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Soak Length Activity Factors for Hot Soak Emissions

Report Number M6.FLT.004

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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. The temporal distribution of emissions is an important factor in the formation of diurnal evaporative and start emissions.

The hourly emission estimates require considerable vehicle activity information and analysis. The term "activity" refers to the vehicle's operating mode, such as running, idling, parked (soaking), etc. The specific activity information needed for emissions estimates includes soak durations, time of soak, trip lengths, time of trip, and other information. This document (M6.FLT.004) discusses the issue of vehicle soak time only as it pertains to hot soak emissions. Other activity estimates needed to develop daily emission factors for exhaust, diurnal, running loss or resting loss emissions will be documented in other MOBILE6 documents listed with the report numbers "M6.FLT.XXX".

2.0 DATA SOURCES USED

The primary data source for this analysis is an EPA instrumented vehicle studies conducted in Baltimore and Spokane. In this studies, instrumentation to monitor vehicle usage was installed with the motorists' permission on 168 randomly selected vehicles while they were tested at an Inspection / Maintenance (I/M) station. The motorists returned one or two weeks later to have the instrumentation removed. Information from more than 8,500 vehicle-trips was recorded. The raw data collected from the studies were processed by the Radian Corporation under EPA contract to create a “trip characteristics” file. This processed file was used to develop the hourly soak time distributions. For more details regarding the instrumented vehicle study and the data processing, please refer to the document “Travel Trip Characteristics Analysis” Final Report under EPA Contract 68-C1-0079 WA 2-05 with Sierra Research.

3.0 METHODOLOGY

This section describes the basic methodology to develop the soak activity estimates used to calculate hot soak emissions. The process consisted of several steps. These are discussed below.

3.1 Definition of a Hot Soak

Hot Soak emissions are evaporative emissions which may be produced by a warm, but no longer running vehicle. Operationally, hot soak emissions are defined as those produced for a duration of time following a vehicle trip which lasted a minimum length of time. This is a general definition. By convention (and assumption) a hot soak duration (the length of time following the key off) is defined to range from a minimum of 1 second (instantaneous) to a maximum of 1 hour. The one hour limit was chosen for consistency with the Federal Test Procedure definition of a hot soak.

The length of time of the trip prior to the hot soak can vary considerably. However, a minimum trip length of 4 minutes was chosen to qualify the subsequent soak as a valid hot soak. The choice of 4 minutes was fairly arbitrary; however, it is believed that a trip of less than 4 minutes will not sufficiently warm the engine or the fuel or over-saturate the evaporative canister so as to produce sufficient hot soak emissions. Thus, trips less than four minutes were assumed to produce no hot soaks and are not reflected in the hourly activity factors for hotsoaks.

3.2 Hourly Intervals

The 24 hour day was divided into 14 different hourly groups. Thirteen of these groups have a duration of one hour. These start at 6:00AM and run through 7:59:59PM. The fourteenth hour contains the remaining nighttime hours as one interval. Collapsing these hours into one group was done for three reasons: (1) the emissions contributed during the night have a relatively smaller impact on daily ozone or CO formation than those contributed during the morning or day, (2) there were relatively little data for these time periods, and (3) what data were available produced results which showed very little hour to hour variance. The hourly intervals are shown in Table 1. In addition to hot soak activity estimates, they are the same hourly groups used in the calculation of activity estimates for start emissions, running emissions, running loss emissions, resting loss emissions, and diurnal emissions.

3.3 Factors Affecting Hot Soak Activity Values

3.3.1 Weekdays Versus Weekends

For a number of the activity parameters a significant difference existed between the value for the weekday and the value for the weekend. Conceptually this make sense since most motorists have different usage patterns for their vehicles on weekdays than on weekends. Differences may also exist for the various days of the week; however, the database was too small to reliably discern these differences.

The MOBILE6 model will distinguish between weekend and weekday in terms of activity and emissions, and a user input will be required to tell the model which one is to be reported. The default will likely be the "weekday."

