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Hot Soak Emissions as a Function of Soak Time

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1.0 INTRODUCTION

MOBILE6 will compute and report (as a user option) hourly emission factors for start, running, and evaporative emissions. These outputs will be in addition to the standard daily emission estimates which are currently calculated by MOBILE5. The hourly emission factors will allow the MOBILE6 model to provide more precise output that accounts for the time of day that vehicle emissions occur.

Hot soaks are one type of evaporative emissions which will be reported on an hourly basis. They are, by definition, the evaporative hydrocarbon (HC) emissions which escape from a vehicle during the first hour after the engine is stopped. The limited data in this analysis suggests that the emissions are not distributed evenly throughout the hour, but decline as the hour passes. This is likely due to the cooling of the vehicle and its evaporative system. However, the exact mechanism may include back purge from the canister to the fuel tank, leaks and permeation effects in the lines, and canister breakthrough considerations. The reasons why the emissions occurred and their resulting distribution formed were not investigated in this analysis.

This document (M6.EVP.007) presents an analysis of the rate hot soak emissions decline over the one hour time period. This information will be used in MOBILE6 with the hot soak activity information from the document "Soak Length Activity Factors for Hot Soak Emissions" - EPA Report Number M6.FLT.004, and the hot soak emission information from the document "Hot Soak Emissions" (M6.EVP.004).

Structurally, this document is divided into three sections. The first section briefly describes the data which were analyzed. The second section discusses the analysis performed on the data. The third section provides the results of the analysis and shows how they will be applied in the MOBILE6 model.

2.0 DATA

All of the data used to determine the distribution of hot soak emissions as a function of soak time were collected as part of an EPA study. This study was designed to be similar to a previous Auto / Oil test program (See SAE Paper 951007 "Real World Hot Soak Emissions - A Pilot Study"). In the EPA study, 250 vehicles were recruited and given the standard hot soak test. Only 240 vehicles were used in this analysis since ten of them received emission control system repairs, and were not representative of the general fleet. During the test, the hot soak emissions were measured at 10 minute intervals. Thus, hot soak emission measurements are available at 10, 20, 30, 40, 50 and 60 minute intervals. By definition, the hot soak emissions at time = 0 were assumed to be 0 grams.

Other information was collected during the study in addition to the hot soak values. This included vehicle identification information, canister type (open bottom, closed bottom, and unknown), preconditioning prior to the hot soak, and fuel RVP. For more details on the EPA study please refer to the Final Contractor's (ATL) Report of Work Assignment 0-2 of EPA Contract 68-C5-0006 "Real World Hot Soak Evaporative Emissions".

3.0 ANALYSIS

3.1 Hot Soak Fraction

All of the hot soak data (hydrocarbon measurements made in a SHED - sealed housing for emission detection) were collected at 10 minute intervals during the 60 minute hot soak test. For this analysis, these measurements were transformed into emission fractions based on the 60 minute test result. This was done by dividing the individual vehicle hot soak emissions at interval X (i.e., 10 minutes) by the hot soak emissions at the 60 minute test point (the end of the test). By definition, the zero point (t=0) was assumed to have a hot soak fraction of 0, and the end of the test (t=60) was assumed to have a hot soak fraction of 1.0.

Figure 1 shows the hot soak fraction data points versus test time duration. The figure indicates that many vehicles quickly reach their maximum hot soak emission value, and emit very little thereafter. Considerable scatter is evident in the figure, particularly during the early portions of the hot soak test. The reduced scatter at the end of the test as evidenced in Figure 1, and the slightly concave pattern of the mean hot soak fractions in Figure 2, suggest that typically hot soak emissions do not occur at or near the end of the 60 minute test.

3.2 Linear Regressions

A linear regression was performed on the data to determine if test duration, canister type, preconditioning prior to the hot soak, and fuel RVP significantly affect the results. The regression results in Appendix A show that test duration and canister type are statistically significant variables. Preconditioning and fuel RVP were not found to be significant at a 95% confidence level; although fuel RVP was significant at a 90% confidence level.

