (Arcadis) under contract to EPA. The basic recommendations of API to EPA are that:

1. *The analysis prepared by Arcadis to support revisions to MOBILE6 hot soak emissions estimates should be discarded;*

2. *The Auto/Oil real-world data be used to develop revised baseline hot soak emission rates; and*

3. *Additional data collected since the release of MOBILE5 be used to develop revised RVP and temperature correction factors which are applied to the baseline emission rates developed from the real-world data.*

The API approach proposes that the new, and relatively small (480 vehicles), Auto/Oil data sample be used to replace the baseline estimate of hot soak emissions. Most of the Auto/Oil data measurements have RVP values less than 8 psi. The baseline estimate of hot soak emissions in MOBILE5 is based on a data sample containing over 3,500 hot soak measurements at 9 psi RVP alone. These measurements include both passenger cars and light duty trucks cover a large range of model years and a range of temperatures. In addition, the API approach proposes that the small EPA sample of 181 vehicle tests be used to determine the adjustment of hot soak emissions for gasoline Reid vapor pressures (RVP) and temperatures for MOBILE6. The Arcadis approach, developed under direction by EPA, attempts only to replace the existing MOBILE5 estimates for adjustment of hot soak emissions for RVP levels below 9 pounds per square inch (psi) with new estimates based on the new data. The baseline estimates of hot soak emissions and the effects of RVP values above 9 psi would be retained for MOBILE6 with the EPA approach.

EPA did commit at workshops and in planning for MOBILE6 to reassess the effects of RVP values below 9 psi in light of the new Auto/Oil data. It was clear that the new data alone, from both Auto/Oil and EPA, did not have sufficient data at RVP levels at 9 psi and above to determine all of the effects of RVP and temperature on hot soak emissions needed for the MOBILE6 model from the new data. EPA had stated clearly at all the MOBILE6 workshops that only hot soak emissions adjustments for RVP levels below 9 psi would be updated using new data and that MOBILE5 hot soak emission rates would be used for all cases with RVP values of 9 psi and above. EPA had never proposed replacing the baseline hot soak emission estimates used for MOBILE5. In the analysis of the new data, EPA specifically directed their contractor, Arcadis, to only consider the effects of RVP below 9 psi on baseline hot soak emissions.

EPA anticipated that hot soak emission levels in the new data would differ to some degree from those in MOBILE5 at 9 psi. It can be expected that emission results from any two data samples describing the same condition might differ to some extent. EPA specifically directed Arcadis to assure that the estimate of hot soak emission levels were consistent with the existing estimate for hot soak emissions at 9 psi RVP to avoid a discontinuity in the hot soak emission levels at 9 psi in MOBILE6. Both Arcadis and EPA were concerned with the magnitude of the differences actually observed as the analysis progressed.

EPA decided that resolution of the observed differences between the MOBILE5 estimates at 9 psi RVP and the new data results would have to wait for a new (future) analysis and additional data. Since the hot soak values used to estimate the baseline 9 psi RVP case in MOBILE5 had been based on a large samples of vehicles at a variety of temperatures, the existing MOBILE5 hot soak values at 9 psi RVP would be retained for use in MOBILE6 and the new analysis of RVP values less than 9 psi would need to account for any differences with the MOBILE5 estimates. EPA believes that the large amount of existing data at RVP values of 9 psi and above should not be ignored in the development of hot soak estimates for MOBILE6.

Once this decision had been made, the options available to EPA and the contractor for completion of the analysis were limited. The final choice of analytical approach chosen by the contractor and approved by EPA is reasonable, given the circumstances. New data, perhaps using data collection methods similar to that used by Auto/Oil, may be able to resolve the differences for future versions of the MOBILE model. Values are needed both above and below the 9 psi RVP level and at a variety of temperatures. One alternative, not explicitly proposed by API, would be to reject the idea that any changes can be made to hot soak emission estimates for use in MOBILE6 using the currently available data. In this case, the MOBILE5 hot soak estimates would be used for MOBILE6 at all temperatures and RVP levels.

