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Modeling Hourly Diurnal Emissions and Interrupted Diurnal Emissions Based on Real-Time Diurnal Data

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ABSTRACT

This document reports on both the methodology used to analyze the data from real-time diurnal (RTD) tests on 270 vehicles and on the results obtained from those analyses. The purpose of the analysis is to develop a proposal for a model of the hourly diurnal (and interrupted diurnal) emissions of the in-use fleet. Since this draft report is a proposal, its analyses and conclusions may change to reflect comments, suggestions, and new data.

Please note that EPA is seeking any input from stakeholders and reviewers that might aid us in modeling any aspect of resting loss or diurnal evaporative emissions.

Comments on this report and its proposed use in MOBILE6 should be sent to the attention of Larry Landman. Comments may be submitted electronically to mobile@epa.gov, or by fax to (734) 214-7939, 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. 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.

This document is being released and posted on May 20, 1998. Comments will be accepted for sixty (60) days, ending July 18, 1998. EPA will then review and consider all comments received and will provide a summary of those comments, and how we are responding to them.

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Modeling Hourly Diurnal Emissions and Interrupted Diurnal Emissions Based on Real-Time Diurnal Data

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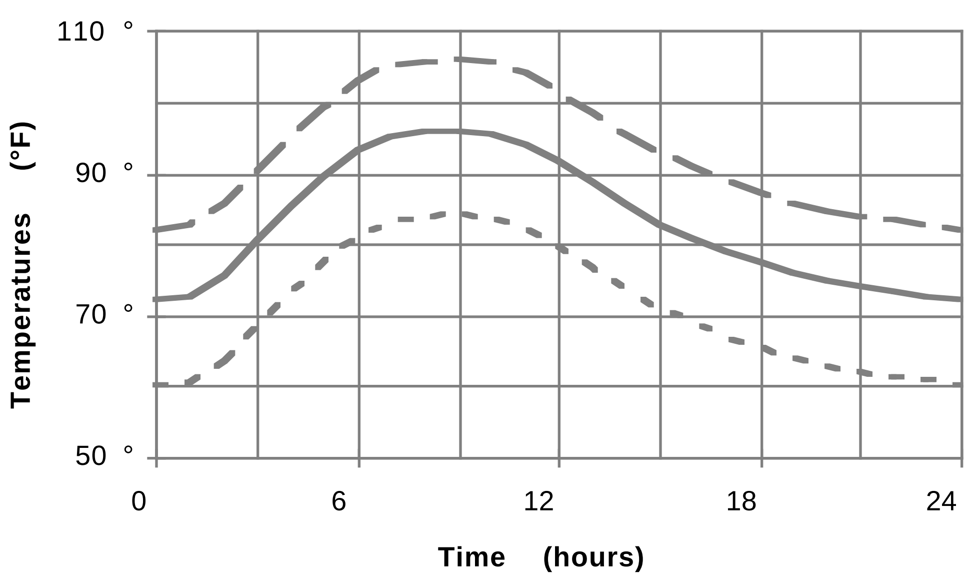
1.0 Introduction

In a recently released draft report (entitled "Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests," originally numbered M6.RTD.001 and then renumbered as M6.EVP.001), the Environmental Protection Agency (EPA) presented a model for estimating resting loss and diurnal emissions over the course of a full day (i.e., 24 hours). (The diurnal emissions are the pressure-driven evaporative HC emissions resulting from the daily increase in temperature, while the resting loss emissions are the evaporative HC emissions not related to pressure changes.) These estimates were based on the results of 24-hour real-time diurnal (RTD) tests during which the ambient temperature cycles over one of three similar 24-degree Fahrenheit ranges. The three ambient temperatures cycles used in those RTD tests are illustrated below

Figure 1-1

Nominal RTD Temperature Cycles



in Figure 1-1; however, most of the testing was performed using the 72 to 96 degree cycle. (Many of RTD tests were actually performed for periods of more than 24 hours. The results after the 24-hour point are analyzed in M6.EVP.003, "Multi-Day Diurnals.")

As illustrated in the preceding figure, these three temperature cycles are parallel (i.e., have identical hourly increases/decreases). The temperature profiles used in all of the RTD tests have the ambient temperature rising gradually from the daily low temperature to the daily high temperature nine hours later. After which, the ambient slowly returns to the daily low temperature over the course of the remaining 15 hours. The three hourly temperature cycles used in this study are given in Appendix A. The most rapid increase in temperatures occurs during the fourth hour. For RTD tests that exceed 24 hours, the cycle is simply repeated. Estimating the effects of alternate temperature profiles is discussed in Section 8.1.

The cumulative hydrocarbon (HC) emissions were measured and reported hourly. Subtracting successive cumulative results produces the hourly emissions. However, using the hourly emissions requires associating a clock time with each test hour. The RTD test is modeled after a proposal by General Motors (GM). (GM's proposal is documented in SAE Papers Numbered 891121 and 901110.) The cycle suggested by GM had its minimum temperature occurring at 5 AM and its maximum temperature at 2 PM. For MOBILE5, EPA analyzed 20-year averaged hourly temperatures by month from Pittsburgh on high ozone days. EPA found that the minimum daily temperature typically occurred at 6 and 7 AM, while the maximum daily temperature typically occurred at 3 to 5 PM. For MOBILE6, EPA proposes to combine the GM and MOBILE5 time estimates and use (as a default) the daily low temperature occurring at 6 AM, and the daily high temperature occurring at 3 PM.

In the previous report, EPA proposed a method for estimating resting loss and diurnal emissions on a daily basis. In this report, EPA proposes a method for estimating resting loss and diurnal emissions on an hourly basis. And then, using those hourly estimates EPA proposes a method to calculate the diurnal emissions that take place over periods of less than 24 hours.