Despite its significance, canister type was eliminated from the analysis because it is not a variable which will be present in MOBILE6. Thus, analysis by canister type would prevent the functional relationship from being used in the model. Fleet canister type information is difficult to obtain, making an accurate default or user defined MOBILE6 input impractical. However, the vehicle descriptions including canister types for the data sample are included in the data reports mentioned earlier in this report.

3.3 Quadratic Fit

Based on Figures 1 and 2, it was decided that a quadratic fit of the hot soak fraction versus soak time would produce a model which would adequately fit the data, and be simple to implement in the MOBILE6 model. The quadratic fit was obtained from a least squares regression of hot soak fraction versus soak time with the regression intercept fixed at zero. Fixing the zero point was done because the hot soak fraction is defined to be zero when the soak time is zero. The regression statistics are shown in Appendix A. The regression equation is:

$$\text{HS Fract} = 0.0258 * \text{Soaktime} + 0.000156 * \text{Soaktime}^2 \qquad \text{Eqn 1}$$

4.0 Using the Hot Soak Fraction in MOBILE6

The hot soak fractions developed in this analysis will be used in conjunction with basic hot soak emission values and hot soak activities to predict hourly hot soak emission rates in MOBILE6.

4.1 Basic Hot Soak Emission Value from MOBILE6

For this illustration the basic hot soak emission value is assumed to be X. It is based on testing and is an average result which reflects the entire 60 minute hot soak test. The actual hot soak value will be calculated by the model based on the specific characteristics of the vehicle class and model year. This calculation will be described in EPA document M6.EVP.004.

4.2 Hot Soak Fraction

The variable HS Fraction shown in Equation 1 is the cumulative hot soak fraction at a given time. For example using Equation 1, at a soaktime of 30 minutes, 59.8% of the hot soak emissions have been emitted.

4.3 Hot Soak Activity

Equation 2 is the general equation for hot soak activity. It can be found in the EPA document "Soak Length Activity Factors for Hot Soak Emissions" - EPA Report Number M6.FLT.004. This equation calculates the cumulative hot soak activity at a give time during the test.

$$\text{Activity(soaktime)} = b1 - b2 * \exp(-b3 * \text{soaktime}^{b4}) \qquad \text{Eqn 2}$$

For example, substituting the coefficients for the 9 to 10 AM Weekday curve estimates that 44.1 percent of all hot soaks have a soak time of 30 minutes or less.

Activity = 3212.9 - 32.712*exp[4.589 * 30 **-0.001003]

However, a cumulative hot soak activity is not used in the MOBILE6 model. Instead, the cumulative distribution is broken into one minute intervals, and the amount of activity for each interval is calculated. This is done by subtracting the previous activity value from the current value. Mathematically this is:

Interval Activity(t) = Activity(t) - Activity(t-1) Eqn 3

Where t is the time from 1 to 60, and “Interval Activity” represents the fraction of hot soaks with a soak time between t and t-1.

4.4 Calculating the Hourly Hot Soak Emissions

In the MOBILE6 model, the hot soak emission and activity distributions will be calculated in one minute intervals ranging from t=0 to t=60 minutes. The overall hot soak emission (X), the cumulative HS Fraction and the Interval Activity parameters will be calculated by weighting the three pieces together and summing the product to produce an overall hourly hot soak emission result.

The hot soak emission value for an individual interval at time = t is calculated by multiplying the cumulative HS Fraction at time = t, and the Interval Activity at time = t, and the mean hot soak 60 minute test emission value (X) together using Equation 5.

Interval Hot Soak(t) = Cumulative HS Fraction(t) * Interval Activity(t)*X Eqn 5

Where X is the average hot soak emissions for a 60 minute test.

The hourly hot soak emissions are calculated by summing the 60 individual Interval Hot Soak(t) values.

