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Update of Hot Soak Emissions

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Assessment and Modeling Division
Office of Mobile Sources
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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 exists 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.

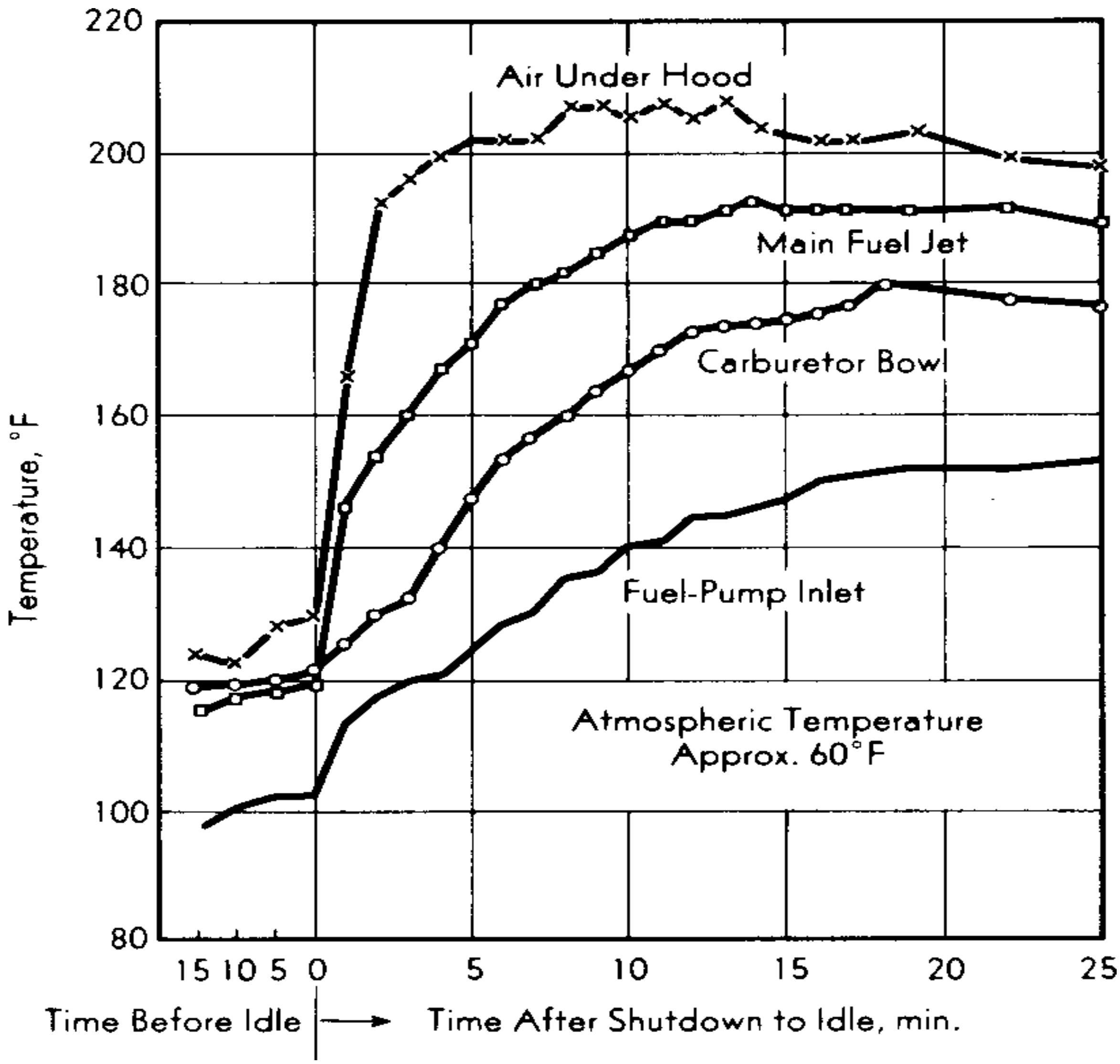
Hot soak emissions generally occur during the one-hour period[1] after the engine is shut down and are measured in a sealed housing for evaporative emission determination (SHED). Results from SHED tests are in grams per one-hour test (g/test). Level of emissions during a hot soak is a function of fuel 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.

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

[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.



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

Figure 1. Temperatures occurring during a hot soak event

never have certification fuel in their fuel tanks and are operated under a wide range of ambient temperature conditions.

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, 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%

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 wer 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]).

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

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.

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 :

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

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:

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

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:

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

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

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

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 was 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.