This document reports both on the methodology used to analyze the data from these RTD tests and on the results obtained from those analyses.

2.0 Stratifying the Test Fleet

The test data used for these analyses are the same data used in the aforementioned EPA draft report (M6.EVP.001 which has been renumbered as M6.EVP.001). The data were obtained by combining RTD tests performed on 270 vehicles tested by the Coordinating Research Council (CRC) and EPA in separate programs. The distribution of the fleet is given in Table 2-1.

Table 2-1

Distribution of Test Vehicles

Vehicle Type	Program	Cars	Trucks
Pre-80 Carbureted	CRC	38	13
	EPA	4	2
80-85 Carbureted	CRC	0	47
	EPA	13	5
80-85 Fuel Injected	CRC	0	3
	EPA	9	0
86-95 Carbureted	CRC	0	7
	EPA	8	0
86-95 Fuel Injected	CRC	0	43
	EPA	67	11

In that previous draft report, EPA noted that the resting loss and diurnal emissions from vehicles classified as gross liquid leakers (vehicles identified as having substantial leaks of liquid gasoline, as opposed to simply vapor leaks) are significantly different from those of the remaining vehicles. Based on that observation, the analyses in that previous report were performed separately for those two groups. That separation of analyses will be continued throughout this report.

The two testing parameters in the EPA programs that were found (in M6.EVP.001) to affect the RTD test results are:

- the Reid vapor pressure (RVP) of the test fuel and
- the temperature cycle.

Similarly, the two vehicle parameters that were found to affect the RTD test results are:

- the model year range:
  1) 1971 through 1979
  2) 1980 through 1985
  3) 1986 through 1995
- the fuel delivery system:
  1) carbureted (Carb) or
  2) fuel-injected (FI).

Also, since many of the vehicles were recruited based on the pass/fail results of two screening tests (i.e., canister purge measured during a four-minute transient test and pressurizing the fuel system using the tank lines to the canister), each of those resulting stratum was further divided into the following three substrata:

- vehicles that passed both the purge and pressure tests,
- vehicles that failed the purge test, but passed the pressure test, and
- vehicles that failed the pressure test (including both the vehicles that passed the purge test as well as those that failed the purge test).*

2.1 Evaluating Untested Strata

As noted in M6.EVP.001, no pre-1980 model year, FI vehicles were recruited because of the small numbers of those vehicles in the in-use fleet.

Since the FI vehicles lack a carburetor bowl, they also lack the evaporative emissions associated with that. This suggests that the resting loss and diurnal emissions of the pre-1980 FI vehicles are likely to be no higher than the corresponding emissions of the pre-1980 carbureted vehicles. For MOBILE6, EPA proposes to estimate the RTD emissions of the (untested) pre-1980 FI vehicles with the corresponding emissions of the pre-1980 carbureted vehicles. This should be a safe assumption since any actual differences between these strata should be balanced by the relatively small number of these FI vehicles in the in-use fleet.

3.0 Evaporative Emissions Represented by the RTD Test

As described in M6.EVP.001, the results from the real-time diurnal (RTD) tests can be used to model the following two categories of evaporative emissions:

1) "Resting loss" emissions are always present and relatively weakly related to the ambient temperature (see Section 7.1 of M6.EVP.001) as opposed to diurnal emissions which are related to the rise in temperature.

   That report calculated the hourly resting loss emissions to be the mean of the RTD emissions from hours 19 through 24 at the nominal temperature for hour 24.

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* For only one of the fuel delivery system/model year range groupings (i.e., pre-1980 carbureted vehicles) was there sufficient data to distinguish between the vehicles that failed both the purge and pressure tests and those that failed only the pressure test. Therefore, these two substrata were combined into a single ("fail pressure") stratum.

2) "Diurnal" emissions are the pressure-driven emissions resulting from the daily increase in temperature (Section 7.2 of M6.EVP.001).

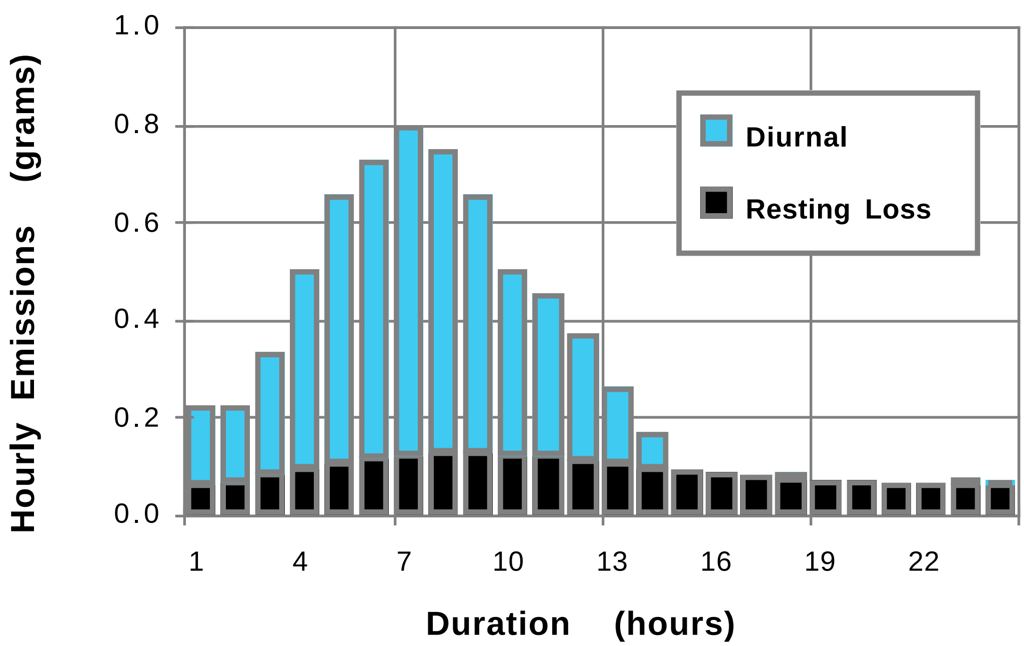
The 24-hour diurnal emissions were calculated by first adjusting the resting loss value for each hour's ambient temperature, and then subtracting that temperature-adjusted resting loss estimate from the full 24-hour RTD test results.