Hourly Hot Soak = SUM[Interval Hot Soak(t)] Eqn 6

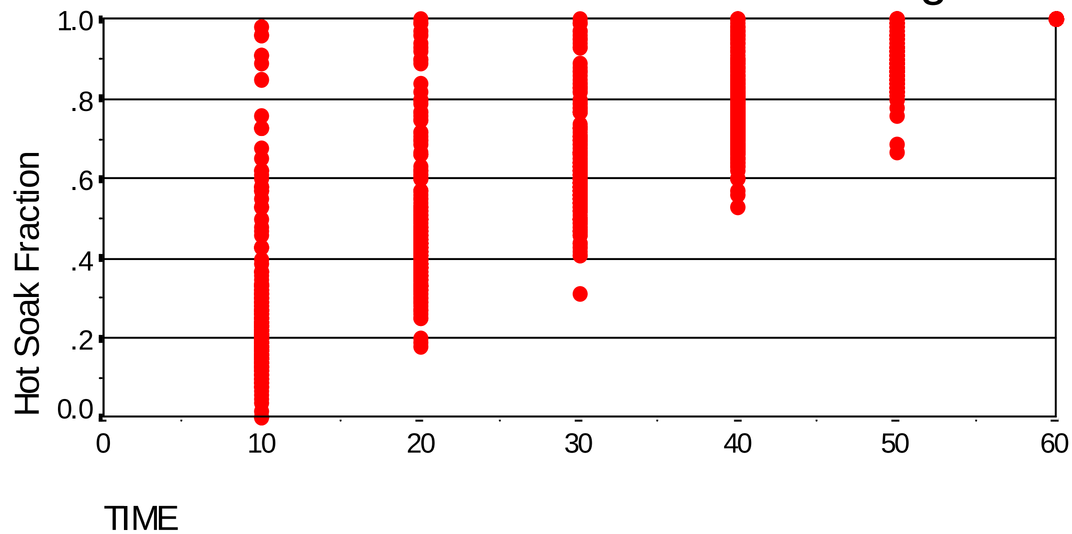
where t ranges from 0 to 60 minutes.

A sample calculation spreadsheet illustrating the hot soak calculation for the 9 to 10 AM weekday case is shown in Appendix B. In the example calculation, the one hour average hot soak (X) is assumed to be 100 grams. This is **not** the actual value which will be used in MOBILE6. It is shown as a round number (100) for illustration only.

For this example when 100 grams is used for the overall average hot soak after 60 minutes, the resulting hourly soak with emission fraction and activity fraction weighting is 63.179 grams.