Table 1
Hourly Ranges

Nominal Name	Hourly Range	Time
6	6 - 7	6 am to 7 am
7	7 - 8	7 am to 8 am
8	8 - 9	8 am to 9 am
9	9 - 10	9 am to 10 am
10	10 - 11	10 am to 11 am
11	11 - 12	11 am to noon
12	12 - 13	noon to 1 pm
13	13 - 14	1 pm to 2 pm
14	14 - 15	2 pm to 3 pm
15	15 - 16	3 pm to 4 pm
16	16 - 17	4 pm to 5 pm

17	17 - 18	5 pm to 6 pm
18	18 - 19	6 pm to 7 pm
24	19 - 24 and 24 - 5	7 pm to 6 am

3.3.2 Vehicle Type and Model Year

The hot soak activity parameters such as the number of trips per day, and the distribution of soak time after the trip end were also investigated by vehicle type or vehicle age. Slight differences were found between cars and trucks in terms of trips per day, with trucks having slightly more trips per day (shown in Tables 2a and 2b). However, little significant difference in the hourly distributions were found between cars and trucks or even by vehicle model year. The lack of difference in the hourly distributions between cars and trucks was not particularly surprising since the number of trips per day are fairly similar, and most light trucks today play virtually the same role as cars. Exceptions might be in rural areas or heavily industrial areas where trucks frequently are used to haul equipment or products.

The lack of difference between model years is a little more surprising. One would expect an older vehicle to have a higher percentage of longer soaks, and possibly shorter trips (i.e., the vehicle sits more and goes on fewer long trips because it is a second vehicle). However, a limited analysis of the data did not conclusively demonstrate these hypotheses. One reason might be the relatively small sample of older vehicles. For example, less than 15 percent of the vehicle sample were more than 10 years old at the time of the testing. This was also too small a sub-sample to further split into 28 hourly and weekday/weekend groups, and still obtain reasonable results. The other reason might be recruitment process which was biased to obtain vehicles which were primary vehicles rather than spare second vehicles. As a result, the hourly distributions shown in Tables 3, 4a and 4b represent both cars and trucks and all vehicle ages.

Since the default MOBILE6 hourly activity estimates are based exclusively on 168 vehicles, and cannot possibility reflect all geographical areas, times, or other variables, the user will have the option of providing hot soak activity data into the MOBILE6 model from an external file.

3.4 Hot Soaks per Car-Day

The first necessary parameters in the model are the estimates for Hot Soaks/car-day. The starting point for this calculation are the trips/car-day values shown in Table 2a. This is a convenient starting point because by definition each hot soak must have a corresponding trip. Four different estimates were obtained from the instrumented vehicle database. There is one estimate for each combination of car versus truck and weekday versus weekend.

To calculate the number of hot soaks per car per day, the values shown in Table 2a were reduced to account for trips which were less than 4 minutes in length. The reduction is a simple percentage of the total trips which were less than 4 minutes. For weekdays, the reduction is 26.1 percent and for weekends it is 28.6 percent. For example, this reduces the average number of weekday trips per day per car from 7.28 trips/car-day to 5.38 hs/car-day. The average number of hot soaks/car-day are shown in Table 2b.

These estimates are subject to revision pending completion of a thorough analysis of national trip data by an EPA contractor. The values could potentially vary considerably from those shown here.

Table 2a
Trips per Car per Day

Cars		**Trucks**	
Weekday	Weekend	Weekday	Weekend
7.28	5.41	8.06	5.68

Table 2b
Hot Soaks per Car per Day

Cars		**Trucks**	
Weekday	Weekend	Weekday	Weekend
Reduction = 26.1%	Reduction = 28.6%	Reduction = 26.1%	Reduction = 28.6%
5.38	3.86	5.96	4.06

3.5 Daily Hot Soak Distribution by Time of Day Increment

Table 3 contains the distribution of the vehicle hot soaks by time of day. An estimate is provided for each of the fourteen groups, and separate estimates are provided for weekends and weekdays. All of the estimates were calculated after removing the hot soaks which had preceding trip durations less than 4 minutes. For example, Table 3 shows that approximately 2.33% percent of the weekday hot soaks occur during the period from

6:00 AM to 6:59:59 AM. The data which underlies Table 3 were obtained from the instrumented vehicle database. Each column sums to 100 percent.

Table 3 **<u>Daily Distribution of Hot Soaks</u>** (in percent)		
Hour	**Weekday**	**Weekend**
6	2.33	0.99
7	6.05	2.26
8	6.30	3.38
9	4.62	6.41
10	5.08	6.98
11	6.32	8.80
12	7.80	9.23
13	7.32	7.40
14	7.87	8.10
15	8.63	6.62
16	8.71	8.03
17	7.99	6.91
18	5.88	6.27
24	15.10	18.62