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

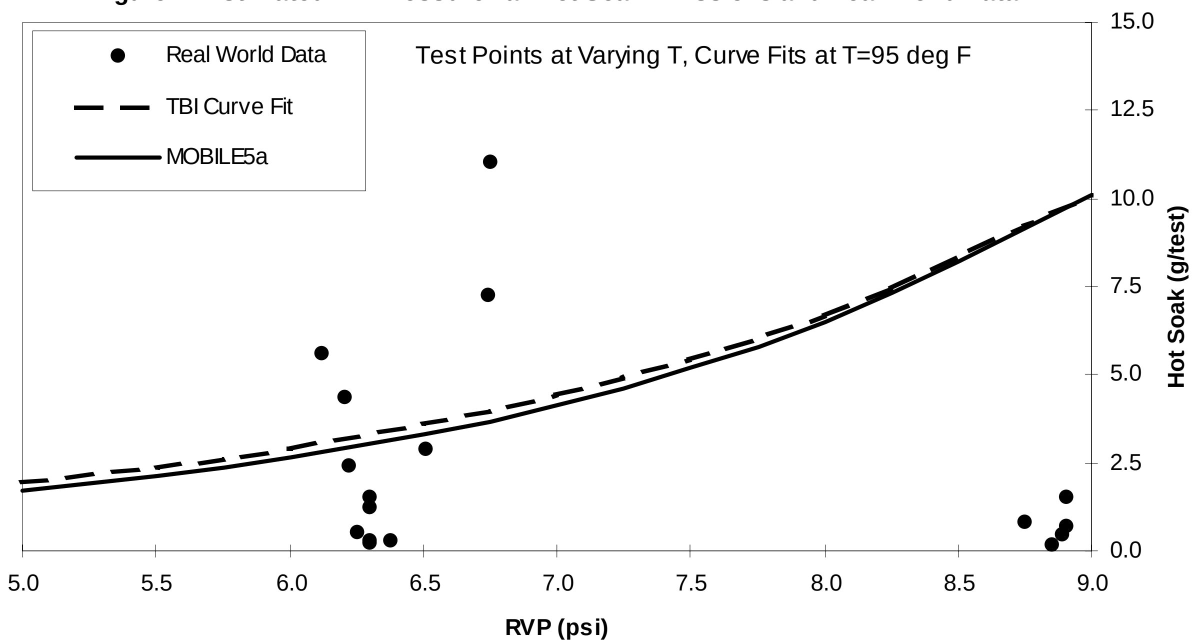


Figure 3. Estimated PFI Pressure Fail Hot Soak Emissions and Real World Data

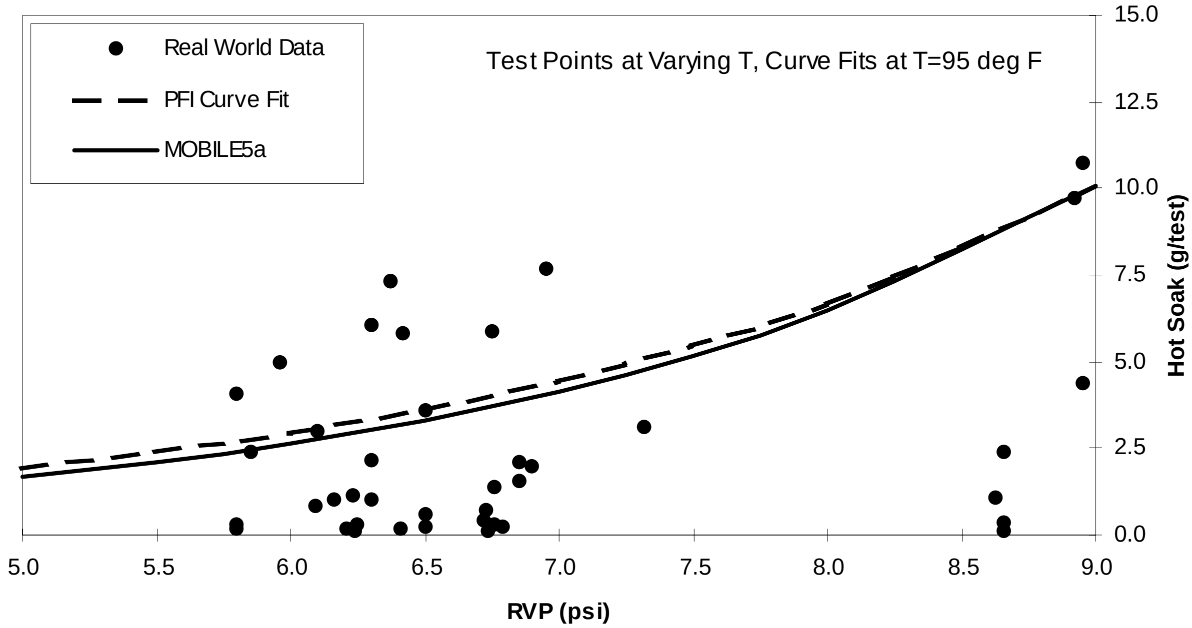
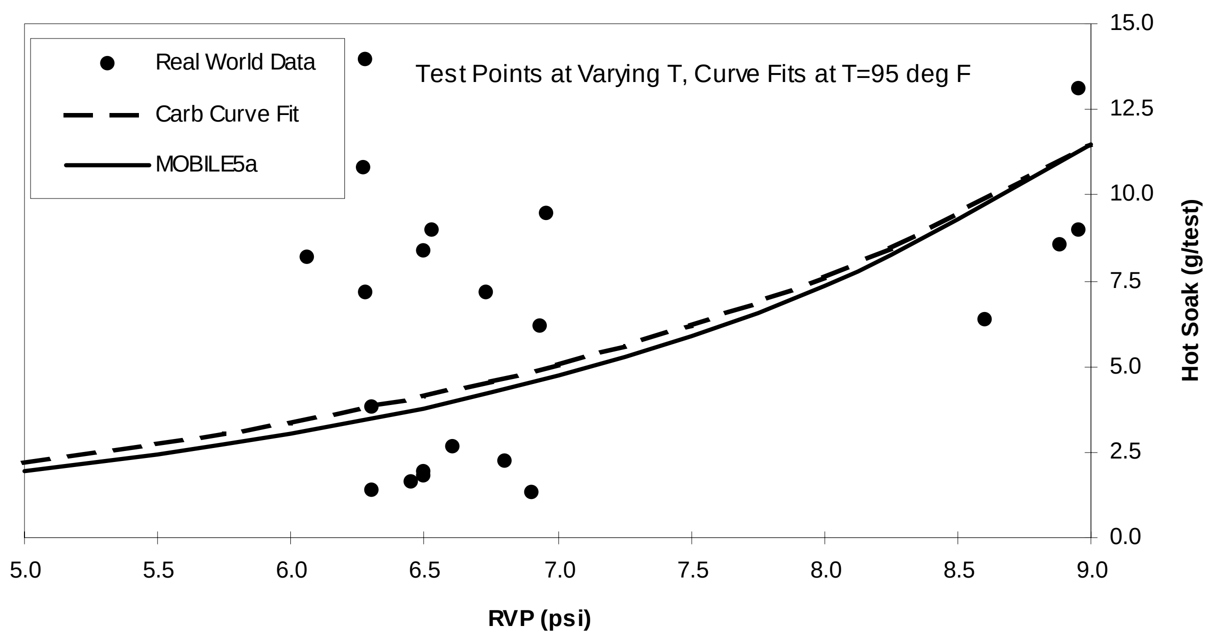


Figure 4. Estimated Carb Pressure Fail Hot Soak Emissions and Real World Data



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 was 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 :

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

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:

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

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:

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

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

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

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.