In addition to their proposal, API had specific criticisms of the work done by Arcadis:

1. *The use of an approach in which Arcadis fabricated data points calculated by MOBILE5a hot soak equations and added those to the "real world" hot soak database because the emissions versus Reid vapor pressure (RVP) trends observed in the "real world" data for some model-year and technology groups were "intuitively incorrect."*

As Auto/Oil found in their own analysis of the data, the correlation of the Auto/Oil/EPA hot soak emissions data with fuel vapor pressure did not yield any significant relationships. The Arcadis method assured that any relationships between the hot soak emissions data with fuel vapor pressure would yield a hot soak value at 9 psi RVP which would match the MOBILE5 results. Their approach included the "known" MOBILE5 value in the regression equation. This approach is similar to forcing an equation through a known value (i.e., zero). Matching the MOBILE5 value at 9 psi was an EPA requirement of the analysis results. The alternate approach suggested by API does not match the MOBILE5 values at 9 psi for any temperature other than 90 degrees Fahrenheit.

2. *The application of a constraint that the revised factors had to match the MOBILE5a factors at 9.0 psi RVP (at all temperatures). This prevented any meaningful revision to the hot soak emission rates, even though the real-world data support significant revisions for a number of technology and model year groups.*

This criticism assumes that the "real world" sample of 480 vehicles tested as part of the Auto/Oil study is sufficient to replace the baseline MOBILE5 hot soak emission estimate based on a much larger sample. Most of the Auto/Oil measurements were at RVP values less than 9 psi. Only three measurements were at RVP values greater than or equal to 9 psi and only an additional two measurements are greater than 8 psi. The average RVP measurement for the Auto/Oil sample is 6.6 psi. Although the MOBILE5 estimate is based on results which did not use real world preconditioning, API has not provided sufficient argument that the large sample of thousands of hot soak data used for MOBILE5 is faulty and should be discarded. The measurement techniques for both the original MOBILE5 sample and the API data are very similar and equally valid. The new real world data certainly is a better estimate of hot soak emissions at the average RVP of 6 to 7 psi, but EPA believes that these data values are insufficient to replace the baseline hot soak emission estimate from MOBILE5.

3. *Data from vehicles tested multiple times over a range of RVPs and temperatures were treated as separate data points in the Arcadis analysis. (These vehicles were not part of the real-world hot soak programs.) This has the effect of assigning more influence to vehicles with multiple test scores relative to vehicles that were tested only once. It would have been more appropriate to generate a mean hot soak score for vehicles tested multiple times (or only use the score best matching the RVP and temperature conditions of the real-world hot soak programs) before generating regression equations that are used to estimate fleet-average emissions.*

This is an unfortunate result of mis-communication between Arcadis and EPA. If there were time and resources to repeat the analysis, these vehicles would likely be handled differently. However, the EPA data in the sample does have the major advantage over the real world measurements in that the same vehicles were tested with fuels of various RVP values; a design desired for inferring RVP effects on hot soak emissions. Removing the EPA vehicles from the analysis would not have improved the validity of the result.

4. *Hot soak emission results from fuel-injected vehicles in the real-world databases were corrected to account for in-use fuel tank level using the adjustment from MOBILE5a. The MOBILE5a-based adjustment is applied to translate the 40% fill level required in the FTP to a nominal 55% fill level observed in-use. However, Arcadis apparently failed to recognize that the real-world hot soak programs tested vehicles with the fuel level they had when recruited for testing. Hence, an adjustment for fuel tank level is not necessary in this case, provided the distribution of fuel levels in the test programs adequately reflects in-use conditions. (That was not investigated in the Arcadis report.)*

Arcadis believed (incorrectly) that the fuel level adjustment was necessary and EPA supervision of the contractor work failed to note this problem during the analysis. Since the error only affects the real world data, the error will likely make the estimate of hot soak emissions at RVP values less than 9 psi lower than they should be and make the effects of reducing in-use RVP levels from 9 psi higher than the data actually shows. It is not clear how this oversight can be corrected without repetition of the analysis. This cannot be done because of time and resource limitations. The estimate of hot soak emissions is clearly an area which should be revisited to resolve this and the other issues presented by API.