A special case of each of these two categories consists of emissions from vehicles that have significant leaks of liquid gasoline. As a functional definition, we defined these "gross liquid leakers" to be vehicles whose resting loss emissions exceeded two grams per hour. As stated in Section 2, these "gross liquid leakers" were analyzed separately from the other vehicles. Alternative definitions of these "gross liquid leakers" are possible; however, with each such new definition, a new frequency distribution and mean emission value would have to be determined.

The following graph (Figure 3-1) is an example of hourly RTD emissions for vehicles that were not gross liquid leakers. For that graph, we averaged the RTD hourly results from 69 1986-and-newer model year, FI vehicles that had passed both the purge and pressure tests, all tested over the 72° to 96° cycle fueled with a

Figure 3-1

An Example of Hourly RTD Emissions



6.8 RVP gasoline. We then plotted the calculated hourly resting loss and diurnal emissions.

The preceding graph is representative of the hourly resting loss and diurnal emissions of the mean of a single stratum. Each combination of the following five parameters (previously discussed in Section 2.0) can produce a different graph:

- the model year range,
- the fuel delivery system,
- the RVP of the test fuel,
- the temperature cycle, and
- the results of the purge and pressure tests.

In the database used for these analyses, there are:

- five combinations of fuel delivery system and model year range,
- six combinations of temperature cycle and fuel RVP, and
- three combinations of results of the purge and pressure tests.

Therefore, using the available data, we could theoretically construct almost 90 such graphs. (Actually, there are only 86 graphs for which there are any data, of which 58 are based on the average of no more than four RTD tests.) An alternative approach, involving a single graph is discussed in the following section.

4.0 Hourly Diurnal Emissions

4.1 Characterizing Hourly Diurnal Emissions by Strata

Diurnal emissions (either on a daily or hourly basis) can vary substantially among vehicles within a single stratum and more so among different strata. In an attempt to normalize the hourly diurnal emissions, we calculated the percentage of the full (i.e., total 24-hour) diurnal emissions that is emitted each hour. Graphing these percentages of hourly diurnal emissions against time seemed to pictorially produce very consistent results among the various strata, suggesting that averaging the hourly percentage of daily diurnal emissions (across all of the tested strata) would produce a representative result.

To test our hypotheses that the percent of daily diurnal emitted hourly was independent of vehicle and test parameters, we coded the RTD results to distinguish among:

- vehicle types (i.e., cars versus trucks),

- model year ranges,
- fuel delivery system (i.e., carbureted versus FI),
- pressure test results (i.e., pass versus fail),
- temperature cycle, and
- RVP of the test fuel.

This coding resulted in dividing the hourly results on 684 RTD tests into 138 strata (many of them with only one or two tests). Within each of those strata, we averaged the calculated diurnal emissions for each of the first 19 hours. (We had previously defined the average RTD emissions from hours 19 through 24 to be the resting loss emissions. Therefore, the calculated diurnal emissions was zero for hour 19.) We then regressed that hourly percentage of the full diurnal's emission against those six coded variables plus four other variables related to the hourly temperature change, the total temperature change since the start of the test, and products of those temperature changes. The result of that regression analysis is given (on the following page) as Table 4-1. The analysis indicates that none of those six vehicle and test parameters is statistically significant (at any level of significance) in estimating the hourly percentage of diurnal emissions. Additionally, the correlation coefficients were calculated, and they were all zero confirming the lack of significance of those six variables.

Since the possibility existed that our analysis was skewed because we had applied equal weighting to each of those 138 test grouping even though some were represented by as many as 39 test while most were represented by only a few tests. Therefore, the regression analysis was repeated but restricting the sample to only those test strata containing at least four tests (reducing the analysis to only 40 strata), at least six tests (reducing the analysis to only 26 strata), and at least 10 tests (reducing the analysis to only 22 strata). In every case, those same six variables were determined to be statistically not significant.

We, therefore, proceeded with calculating a (representative) hourly percentage of diurnal emissions for all vehicles that are not gross liquid leakers by averaging the individual hourly percentages. (Gross liquid leakers will be analyzed separately.) Table 4-2 is a listing of those resulting percentages in tabular form.

Later in the report (Section 6.1), we will repeat the regression analysis using the temperature variables from this analysis and the hourly averages from Table 4-2.

Table 4-1

Regression of Diurnal Emissions (Vehicles Other Than Gross Liquid Leakers)

Dependent variable is: **Percent of 24-Hour Diurnal**
No Selector

2736 total cases of which 114 are missing
R squared = 49.9% R squared (adjusted) = 49.7%
s = 0.0431 with 2622 - 11 = 2611 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	4.82643	10	0.482643	260
Residual	4.85250	2611	0.001858	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.028265	0.0105	2.69	0.0072
Fuel RVP	0.000000	0.0007	0.000	1.0000
Hourly Temperature Change	0.000986	0.0008	1.19	0.2328
Total Temperature Change	-0.002850	0.0005	-5.64	0.0001
Hourly*Total Temperature Changes	0.000635	0.0000	11.0	0.0001
Square of Total Temperature Change	0.000241	0.0000	13.1	0.0001
Car vs Truck	0.000000	0.0018	0.000	1.0000
Model Year Range	0.000000	0.0014	0.000	1.0000
Carbureted vs FI	0.000000	0.0021	0.000	1.0000
Pressure Test	0.000000	0.0018	0.000	1.0000
Temperature Cycle	0.000000	0.0001	0.000	1.0000

Presenting the data from Table 4-2 in a bar chart format yields Figure 4-1 (on the following page).