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

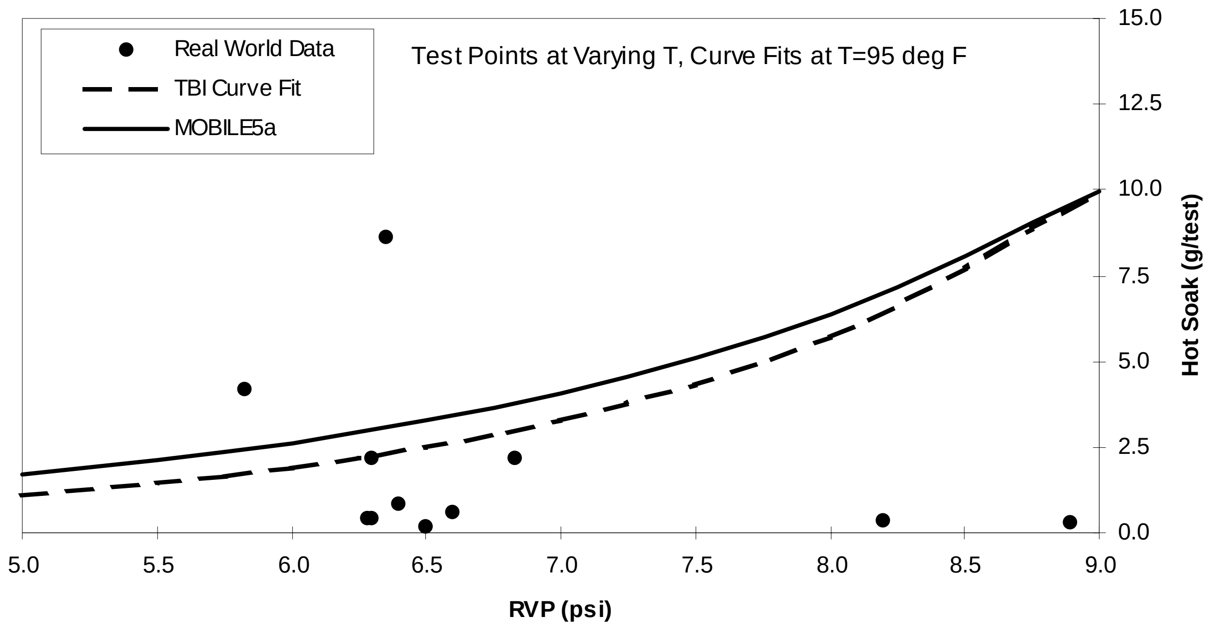


Figure 6. Estimated PFI Purge Fail Hot Soak Emissions and Real World Data

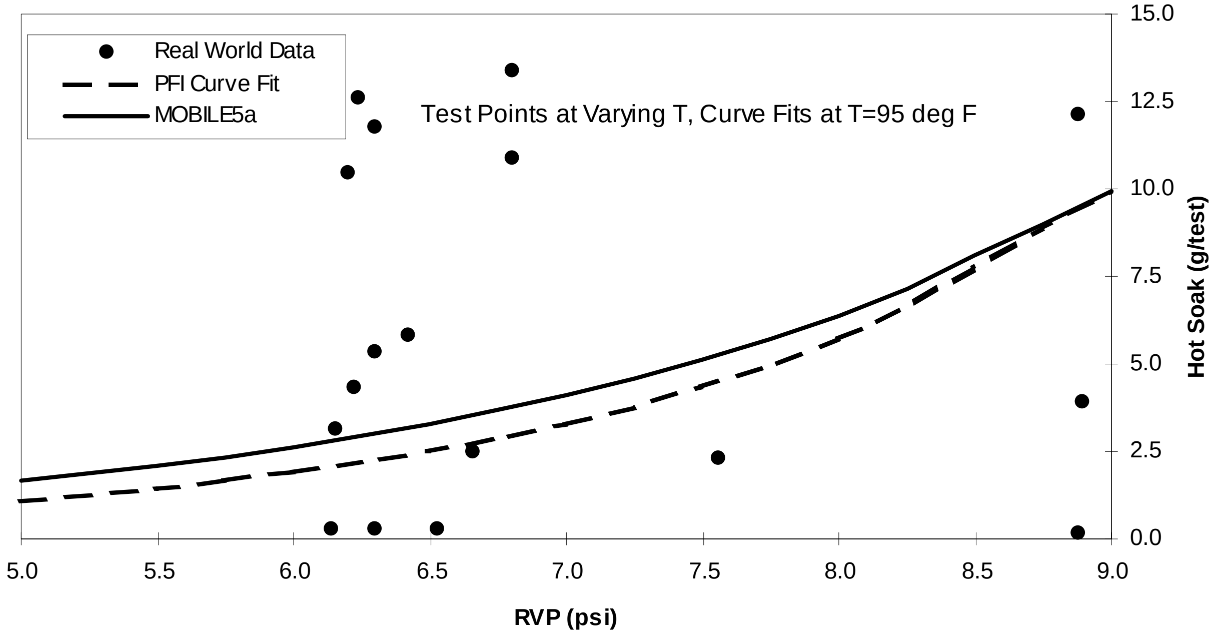
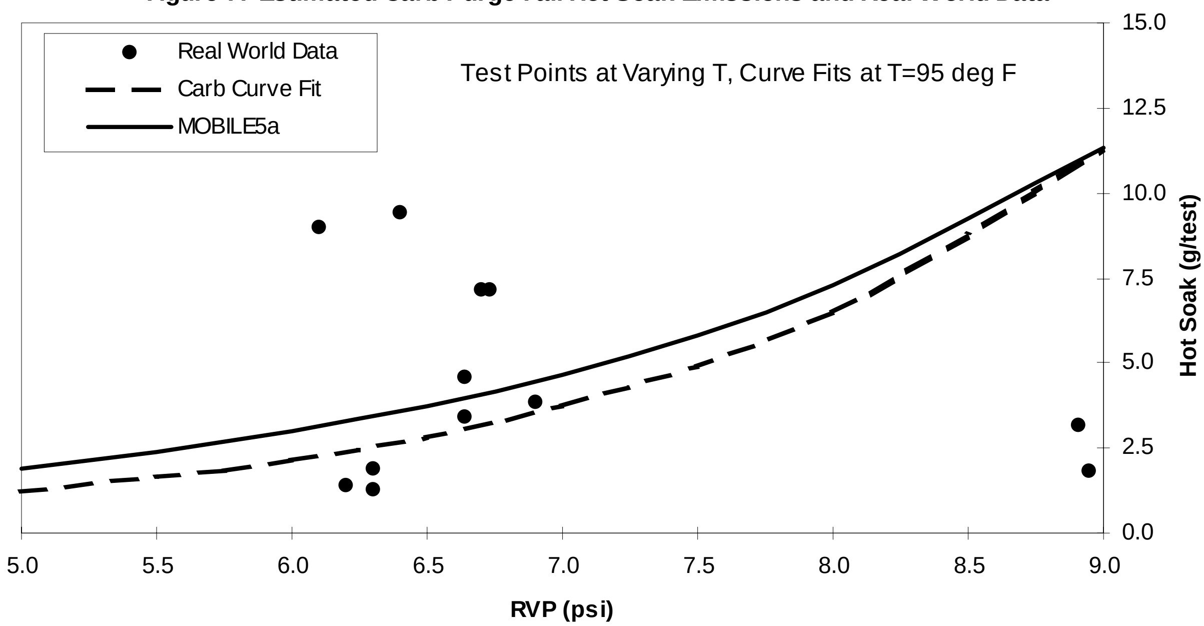