5. *In the report M6.RTD.001, EPA acknowledges that ". . . neither the purge test nor the pressure test is a perfect identifier of vehicles that have problems with their evaporative control systems." We agree with this observation. In the report, "Analysis of Real-Time Evaporative Emissions Data," Sierra Research demonstrates that the pressure/purge test is clearly not very reliable in identifying excess hot soak and diurnal emissions. For example, Sierra Research shows that well over half of the excess hot soak emissions measured in a recent program sponsored by the Coordinating Research Council (CRC) and in one conducted for EPA were not identified by the purge/pressure test procedures. Sierra Research also evaluated the data from a recent CRC diurnal emissions test program and concluded that (a) the pressure/purge test was unsuccessful in identifying a substantial fraction of late-model vehicles with high evaporative emissions, and (b) resting loss emissions were not strongly influenced by pressure/purge test status.*

EPA agrees that the pressure/purge test pass/fail status of vehicles is not necessarily needed to determine the base hot soak emission levels. The original intention of separating hot soak emissions into pass/fail categories was intended to better quantify the effects of evaporative system failures by using a stratified random sampling technique. This is similar to the sampling approach used for exhaust emissions, which often targets high emitting vehicles using a screening test. In MOBILE6 the hot soak emission rates themselves do not depend on vehicle age. By adjusting the fraction of pressure/purge failures by age, MOBILE6 accounts for the increase in evaporative emissions that is expected as the vehicles age. In addition, the pass/fail status is used in the MOBILE model to allow for the evaluation of in-use control strategies. If the need to evaluate these programs disappears or alternate methods are devised to determine program benefits, and other methods are used to account for the effects of age on evaporative emissions, then the need to test and evaluate hot soak data by pass/fail status will not necessarily be needed in future versions of the model.

6. *It is important to note that if EPA moves any existing evaporative emission factors components in MOBILE to a new liquid leaks category, the effect of lowering RVP on the remaining evaporative (hot soak, diurnal, and running loss) emissions will be increased (in percentage terms). This is because leaks are not expected to be influenced by lower RVP while the decrement in the volatility-driven evaporative emissions will be spread over a lower baseline.*

Since the effect of RVP is integral to the calculation of the hot soak emission levels. Vehicles which have liquid leaks are removed from the sample before the base hot soak emission rates are determined. As a result, the hot soak emission estimates appropriately account for the effects of changes in RVP. The emission impact of liquid leaks, which do not include an adjustment for changes in RVP, is added to the evaporative emission estimates. This issue will be of more concern in data sets where liquid leakers are not removed from the base emission estimates.

FACA Comments:

An Auto/Oil hot soak pilot study has been conducted. The results of these analyses should be reviewed when available to provide insight into evaporative emissions deterioration.

Although EPA did use these data along with the data collected under EPA sponsorship, the data did not show any significant evaporative emission deterioration. It should be pointed out, however, that the available studies on hot soak emissions were not designed to specifically answer the question of emission deterioration over time.

AAMA Comments:

The American Automobile Manufacturers Association had the following comment regarding hot soak emissions:

EPA did not address how it will estimate hot soak emissions from vehicles that either do or do not have onboard refueling vapor control or how it intends to estimate hot soak emissions from vehicles certified to the enhanced evaporative requirements or onboard diagnostic requirements.

EPA did not intend to change the estimate for the basic hot soak emission rates from those used in MOBILE5 to be used in MOBILE6. The effects of onboard refueling vapor recovery (ORVR) systems and the effects of the enhanced evaporative requirements were addressed in the development of MOBILE5. These effects have not been changed for MOBILE6. The onboard diagnostic requirements are addressed in a separate document, “Modeling Diurnal and Resting Loss Emissions from Vehicles Certified to Enhanced Evaporative Standards, Including OBD Assumptions,” (M6.EVP.005, EPA420-P-99-009).

AIR Comments:

Air Improvement Resource, Inc., has five areas of comment on the update to the hot soak emission rates:

1. *The RVP regression analysis, which includes the restriction that the curve equals the MOBILE5 value at 9 psi, is inappropriate and should be revised.*

The plots showing the new test data, which include the RVP regression curves, are provided in the EPA documentation and clearly show that the new test data fall well below the MOBILE5 values assumed at 9 psi. If regressions were developed without the fixed point at 9 psi, the hot soak predictions would be significantly less. There is not a valid reason to have the new regressions fixed to the MOBILE5 value at 9 psi other than for convenience sake for EPA (i.e., it eliminates the need to reinvestigate the hot soak regression over 9 psi in MOBILE).

The reasons for the significant difference between the new test data and MOBILE5 at 9 psi may be due to differences in test conditions and/or due to the passage of time. The MOBILE5 hot soak data were measured at standard conditions (e.g., tank fill level of 40%) with certification fuel (i.e., Indolene). The MOBILE5 data may also be outdated, as more than 90 percent of hot soak tests were carried over from MOBILE4.1.