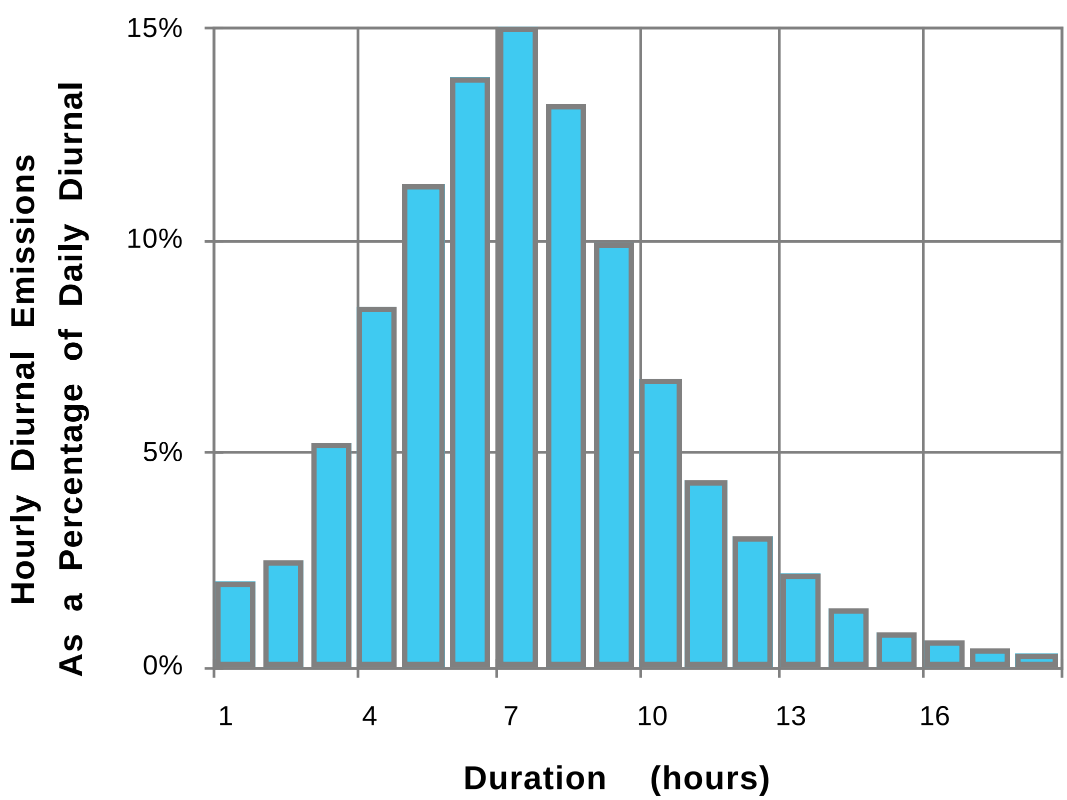
Table 4-2

Distribution of Fleet Hourly Diurnal Emissions
(Hourly Emissions as Percent of 24-Hour Diurnal)

Hour	Time of Day	Emissions	Hour	Time of Day	Emissions
1	6 - 7 AM	1.89%	13	6 - 7 PM	2.09%
2	7 - 8 AM	2.45%	14	7 - 8 PM	1.32%
3	8 - 9 AM	5.13%	15	8 - 9 PM	0.75%
4	9 - 10 AM	8.36%	16	9 - 10 PM	0.53%
5	10 - 11 AM	11.24%	17	10 - 11 PM	0.35%
6	11 AM - Noon	13.78%	18	11 PM - Midnight	0.26%
7	Noon - 1 PM	14.93%	19	Midnight - 1 AM	**0 %**
8	1 - 2 PM	13.08%	20	1 - 2 AM	**0 %**
9	2 - 3 PM	9.85%	21	2 - 3 AM	**0 %**
10	3 - 4 PM	6.69%	22	3 - 4 AM	**0 %**
11	4 - 5 PM	4.31%	23	4 - 5 AM	**0 %**
12	5 - 6 PM	2.97%	24	5 - 6 AM	**0 %**

Figure 4-1

Distribution of Fleet Hourly Diurnal Emissions



From the data in Table 4-2 and Figure 4-1, we make the following observations:

- Although the daily ambient temperatures do not peak until the end of the ninth hour of the test (i.e., at 3 PM), the average hourly diurnal emissions peak during hour seven (from noon to 1 PM). That is, the mode of this distribution occurs during the seventh hour.

- The median of this distribution occurs during the ninth hour. That is, the diurnal emissions that occur through the first nine hours are approximately half (57 percent) of the full day's diurnal emissions.

- Almost 43 percent of the full day's diurnal emissions occur in the morning (i.e., between 6 AM and noon).

- Approximately 98 percent of the full day's diurnal emissions occur from 6 AM through 8 PM (i.e., from hours one through 14).

- Most (53 percent) of the full day's diurnal emissions occur during the four-hour period from 10 AM through 2 PM (i.e., test hours five through eight).

- Almost 19 percent of the full day's diurnal emissions occur during the cool-down period (i.e., test hours 10 through 24).

While these observations are not used in the following analyses, they are useful in gaining a perspective of the distribution of the diurnal emissions. All of these observations are based on data from tests in which daily temperature cycled over a 24-degree range. Other temperature cycles are discussed in Section 8.1.