Figure 7. Estimated Carb Purge Fail Hot Soak Emissions and Real World Data



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. PASS/PASS 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. Data was 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 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 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

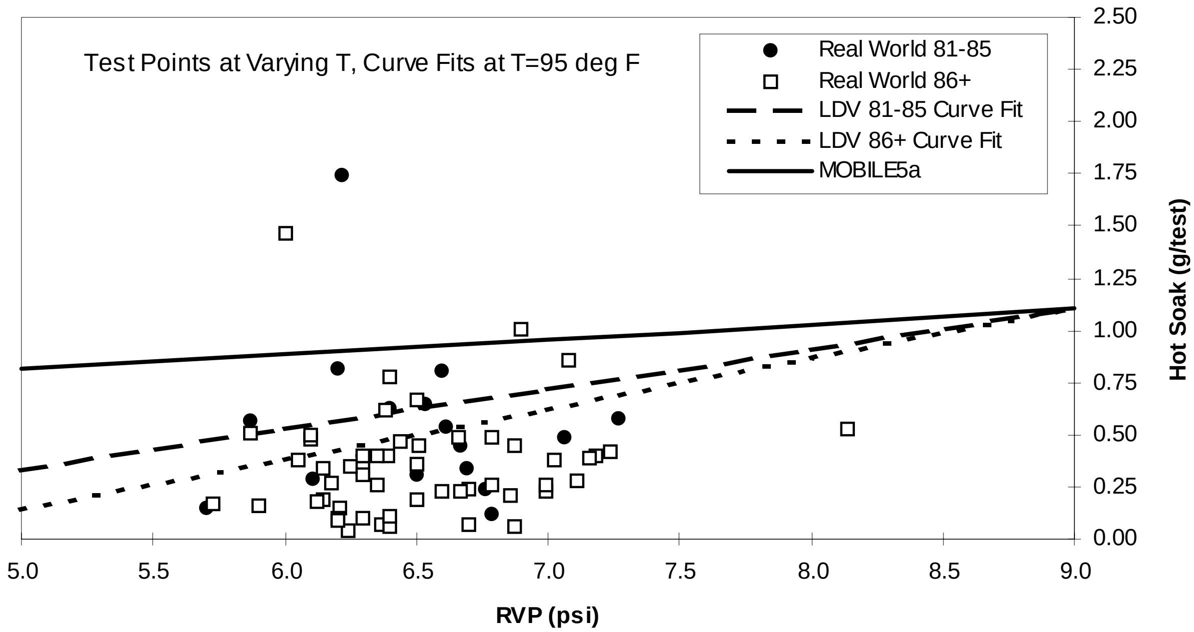
$$\text{Hot Soak} = (-0.71055 + 0.17803*\text{RVP})*(-2.4636 + 0.00056161*\text{Temp}^2)/2.596 \qquad \text{(VI.6)}$$

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



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

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

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:

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

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:

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

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.