An improved statistical approach would be to combine the new data with the raw data used to develop MOBILE5. Once the data were combined, the development of RVP regression coefficients would be completed with a complete set of all the hot soak test data.

Alternatively, EPA could throw out the older data and use only the data from the recent test programs. Since 1992, summer gasoline volatility limits restrict summer gasoline RVP to below 9 psi, thus there is little need for the older, MOBILE5 data over 9 psi. Given that the documentation describes the new test data as an improvement over that in MOBILE5, the best approach for MOBILE6 would be simply to rely solely on the new test data.

The intention of EPA's analysis of hot soak emissions was only to update the estimate for Reid vapor pressures (RVP) below 9 psi. EPA does not feel that the newer data alone is sufficient to estimate base emission levels for all RVP levels and temperatures. Although the idea of combining the new data with the existing data has much merit, this level of effort was not anticipated for addressing hot soak emissions for MOBILE6. This approach can be used for future updates to the hot soak emission estimates.

2. *The inclusion of additional data points (i.e., "dummy" data) in the cases for which the RVP regression produced negative coefficients is statistically inappropriate. In this instance, a negative coefficient signifies an increase in emissions with lowering RVP. The additional data points need to be removed from the analysis.*

As an example, the regression for 1986-and-later LDGVs passing both pressure and purge tests is based on 223 actual test records combined with 25 additional data points. The 25 data points all equal the MOBILE5 prediction at 9 psi for 1981-and-later LDGVs passing the pressure and purge tests. The documentation states that the MOBILE5 9 psi data points were added until the resulting regression coefficients became positive. Thus for this case, 10 percent of the regression data did not originate from either test program, but was taken from MOBILE5. In another, worst-case example, half of the data used in the regression was based on the MOBILE5 prediction (i.e., 1981 to 1985 model year PFI LDGV passing both *pressure and purge tests). The inclusion of these data points biases the resulting statistical analysis toward an overestimation of the RVP effect on hot soak emissions. EPA needs to redo the RVP analysis without the addition of MOBILE5 data points at 9 psi (and with the raw data used for MOBILE5), otherwise the proposed model will over state the impacts of reduced RVP on hot soak emissions.*

API had a similar comment. As Auto/Oil found in their own analysis of the data, the correlation of the hot soak emissions data with fuel vapor pressure did not yield any significant relationships. Arcadis was attempting to assure that any relationships between the hot soak emissions data with fuel vapor pressure would yield a hot soak value at 9 psi RVP which would match the MOBILE5 results. Their approach was intended to include the "known" MOBILE5 value in the regression equation. This approach is similar to forcing an equation through a known value (i.e., zero). Matching the MOBILE5 value at 9 psi was an EPA requirement of the analysis results. Without an alternate method, it is not clear how the results from the new data could have been made to match the existing estimate at 9 psi.

3. *The documentation does not address how EPA intends to estimate the proportion of the fleet falling in each of the hot soak emission categories (i.e., liquid leakers, pressure/purge test complying, and pressure/purge test failing).*

For each model year and vehicle class there are four categories of pressure and purge test complying, pressure test failing, and purge test failing, and liquid leakers. The estimation of model year fleet-average hot soak emission rates will be highly dependent upon what proportion of the fleet is assumed to fall into each of these categories.

In the case of 1986-and-later LDGVs, for instance, the average hot soak emission rates reported for the two test programs combined are 0.66, 2.50, 10.69 and 57.79 grams for pressure and purge test complying, pressure test failing, and purge test failing, and liquid leakers, respectively. These data show a factor of 100 difference in emission rates between the lowest and highest emitters.

The method EPA intends to use to estimate what portion of the fleet is pressure test failing, purge test failing and liquid leakers needs to be provided for comment. This method needs to address the impacts of vehicle age and I/M on the estimated proportions.

The derivation of the pressure test and purge test pass/fail rates is addressed in a separate report, "Estimating Weighting Factors for Evaporative Emissions in MOBILE6," (M6.EVP.006, EPA420-P-99-023).