Figure 1

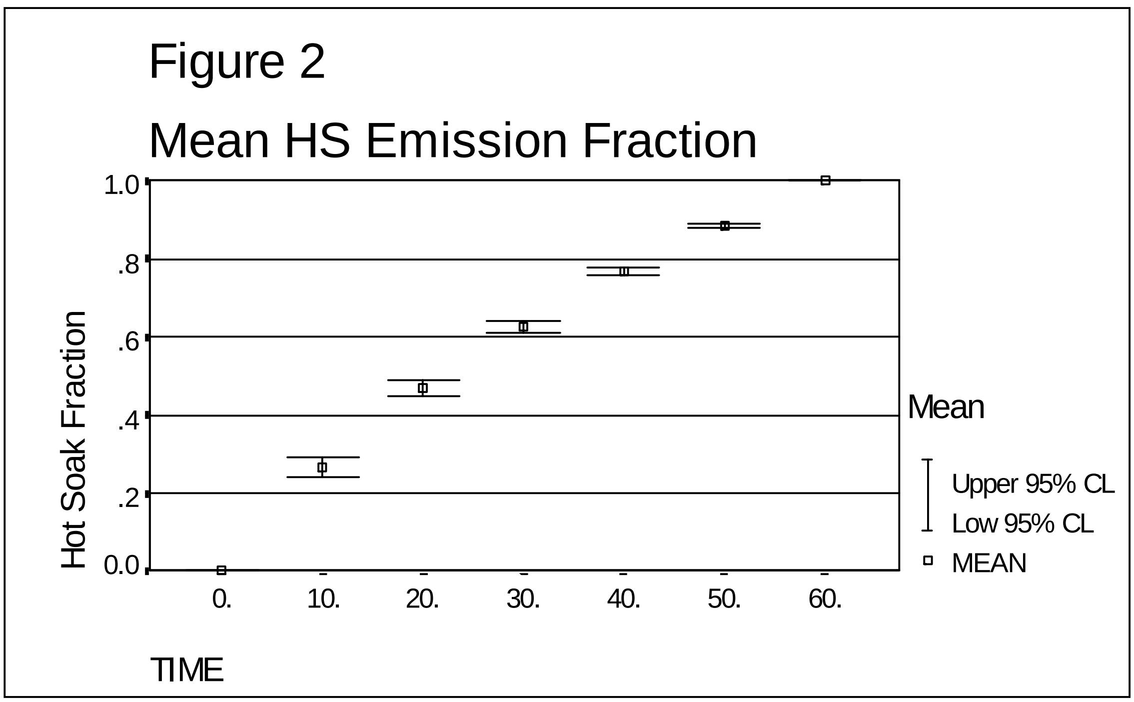
Fraction of HS Emissions vs Test Length



Appendix A

Statistical Results

```
-> USE ALL.
-> COMPUTE filter_$=(test_seq = 17).
-> VARIABLE LABEL filter_$ 'test_seq = 17 (FILTER)'.
-> VALUE LABELS filter_$  0 'Not Selected' 1 'Selected'.
-> FORMAT filter_$ (f1.0).
-> FILTER BY filter_$.

-> EXECUTE .

-> EXAMINE
->   VARIABLES=hs_perc BY time
->   /PLOT NONE
->   /STATISTICS DESCRIPTIVES
->   /CINTERVAL 95
->   /MISSING LISTWISE
->   /NOTOTAL.


     HS_PERC
 By  TIME      10

 Valid cases:       240.0   Missing cases:        .0   Percent missing:      .0


 Mean          .2659  Std Err      .0120  Min          .0000  Skewness    2.0959
```




```
 Median        .2100  Variance     .0343  Max         1.0200  S E Skew     .1571
 5% Trim       .2441  Std Dev      .1853  Range       1.0200  Kurtosis    4.5601
```

```
95% CI for Mean (.2423, .2894)         IQR          .1300  S E Kurt     .3130


    HS_PERC
By  TIME      20

Valid cases:       240.0   Missing cases:        .0   Percent missing:      .0


Mean         .4687  Std Err      .0104  Min          .1800  Skewness    1.4434
Median       .4300  Variance     .0260  Max         1.0000  S E Skew     .1571
5% Trim      .4549  Std Dev      .1613  Range        .8200  Kurtosis    1.9371
95% CI for Mean (.4482, .4892)         IQR          .1400  S E Kurt     .3130


    HS_PERC
By  TIME      30

Valid cases:       240.0   Missing cases:        .0   Percent missing:      .0


Mean         .6276  Std Err      .0083  Min          .3100  Skewness    1.0080
Median       .5950  Variance     .0164  Max         1.0600  S E Skew     .1571
5% Trim      .6198  Std Dev      .1282  Range        .7500  Kurtosis    1.0257
95% CI for Mean (.6113, .6439)         IQR          .1300  S E Kurt     .3130


    HS_PERC
By  TIME      40

Valid cases:       240.0   Missing cases:        .0   Percent missing:      .0


Mean         .7686  Std Err      .0059  Min          .5300  Skewness     .8471
Median       .7500  Variance     .0085  Max         1.1600  S E Skew     .1571
5% Trim      .7649  Std Dev      .0919  Range        .6300  Kurtosis    1.2231
95% CI for Mean (.7569, .7803)         IQR          .1075  S E Kurt     .3130


    HS_PERC
By  TIME      50

Valid cases:       240.0   Missing cases:        .0   Percent missing:      .0


Mean         .8853  Std Err      .0033  Min          .6700  Skewness     .0098
Median       .8800  Variance     .0026  Max         1.0000  S E Skew     .1571
5% Trim      .8849  Std Dev      .0514  Range        .3300  Kurtosis    1.5568
95% CI for Mean (.8788, .8919)         IQR          .0650  S E Kurt     .3130


    HS_PERC
By  TIME      60

Valid cases:       240.0   Missing cases:        .0   Percent missing:      .0

>Note # 17570.  Command name: EXAMINE
>The number of unique data values for this cell is equal to one.  The cell
>will be included in any boxplots produced but other output will be omitted.
```

```
 -> USE ALL.
-> COMPUTE filter_$=(test_seq = 17).
-> VARIABLE LABEL filter_$ 'test_seq = 17 (FILTER)'.
-> VALUE LABELS filter_$  0 'Not Selected' 1 'Selected'.
-> FORMAT filter_$ (f1.0).
-> FILTER BY filter_$.

-> EXECUTE .

-> REGRESSION
->   /MISSING LISTWISE
->   /STATISTICS COEFF OUTS CI R ANOVA