4.2 Calculating Hourly Diurnal Emissions by Strata

In the previous report (M6.EVP.001), we developed equations that would predict the full day's diurnal emissions based on the RVP of the fuel, on the temperature cycle, and on the vehicle grouping (fuel delivery system plus model year range). In that report, we used both the RVP of the fuel and the ambient temperature to estimate the vapor pressure (VP). (The formula used to estimate VP is given in Appendix B. The VP coincides with RVP at 100° F.) The VP was then used to create a new parameter that was used as the variable on which diurnal emissions were calculated. That new parameter is defined by the formula:

$$(VP_{HIGH} - VP_{LOW}) * (VP_{HIGH} + VP_{LOW}) / 2$$

Where

VP_{HIGH} is the VP associated with the day's high temperature.

VP_{LOW} is the VP associated with the day's low temperature.

For each of the six vehicle groups and each of the three purge / pressure recruitment groups, we created an equation that would model the full day's diurnal emissions. (Those equations are reproduced in Appendix C.)

Therefore, to estimate the mean hourly diurnal emissions, MOBILE will first use the equations in Appendix C to estimate the full day's diurnal emissions, then multiply that value by the hourly percentages from Table 4-2.

5.0 Hourly Diurnal Emissions for Gross Liquid Leakers

In the previous report (M6.EVP.001), vehicles classified as gross liquid leakers were analyzed separately from the other vehicles due to both:

- the order of magnitude difference in resting loss and diurnal emissions, as well as,
- the mechanisms that produce those high emissions.

For these vehicles, the primary source of the evaporative emissions is the leakage of liquid (as opposed to gaseous) fuel. Therefore, we would expect the diurnal emissions from these vehicles to be less sensitive to changes in ambient temperature than the diurnal emissions from vehicles that do not have significant leaks of liquid gasoline.

The analyses in Sections 4.1 and 4.2 were repeated for the vehicles identified as being gross liquid leakers. The hourly RTD results of those test vehicles is given in Appendix D. These tests indicate that several of the higher emitting vehicles exhibited unusually high emissions during the first one or two hours of the test (relative to their emissions for the next few hours). One possible explanation is that during the first two hours of the RTD test, the analyzer was measuring gasoline vapors that resulted from leaks that occurred prior to the start of the test. These additional evaporative emissions (if they existed as hypothesized) would have resulted in a higher RTD result than this vehicle would actually have produced in a 24 hour period. In the last column of Appendix D, we attempt to compensate for what appears to be simply an artifact of the test procedure. The modified RTD evaporative emissions were then converted to diurnals by assuming that the hourly resting loss for these vehicles is completely independent of ambient temperature, subtracting that amount (8.52 grams per hour) from each hour's modified RTD emissions, and then dividing by the total diurnal to yield the hourly percentages in Table 5-1.

Table 5-1

Distribution of Hourly Diurnal Emissions of Gross Liquid Leakers (Hourly Emissions as Percent of 24-Hour Diurnal)

Hour	Time of Day	Emissions	Hour	Time of Day	Emissions
1	6 - 7 AM	1.82%	13	6 - 7 PM	4.53%
2	7 - 8 AM	3.64%	14	7 - 8 PM	2.99%
3	8 - 9 AM	7.27%	15	8 - 9 PM	1.95%
4	9 - 10 AM	8.63%	16	9 - 10 PM	1.73%
5	10 - 11 AM	9.19%	17	10 - 11 PM	1.48%
6	11 AM - Noon	9.80%	18	11 PM - Midnight	1.28%
7	Noon - 1 PM	9.64%	19	Midnight - 1 AM	**0 %**
8	1 - 2 PM	9.61%	20	1 - 2 AM	**0 %**
9	2 - 3 PM	7.95%	21	2 - 3 AM	**0 %**
10	3 - 4 PM	7.50%	22	3 - 4 AM	**0 %**
11	4 - 5 PM	5.89%	23	4 - 5 AM	**0 %**
12	5 - 6 PM	5.09%	24	5 - 6 AM	**0 %**

A comparison of the values in Table 5-1 with the corresponding values in Table 4-2 (or Figure 5-1 with Figure 4-1) indicates that the distribution of emissions for the gross liquid leakers is flatter than for the other vehicles, achieving most of the peak value by the third hour (i.e., after a temperature rise of approximately eight degrees Fahrenheit), and then maintains that high level of emissions until the ambient drops to within 15 to 20 degrees of the initial temperature. This tends to confirm the hypothesis that the diurnal emissions from vehicles with significant leaks of liquid gasoline are less sensitive to changes in ambient temperature than the diurnal emissions from vehicles that do not have significant leaks of liquid gasoline.

We calculated (from Appendix A) both the hourly change in temperature as well as the total change in temperature for each of the first 18 hours of the RTD test, and then regressed the diurnal emissions from Table 5-1 against those two variables. From this empirical (i.e., data driven) approach, we obtain the regression analysis in Table 5-2.

Table 5-2

**Regression of Diurnal Emissions
(Gross Liquid Leakers)**

Dependent variable is: **Percent of 24-Hour Diurnal**
No Selector

R squared = 98.0% R squared (adjusted) = 97.8%
s = 0.0048 with 18 - 3 = 15 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	0.017169	2	0.008584	371
Residual	0.000347	15	0.000023	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.008958	0.0025	3.62	0.0025
Hourly Temperature Change	0.007383	0.0004	17.9	0.0001
Total Temperature Change	0.003053	0.0002	20.3	0.0001

This regression analysis produces the following equation that predicts hourly diurnal emissions from the sub-fleet of gross liquid leakers:

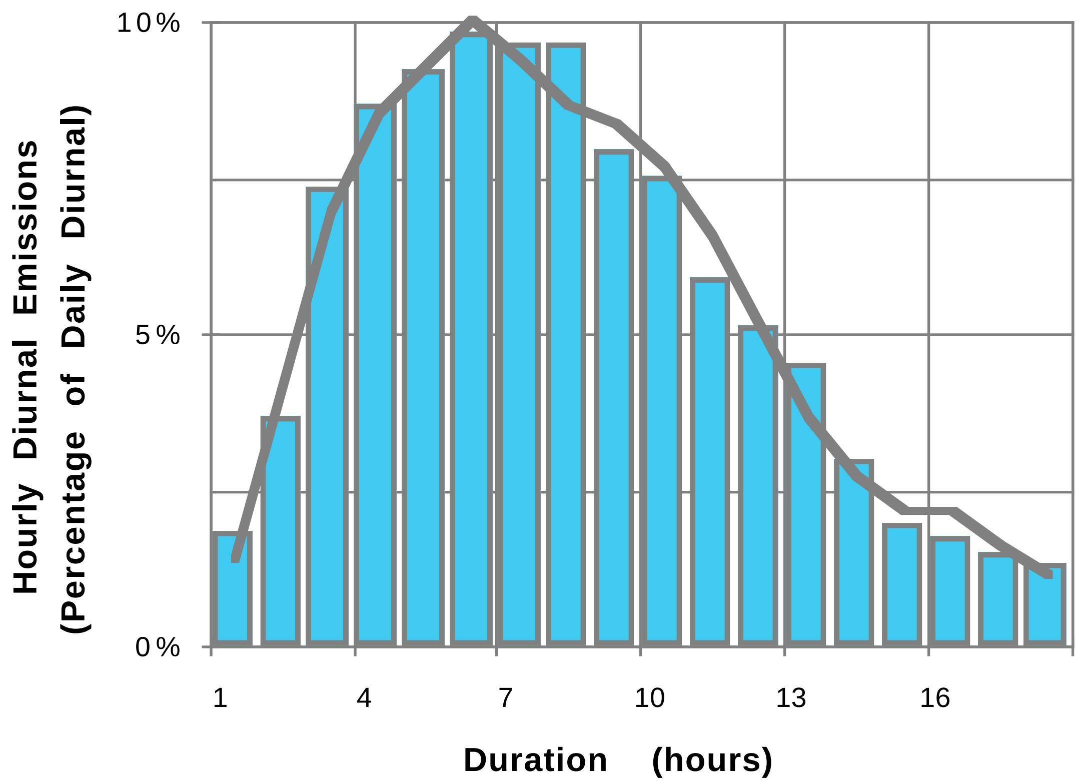
Hourly Diurnal Emissions (grams of HC)
= 100.29 * [0.008958
+ (0.007383 * Hourly_Temperature_Change)
+ (0.003053 * Total_Temperature_Change)]

If the equation produces a negative value, then zero will be used.

Where **100.29** is the average 24-hour diurnal for gross liquid leakers (from Section 10.2 of M6.EVP.001). Omitting the **100.29** produces the estimate of percent of daily diurnal (instead of actual grams). Graphing that linear equation as a solid line with a bar chart of data from Table 5-1 yields Figure 5-1.

Figure 5-1

Distribution of Hourly Diurnal Emissions from Gross Liquid Leakers



Because the regression fits the data well, EPA proposes to use that linear equation to estimate for gross liquid leakers:

- hourly diurnal emissions,
- interrupted diurnal emissions, and
- full day's diurnal over different temperature cycles.

An interrupted diurnal is any diurnal for which the soak period has been interrupted by a period of vehicle operation. Using the regression equation that follows Table 5-2 to estimate the diurnal emissions in that situation is discussed in Section 6.3.

All three temperature cycles in Appendix A are parallel (i.e., corresponding hourly changes in temperatures are identical). Given a different temperature cycle in which all of the hourly changes in temperatures are proportional (rather than identical) to the cycles in Appendix A, then applying the regression equation that follows Table 5-2 to that cycle yields:

Total 24-Hour Diurnal Emissions (grams)

= 100.29 * (0.2 + (0.03333 * Diurnal_Temperature_Range))

Where **100.29** is the average 24-hour diurnal for gross liquid leakers (from Section 10.2 of M6.EVP.001), and where the **Diurnal_Temperature_Range** is the difference of the daily high temperature minus the daily low temperature.

This equation predicts a 24-hour total diurnal emission of 20.06 grams for a day during which the temperatures do not change. This is not reasonable since diurnal emissions result from the daily rise in ambient temperatures. Therefore, EPA proposes to set the 24-hour diurnal equal to zero for a diurnal temperature range of zero degrees Fahrenheit. For diurnal temperature ranges between zero and ten degrees Fahrenheit, EPA proposes to calculate the 24-hour diurnal as increasing linearly from zero to 53.48 grams (i.e., the value predicted by the equation for a diurnal temperature range of 10 degrees).

6.0 Interrupted Diurnal

Many vehicles do not actually experience a full (i.e., 24-hour) diurnal. That is, their soak is interrupted by a trip of some duration. This results in what this report refers to as an "interrupted diurnal." The following example illustrates such an interrupted diurnal.

6.1 Example of an Interrupted Diurnal

For the purpose of this example, we will use the type of vehicle and conditions in Figure 3-1 (i.e., a 1986-95 model year FI vehicle that passes both the purge and pressure tests, that uses a 6.8 RVP fuel, and where the daily temperature profile is the standard 72° to 96° F cycle from Appendix A). For those conditions, we will assume the following vehicle activity:

1. The vehicle soaks over night.

2. Shortly after 9 AM (corresponding to the fourth hour of the RTD test), the vehicle is driven (for 15 to 50 minutes). The vehicle reaches its destination and is parked by 10 AM. (That is, the entire drive takes place during RTD test hour 4.)

3. The vehicle remains parked until the following morning.

The resting loss emissions would continue throughout the entire 24-hour period of this example. However, the other types of evaporative emissions would occur for only limited periods.

1. The first segment of this example (from 6 AM through 9 AM) corresponds to the first three hours of the RTD test. Therefore, the diurnal emissions are represented by the first three hours in Figure 3-1.