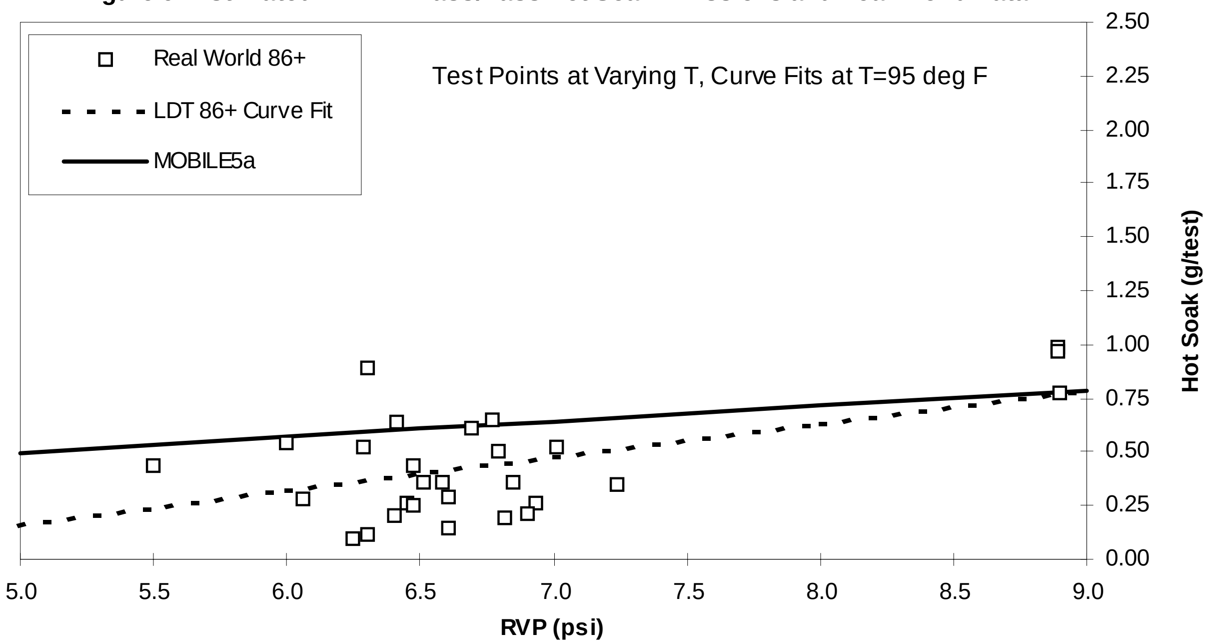
For the PFI LDVs with model years (MY) between 1981 and 1985, the first regression analysis resulted in a negative B coefficient, implying a decrease in emissions with increasing fuel RVP, which is intuitively incorrect. To correct this situation, 15 additional data points calculated using the MOBILE5a 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

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



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

Hot Soak = (-0.058967 + 0.100658*RVP)*(0.0055541*Temp)/0.749 (VI.10)

1986+ MY LDVs

Hot Soak = (-0.0097563 + 0.082809*RVP)*(0.0055541*Temp)/0.651 (VI.11)

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

Hot Soak = (-0.40673 + 0.10297*RVP)*(0.0055541*Temp)/0.46 (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

Hot Soak = (0.3456+0.04906*RVP)*(0.0055541*Temp)/0.805 (VI.13)

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

Hot Soak = (0.078327 + 0.041297*RVP)*(0.0055541*Temp)/0.46 (VI.14)

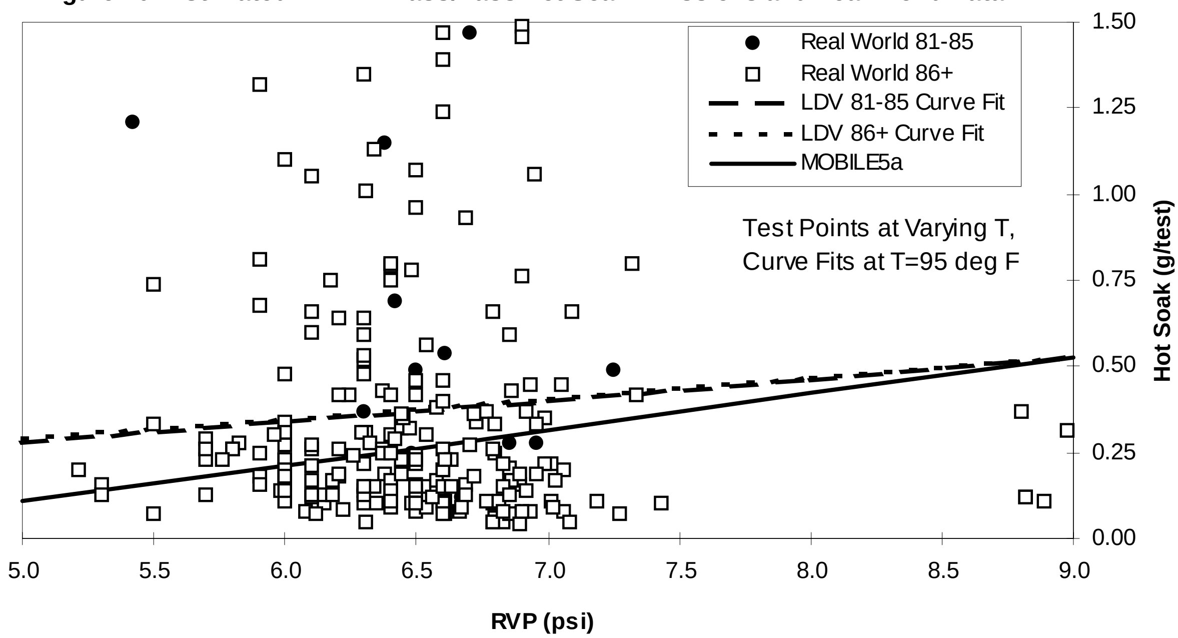
Equations VI.13 and VI.14 should be multiplied by the fuel system adjustment factor of 0.88 to obtain hot soak emission results.