3.6 Hot Soak Length Distribution by Hourly Group

The MOBILE6 model will contain a cumulative soak length distribution for each of the 14 hourly groups, and for both weekdays and weekends. As a result, there will be 28 cumulative soak length distributions. These 28 distributions are based on data from the instrumented vehicle study. To make the distributions smoother for use in the MOBILE6 model, a Weibull function fit was generated for each of the 28 soak length distributions using the non-linear fit algorithms in the statistical software package SPSS. Only the first 59 minutes of the cumulative distribution were fitted. Since the 60 minute (the last minute) contained all of the soaks which were 60 minutes or greater in length it produced a discontinuous function which jumped up to 100 percent. The 60 minute point will be accounted for separately in the MOBILE6 model by coding the value of 100 percent for the 60 minute point. Also, in a few cases negative values for the Weibull distribution function were obtained for short duration soaks (1 or 2 minutes). In these cases, a value of zero will be assumed. Overall, the Weibull function produced a fairly close fit for all of the 28 distributions. The typical r-squared value was 0.97 or better for weekdays, and 0.92 or better for weekends. The better fit for the weekdays versus the weekends is the result of a considerably larger weekday database.

The Weibull function fit is of the form:

$$Y = b1 - b2 * \exp(-b3 * \text{Soaklength}^{b4}) \qquad \text{Eqn 1}$$

where b1, b2, b3 and b4 are regression coefficients, and soaklength in minutes (0 to 59) is the independent variable. The variable Y is the cumulative distribution in percent.

Tables 4a and 4b lists all of the regression coefficients (b1, b2, b3, and b4) and r-squared values for each of the 28 hourly and weekday/weekend groups. Figure 1a shows the raw data distribution and the corresponding Weibull fit for the 7 to 8 AM weekday group. The heavier dots in the figure are the points fitted by the weibull function, the lighter dots are the actual data points. The 7 to 8 AM function was plotted because it is generally typical of the fit of the other 27 hourly/week groups.

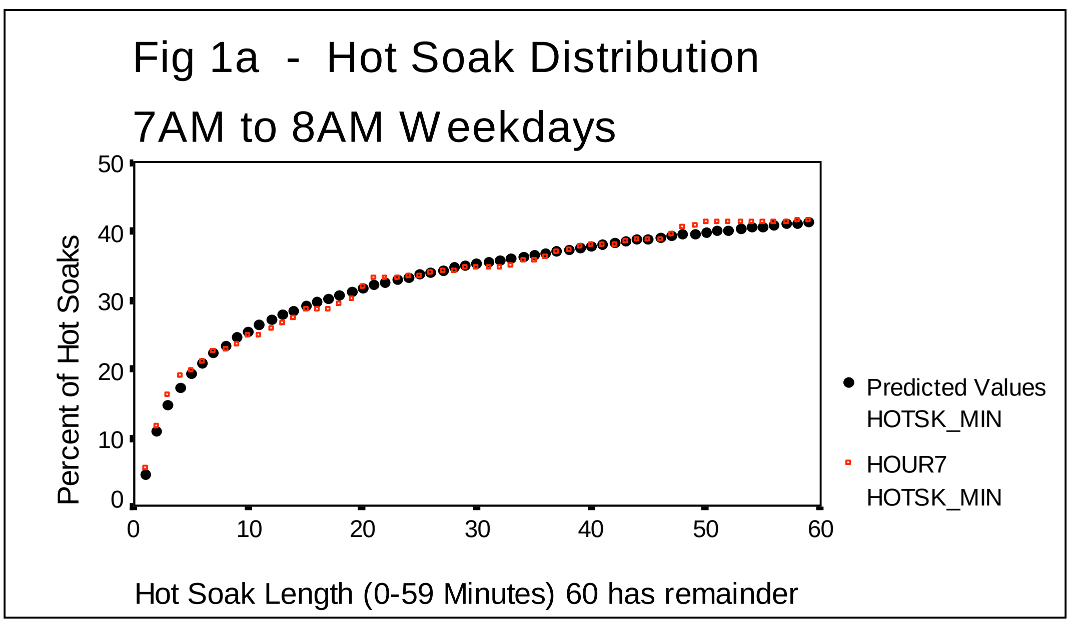

Table 4a
Weekdays
Hot Soak Length Distribution Coefficients by Hourly Group

Hourly Group	Coefficient B1	Coefficient B2	Coefficient B3	Coefficient B4	R-squared Value
6	1143.5	20.261	-4.028	-0.001095	0.947
7	1749.6	24.655	-4.259	-0.001225	0.990
8	2483.7	29.051	-4.449	-0.000981	0.981
9	3212.9	32.712	-4.589	-0.001003	0.971
10	4010.7	36.230	-4.709	-0.000929	0.955
11	2985.7	31.546	-4.552	-0.001310	0.988
12	3208.4	32.605	-4.590	-0.001202	0.985
13	4042.0	36.357	-4.714	-0.009702	0.964
14	3066.0	31.957	-4.565	-0.001189	0.987
15	3207.6	32.627	-4.590	-0.001167	0.987
16	2957.4	31.546	-4.549	-0.001149	0.977
17	2435.8	28.726	-4.440	-0.001239	0.995
18	2096.7	26.827	-4.361	-0.001445	0.969
24	1906.5	25.712	-4.306	-0.000900	0.977