4. *The documentation does not include how MOBILE6 will model hot soak emissions for vehicles subject to enhanced evaporative test procedures.*

EPA has not yet documented how hot soak emission rates will be estimated for vehicles subject to enhanced evaporative test procedures and standards. In MOBILE5, EPA assumed *a 50 percent reduction for pressure and purge test complying vehicles and a 30 percent reduction for pressure and purge failing vehicles. It may be that the same hot soak reductions assumed in MOBILE5 will still be applied in MOBILE6. This should be clarified. In addition, the impacts of enhanced evaporative standards on liquid leakers, which were not modeled in MOBILE5, also needs to be documented.*

EPA is using in MOBILE6 the same assumptions about the effect of the new enhanced test procedure effects on hot soak emissions as were used in MOBILE5. However, in addition to the effect on the emission rates of vehicles with properly operating emission controls, MOBILE6 now assumes that the new enhanced test procedure will affect the rate of emission control system failures. The derivation of the base pressure test and purge test pass/fail rates is addressed in a separate report, "Estimating Weighting Factors for Evaporative Emissions in MOBILE6," (M6.EVP.006, EPA420-P-99-023). The effect of enhanced evaporative standards on the base pressure test and purge test pass/fail rates is addressed in a separate document, "Modeling Diurnal and Resting Loss Emissions from Vehicles Certified to Enhanced Evaporative Standards, Including OBD Assumptions," (M6.EVP.005, EPA420-P-99-009).

Evaporative emissions due to liquid leaks is discussed in a separate report, "Evaporative Emissions of Gross Liquid Leakers in MOBILE6," (M6.EVP.009, EPA420-P-99-025).

5. *EPA has not yet documented how hot soak emission rates will be estimated for heavier LDGT (6001 to 8500 lbs. GVWR) or for HDGV (over 8500 lbs. GVWR) vehicle classes. In the updated hot soak analysis, EPA did not state whether the two test programs include any vehicles over 6000 lbs. GVWR. The hot soak methodology for the heavier LDGT and HDGV needs to be explicitly stated, even if EPA expects to continue to use MOBILE5 data and methods for these vehicle classes.*

Section VIII has been added to this report to address the calculation of hot soak emissions for gasoline fueled heavy duty vehicles.

<u>California Comments</u>:

The California Inspection and Maintenance Review Committee had the following comment:

In the MOBILE6 evaporative emissions module, EPA classifies vehicles based on whether they fail the pressure or purge test. MOBILE6 assumes that gross liquid leaks occur only among vehicles that fail one of these tests. However, EPA's paradigm for evaporative emissions is at odds with the results of real-world studies. For example, an Auto/Oil study of hot soak emissions from 300 vehicles ("Real World Hot Soak Evaporative Emissions – A Pilot Study," Brooks, D. et al. (1995), SAE Paper 951007) found that more than half of excess evaporative emissions come from cars that do not fail either the pressure or purge tests.

Failure of the pressure or purge tests is thus a poor surrogate for actual evaporative *emission rates. Furthermore, no I/M program includes the pressure or purge tests so failure of these tests does not appear to be a relevant factor in assessing actual I/M programs.*

Several studies, including recent CRC-sponsored studies, have measured actual evaporative emission rates of vehicles. EPA should not continue to base evaporative emissions estimates on an errant paradigm. Instead, EPA should simply use the real world data directly (with appropriate attention to sample validity issues of course) to determine evaporative emission rates.

MOBILE6 does assume that liquid leaks occur for all categories of pass/fail. Evaporative emissions due to liquid leaks is discussed in a separate report, "Evaporative Emissions of Gross Liquid Leakers in MOBILE6," (M6.EVP.009, EPA420-P-99-025).

EPA agrees that the pressure/purge test pass/fail status of vehicles is not necessarily needed to determine the base hot soak emission levels. The original intention of separating hot soak emissions into pass/fail categories was intended to better quantify the effects of evaporative system failures by using a stratified random sampling technique. This is similar to the sampling approach used for exhaust emissions, which often targets high emitting vehicles using a screening test. In MOBILE6 the hot soak emission rates themselves do not depend on vehicle age. By adjusting the fraction of pressure/purge failures by age, MOBILE6 accounts for the increase in evaporative emissions that is expected as the vehicles age. In addition, the pass/fail status is used in the MOBILE model to allow for the evaluation of in-use control strategies. If the need to evaluate these programs disappears or alternate methods are devised to determine program benefits, and other methods are used to account for the effects of age on evaporative emissions, then the need to test and evaluate hot soak data by pass/fail status will not necessarily be needed in future versions of the model.