->   /CRITERIA=PIN(.05) POUT(.10)
->   /NOORIGIN
->   /DEPENDENT hs_perc
->   /METHOD=ENTER time can fuel_rvp precond
->   /RESIDUALS HIST(ZRESID) NORM(ZRESID) .
```

```
           * * * *   M U L T I P L E   R E G R E S S I O N   * * * *


Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   HS_PERC

Block Number  1.  Method:  Enter      TIME     CAN      FUEL_RVP PRECOND


Variable(s) Entered on Step Number
   1..    PRECOND
   2..    TIME
   3..    CAN
   4..    FUEL_RVP


Multiple R           .89825
R Square             .80686
Adjusted R Square    .80632
Standard Error       .12165

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           4            88.71651         22.17913
Residual          1435            21.23650           .01480

F =    1498.69575       Signif F =  .0000


---------------------- Variables in the Equation -----------------------

Variable              B        SE B     95% Confdnce Intrvl B       Beta

TIME            .014461  1.8771E-04      .014093      .014830    .893783
CAN            -.020136     .002674     -.025381     -.014891   -.087556
FUEL_RVP   -3.19716E-04  1.7195E-04 -6.57019E-04  1.75872E-05   -.021644
PRECOND        -.004923     .008094     -.020800      .010954   -.007070
(Constant)      .233692     .014555      .205140      .262244


----------- in ------------

Variable           T  Sig T

TIME          77.041  .0000
CAN           -7.531  .0000
FUEL_RVP      -1.859  .0632
```

```
PRECOND         -.608  .5431
(Constant)     16.055  .0000


           * * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Equation Number 1    Dependent Variable..   HS_PERC


End Block Number   1   All requested variables entered.


           * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


Residuals Statistics:

              Min      Max     Mean  Std Dev     N

*PRED       .2560   1.0746    .6694    .2483  1440
*RESID     -.3512    .7089    .0000    .1215  1440
*ZPRED    -1.6649   1.6319    .0000   1.0000  1440
*ZRESID   -2.8872   5.8271    .0000    .9986  1440

Total Cases =     1440

Hi-Res Chart  # 13:Histogram of *zresid

Hi-Res Chart  # 14:Normal p-p plot of *zresid
```

```
-> GET
->   FILE='D:\MOBILE6\EVAP\EMIS\AOH95_2.SAV'.

-> EXECUTE .

-> * Curve Estimation.
-> TSET NEWVAR=NONE .
-> CURVEFIT /VARIABLES=hs_perc  WITH time
->   /NOCONSTANT
->   /MODEL=QUADRATIC
->   /PRINT ANOVA
->   /PLOT FIT.

MODEL:  MOD_8.


Dependent variable.. HS_PERC           Method.. QUADRATI

Listwise Deletion of Missing Data

Multiple R           .98589
R Square             .97197
Adjusted R Square    .97194
Standard Error       .12122

            Analysis of Variance:

                 DF   Sum of Squares      Mean Square

Regression        2        763.37082        381.68541
Residuals      1498         22.01098           .01469

F =   25976.34126       Signif F =  .0000

-------------------- Variables in the Equation --------------------

Variable                   B        SE B       Beta         T  Sig T

TIME                 .025772     .000326   1.387091    78.938  .0000
TIME**2             -.000156  6.5297E-06   -.419536   -23.875  .0000

Notes:
*  Equation was estimated without the constant term; Rsq is redefined.
```

Notes:
* Equation was estimated without the constant term; Rsq is redefined.