Table 4b Weekends Hot Soak Length Distribution Coefficients by Hourly Group					
Hourly Group	Coefficient B1	Coefficient B2	Coefficient B3	Coefficient B4	R-squared Value
6	51.25	5.911	-18.036	-0.0359	0.935
7	55.31	0.0000633	-13.695	-0.0325	0.924
8	2732.31	0.1819	-9.620	-0.000651	0.943
9	2208.97	0.1645	-9.507	-0.000750	0.978
10	2706.57	0.1784	-9.631	-0.000628	0.951
11	2432.70	0.1674	-9.591	-0.000862	0.945
12	1824.07	0.1564	-9.364	-0.000857	0.972
13	1930.61	0.1506	-9.464	-0.000904	0.950
14	2424.95	0.1761	-9.531	-0.000692	0.980
15	1921.98	0.1496	-9.464	-0.000861	0.922
16	2129.29	0.1602	-9.498	-0.000819	0.978
17	1292.06	0.1333	-9.183	-0.001161	0.969
18	178.02	0.0327	-8.586	-0.007661	0.957
24	520.28	0.0902	-8.653	-0.001729	0.991

3.7 Using the Hourly Hot Soak Activities in MOBILE6

3.7.1 Average Hourly Hot Soak Emissions

The average hourly hot soak emissions will be calculated by multiplying the hot soak emissions function (discussed in document M6.EVP.003) with the corresponding hot soak activity function (calculated from the coefficients in Tables 4a and 4b and Eqn. 1), and summing the products to produce an overall hourly average. This average is then multiplied by the number of hot soaks per day per vehicle which occur in the given hourly group to produce the average hot soak emission emission level for the given hourly group. In the MOBILE6 model this is done by multiplying the 60 (one for each minute of the hot soak) hot soak emission estimates with the 60 activity values (activity distribution at each one minute point), and summing the result. This calculation will be done separately for each of the 28 hourly and weekday/weekend groups to produce hourly hot soak emission estimates. The number of hot soaks per day per vehicle is obtained in Table 2b, and the factors which determine how many hot soaks to allocate to a particular hourly group is shown in Table 3. For example, the 10 to 11 AM weekday hourly group for cars would be allocated 5.38 hot soaks/day-car x 5.08 percent (Table 3) = 0.273 hot soaks/car.

Calculation of the average hourly hot soak is shown mathematically as:

given: HS emissions[soak length]
HS activity[soak length]
Soak length: i = 1, 59 minutes
Hourly group: j = 1, 28 hourly/weekday-weekend groups

Wt HS emissions(i) = HS emissions(i) * [HS activity(i+1) - HS activity(i)] Eqn. 2

Average HS emissions(j) = SUM(Wt HS emissions(i))

where the range of the SUM(Wt HS emissions(i)) is: i = 1, 59 minutes

Both the activity function (Weibull fit) and the hot soak emissions function are continuous functions. However, both were turned into discrete functions with 60 intervals in the MOBILE6 model. This was done for computation purposes, and to allow the MOBILE6 user to input a set of alternative hot soak activity values in an attached file rather than a set of different Weibull function parameters.

3.7.2 Average Daily Hot Soak Emissions

An average daily hot soak value will also be calculated in the MOBILE6 model. This hot soak emission value is analogous to the hot soak emission values reported by MOBILE4 and MOBILE5. It will be the product of the number of hot soaks per day, and a weighted average of the individual hourly average hot soaks. The average number of hot soaks per day are shown in Table 2a. The weighting factors used to weight the hourly groups together are the values shown in Table 3.

COMMENTS

Comments on this report and its proposed use in MOBILE6 should be sent to the attention of the author, and submitted electronically to mobile@epamail.epa.gov, or by fax to (313)741-7939, or by mail to MOBILE6 Review Comments, US EPA Assessment and Modeling Division, 2565 Plymouth Road, Ann Arbor MI 48105. Electronic submission of comments is preferred, since we will make any comments available on our web site. In your comments, please note clearly the document that you are commenting on including the report title and the code number listed. Please be sure to include your name, address, affiliation, and any other pertinent information.