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



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+.

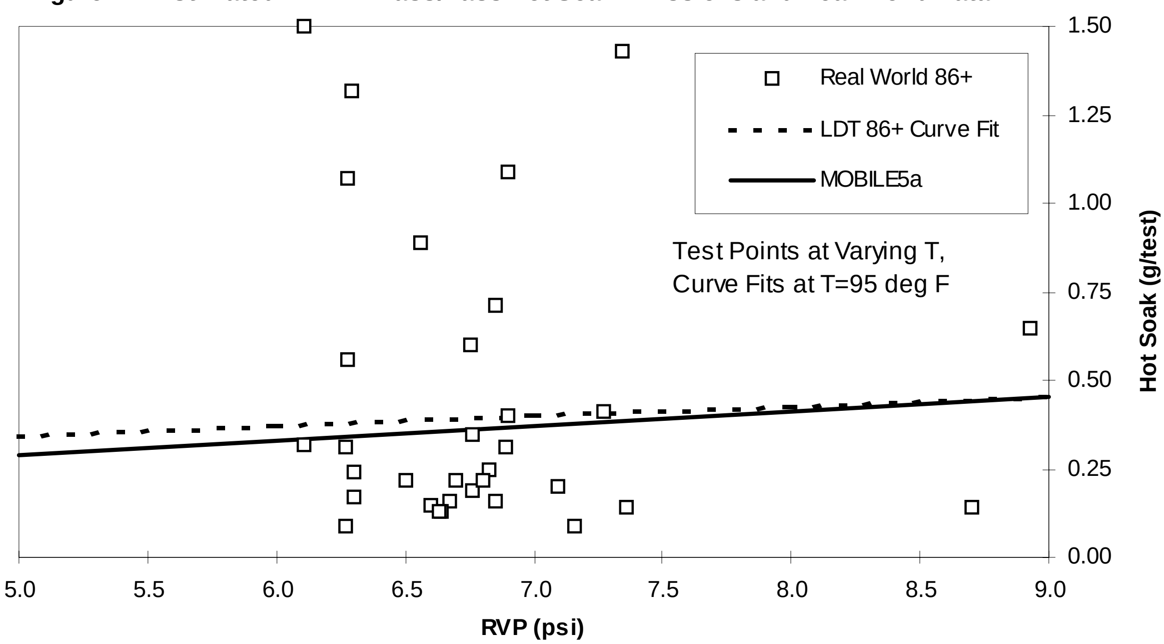
For Carb LDVs with MYs 1981-1985, the first regression analysis resulted in a negative B coefficient. To correct this situation, 4 additional data points were calculated using the MOBILE5a curve fit at 9 psi RVP and 95°F and added to the 43 real world data points. This produced a positive B coefficient 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.