Appendix B - Sample Calculation

Soak time	Activity %	Activity Fract	Delta Act Fract	Emission	HS Average	Wt Emiss
1	0.0000	0.0000	0.0442	0.0256	100	0.1133
2	4.4196	0.0442	0.0598	0.0510	100	0.3047
3	10.3965	0.1040	0.0423	0.0760	100	0.3217
4	14.6290	0.1463	0.0328	0.1007	100	0.3301
5	17.9073	0.1791	0.0268	0.1251	100	0.3347
6	20.5828	0.2058	0.0226	0.1492	100	0.3372
7	22.8427	0.2284	0.0196	0.1730	100	0.3383
8	24.7988	0.2480	0.0172	0.1964	100	0.3387
9	26.5230	0.2652	0.0154	0.2196	100	0.3384
10	28.0644	0.2806	0.0139	0.2424	100	0.3378
11	29.4580	0.2946	0.0127	0.2649	100	0.3369
12	30.7295	0.3073	0.0117	0.2871	100	0.3357
13	31.8987	0.3190	0.0108	0.3090	100	0.3344
14	32.9808	0.3298	0.0101	0.3306	100	0.3329
15	33.9877	0.3399	0.0094	0.3519	100	0.3313
16	34.9293	0.3493	0.0088	0.3729	100	0.3297
17	35.8135	0.3581	0.0083	0.3935	100	0.3279
18	36.6468	0.3665	0.0079	0.4139	100	0.3261
19	37.4348	0.3743	0.0075	0.4339	100	0.3243
20	38.1822	0.3818	0.0071	0.4536	100	0.3224
21	38.8929	0.3889	0.0068	0.4730	100	0.3204
22	39.5704	0.3957	0.0065	0.4921	100	0.3185
23	40.2176	0.4022	0.0062	0.5109	100	0.3165
24	40.8370	0.4084	0.0059	0.5293	100	0.3145
25	41.4311	0.4143	0.0057	0.5475	100	0.3124
26	42.0017	0.4200	0.0055	0.5653	100	0.3104
27	42.5507	0.4255	0.0053	0.5829	100	0.3083
28	43.0796	0.4308	0.0051	0.6001	100	0.3062
29	43.5898	0.4359	0.0049	0.6170	100	0.3041
30	44.0826	0.4408	0.0048	0.6336	100	0.3020
31	44.5592	0.4456	0.0046	0.6499	100	0.2998
32	45.0205	0.4502	0.0045	0.6659	100	0.2977
33	45.4676	0.4547	0.0043	0.6815	100	0.2955
34	45.9013	0.4590	0.0042	0.6969	100	0.2934
35	46.3223	0.4632	0.0041	0.7119	100	0.2912
36	46.7314	0.4673	0.0040	0.7266	100	0.2891
37	47.1292	0.4713	0.0039	0.7410	100	0.2869
38	47.5164	0.4752	0.0038	0.7551	100	0.2847
39	47.8934	0.4789	0.0037	0.7689	100	0.2825
40	48.2609	0.4826	0.0036	0.7824	100	0.2804
41	48.6192	0.4862	0.0035	0.7956	100	0.2782
42	48.9689	0.4897	0.0034	0.8084	100	0.2760
43	49.3102	0.4931	0.0033	0.8210	100	0.2738
44	49.6437	0.4964	0.0033	0.8332	100	0.2716
45	49.9696	0.4997	0.0032	0.8451	100	0.2694
46	50.2884	0.5029	0.0031	0.8567	100	0.2672
47	50.6002	0.5060	0.0031	0.8680	100	0.2649
48	50.9054	0.5091	0.0030	0.8790	100	0.2627
49	51.2044	0.5120	0.0029	0.8896	100	0.2605
50	51.4972	0.5150	0.0029	0.9000	100	0.2583
51	51.7842	0.5178	0.0028	0.9100	100	0.2561
52	52.0656	0.5207	0.0028	0.9198	100	0.2539
53	52.3416	0.5234	0.0027	0.9292	100	0.2516
54	52.6124	0.5261	0.0027	0.9383	100	0.2494
55	52.8783	0.5288	0.0026	0.9471	100	0.2472
56	53.1393	0.5314	0.0026	0.9556	100	0.2450
57	53.3957	0.5340	0.0025	0.9638	100	0.2428
58	53.6475	0.5365	0.0025	0.9716	100	0.2405
59	53.8951	0.5390	0.0024	0.9792	100	0.2383
60	54.1385	0.5414	0.4586	1.0000	100	45.8615
	100.0000	1.0000				
						63.1797