2. The evaporative emissions associated with the morning drive are the "running loss" emissions (for that vehicle stratum, fuel RVP, and temperature cycle) and the continuing resting loss emissions. Thus, the running loss emissions replace the diurnal emissions for the fourth hour (from 9 AM through 10 AM). Due to the limitations of the activity data (see M6.FLT.006), we will allocate the entire hour interval (rather than fractional intervals) to running loss emissions even if the actual drive is much shorter than one hour. (Since running loss emissions are calculated as a function of distance, rather than of time, this approach will not change the total running loss emissions. Also, since MOBILE6 will not report emissions for intervals smaller than one hour, this approach will not change the calculated emissions.)

3. While the vehicle was being driven, the temperature in its fuel tank was gradually rising by about 10 to 30 degrees Fahrenheit*. After the vehicle stops and until this elevated fuel temperature drops to become equal with the ambient air temperature, the vehicle will be experiencing what is referred to as "hot soak" emissions.

   In MOBILE5 (and MOBILE4.1), EPA determined the time required to stabilize the temperatures was two hours. Therefore, the hot soak emissions replace the diurnal emissions for the fifth and sixth hours (from 10 AM through noon). For calculation purposes, the entire hot soak emissions will be credited to the first hour.

4. At noon, the hourly diurnal emission will resume but in a modified form due to the heating of the fuel that is

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* In SAE Paper Number 931991 (referenced in Appendix B), the authors discuss the increase in tank temperatures as a function of trip duration. The data presented in that report (in Table 4) suggest that for trips of over five minutes in length, fuel tank temperature increases as a function of the trip length. A 15 minute trip would be associated (on average) with an increase in tank temperature of about 12 to 13 degrees Fahrenheit. A 30 minute trip would be associated with an increase in tank temperature of about 20 degrees Fahrenheit, while a one hour trip would be associated with an increase in tank temperature of about 30 degrees Fahrenheit.

associated with the drive. To modify the hourly diurnal emissions, we will make the following assumptions:

- At the beginning of the driving cycle, the ambient temperature was 80.3° F (from Appendix A), and the effect of the drive was to increase the fuel tank temperature to 95° F (what would be expected from a trip just under 20 minutes in length). By the end of the hot soak period (noon), we are assuming that the falling fuel tank temperature will have reached equilibrium with the rising ambient temperature (which would have climbed to 93.1° F by noon).

- The pressure that is driving these interrupted diurnal emissions (starting at noon) results from the fuel being heated to above the temperature which occurred at the end of the hot soak (in this example, 93.1° F). Therefore, had the ambient temperature <u>not</u> risen above 93.1° F, there would have been <u>no</u> further diurnal emissions for the remainder of that day, <u>only</u> resting loss emissions.

5. Calculating emissions of an interrupted diurnal:

   - This suggests that the interrupted diurnal emissions will end once the ambient temperature returns to its starting point (i.e., 93.1° F). Since the ambient temperature will return to 93.1° at 5:25 PM, we will assume the after 5:25 PM, there are only resting loss emissions. Therefore, we need to modify the hourly diurnal emissions so that the modified values are zero after 6 PM (i.e., from test hour 13 through 24).

   - One such method of modifying the hourly diurnal values is to create a function that closely approximates the hourly emissions (in a fashion similar to what was done in Table 5-2).

For the analysis that produced Table 5-2, we only needed to consider the temperature change within the given hour and the total change (above the initial temperature) to closely estimate the hourly diurnal emissions from vehicles having significant leaks of liquid gasoline. It is likely that the reason such a simple model was so successful was that the primary mechanism of the diurnal emissions of such vehicles (i.e., the leakage of liquid gasoline) is a fairly simple process. Attempting to model the diurnal emissions from vehicles that were not gross liquid leakers required a more complicated set of (independent) variables and produced hourly estimates that were not as close to the values in Table 4-2. The regression analysis that required the least complexity in the number and type of its independent variables and yet produced one of the best fits (of predicted versus actual) is given in Table 6-1.

Table 6-1

Regression of Percent of Total Diurnal Emissions (Non-Gross Liquid Leakers)

Dependent variable is: **Percent of 24-Hour Diurnal**
No Selector

R squared = 95.8% R squared (adjusted) = 95.3%
s = 0.0110 with 18 - 3 = 15 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	0.041867	2	0.020933	172
Residual	0.00183	15	0.000122	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.01102	0.0042	2.6	0.0201
Hourly Temperature Change Times Total Temperature Change	0.000819	0	12.1	0.0001
Square of Total Temperature Change	0.000152	0	12.4	0.0001

From Table 6-1, we obtain the following equation predicting hourly diurnal emissions:

Percent Hourly Diurnal Emissions (as percent of 24-hour diurnal)

= 0.01102

+ 0.07383 * Hourly_Temperature_Change * Total_Temperature_Change

+ 0.000152 * Square of Total_Temperature_Change

If the preceding equation produces a negative value, then zero will be used.