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



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

1981-1985 MY LDVs

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

1986+ MY LDVs

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

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

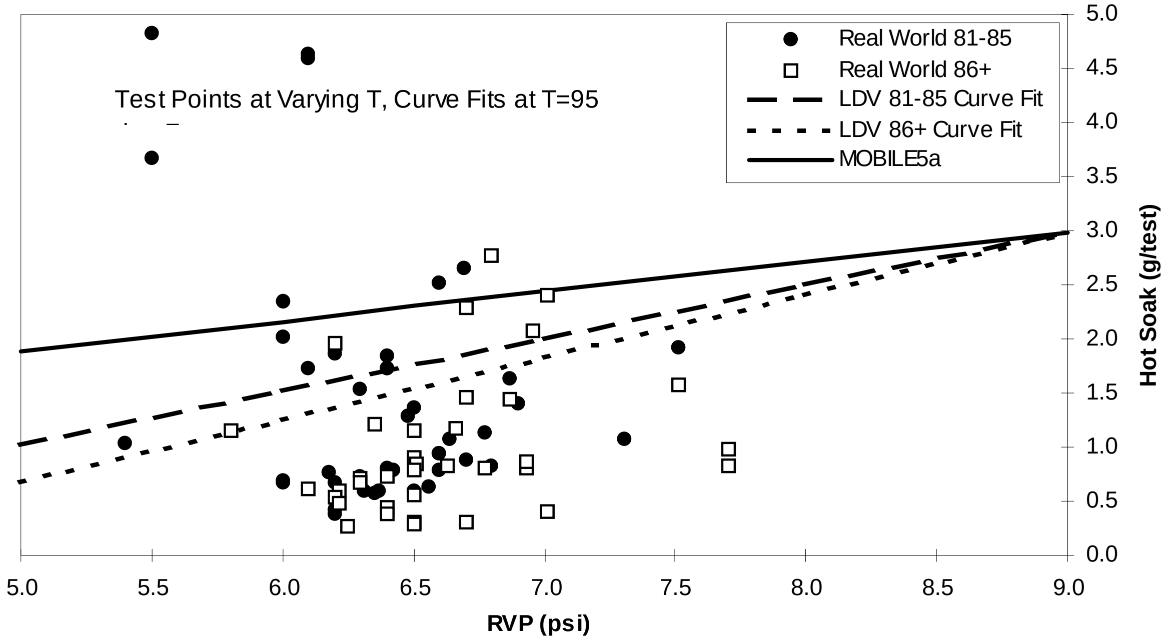
$$\text{Hot Soak} = (0.25593 + 0.13823*RVP)*(-2.4636+0.00056161*Temp^2)/1.31 \qquad (VI.19)$$

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.

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



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:

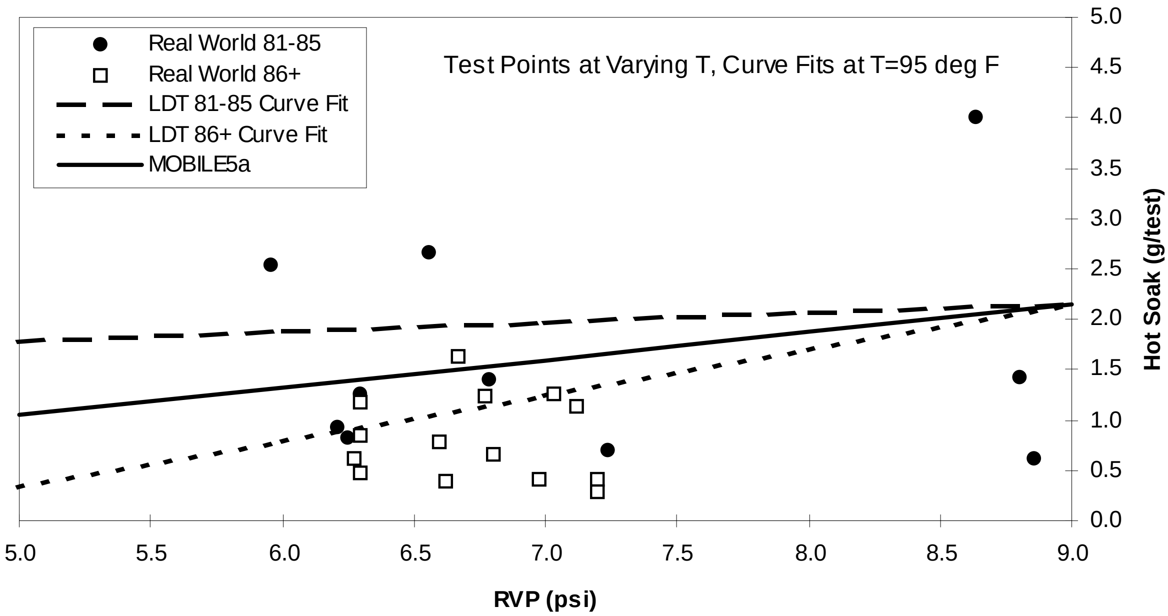
$$\text{Hot Soak} = (-0.164070 + 0.13823*\text{RVP})*(-2.4636+0.00056161*\text{Temp}^2)/1.31 \qquad \text{(VI.22)}$$

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.

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



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.