In this example, in which the interrupted diurnal begins at noon (at 93.1° F), we would use:

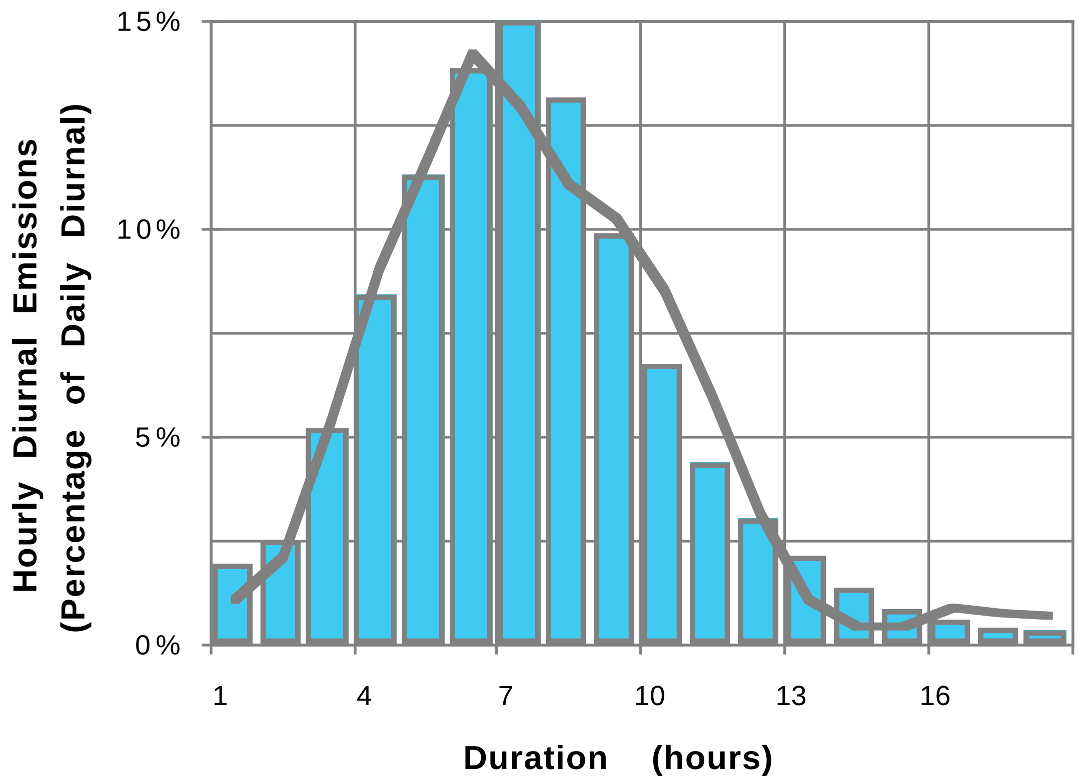
- the difference of each hour's temperature (as given in Appendix A) minus the initial temperature of 93.1°F as the **Total_Temperature_Change** and
- the **Hourly_Temperature_Change** also as given in Appendix A.

The results of applying this equation to an interrupted diurnal that begins at noon are given in Appendix E.

Graphing that linear equation as a solid line with the bars from Figure 4-1 yields Figure 6-1.

Figure 6-1

Distribution of Hourly Diurnal Emissions from Non-Gross Liquid Leakers



Because the regression equation does not fit the data as well as we would like, EPA proposes to use the values in Table 4-2 to estimate the hourly diurnal emissions of the full 24-hour diurnal for the non-leakers. However, because data are not available for interrupted diurnals, EPA proposes to use this equation to estimate the hourly diurnal emissions of the interrupted diurnal of the non-leakers. (For the vehicles classified as gross liquid leakers, EPA proposed in Section 5.0 to use the corresponding equation for <u>both</u> situations.)

Returning to the example at the beginning of Section 6.1, we make the following observations:

- Requiring the estimated hourly emissions of the interrupted diurnal to drop to zero once the ambient temperature drops to the starting temperature results in a shortened period of emissions for the interrupted diurnal.

- Since diurnal emissions are dependent upon rising ambient temperatures to induce the pressure-driven evaporative emissions, the diurnal must <u>begin</u> while the air temperature is increasing (i.e., prior to 3 PM).

  As corollaries to this observation:

  - There can be <u>no</u> interrupted diurnal emissions following a drive that ends after 1 PM.

  - A daily activity consisting of several trips, with each period of inactivity between the trips no more than two hours and the final trip ending after 1 PM, will produce no diurnal evaporative emissions. (However, there will be running loss and hot soak emissions associated with each trip.)

6.2 Calculating Emissions of an Interrupted Diurnal

In the preceding paragraphs, we analyzed one situation in which the hot soak (following a period of vehicle operation) ended during the fifth hour (i.e., between 10 and 11 AM). EPA then proposed a method for calculating the hourly emissions that would have resulted from the abbreviated diurnal cycle that began at 11 AM. Repeating this procedure for (interrupted) diurnals beginning at each hour of the day produces seven interrupted diurnals plus the full-day diurnal. The values for each of the interrupted diurnals are given in Appendix E. (The values for the full 24-hour diurnal were simply copied from Table 4-2.) To estimate the grams of evaporative emissions emitted in any given hour, MOBILE6 will multiply the appropriate percentage from Appendix E times the full 24-hour diurnal's emission (calculated in Appendix C for each vehicle stratum and for each combination of ambient temperature cycle and fuel RVP).

6.3 Interrupted Diurnals of Gross Liquid Leakers

In Section 5.0, we estimated the hourly diurnal emissions from vehicles with gross leaks of liquid gasoline as a linear function of both the temperature change during that hour and the total temperature change up through that hour.

The basic premise in the preceding section was that the base temperature for calculating interrupted diurnals is the ambient temperature at the beginning of the diurnal period, which is also the end of the hot soak period. For each hour of the interrupted diurnal, we calculate both the temperature change during that hour and the total temperature change from the beginning of the interrupted diurnal through that hour. The regression equation following Table 5-2 will then produce the hourly emissions of the interrupted diurnal of gross liquid leakers.

7.0 Assumptions Related to Hourly Emissions

Two basic assumptions related to estimating hourly emissions were made in this analysis:

- the distribution of hourly diurnal emissions being independent of vehicle and test parameters (except for leaker status)

and

- the approach used in Section 6 on estimating diurnals following an interruption (i.e., a trip).

7.1 Distribution of Hourly Diurnal Emissions

In Section 4, we assumed that the distribution of hourly diurnal emissions (as a percentage of the full day's diurnal emission) for non-leakers is independent of all of the vehicle and test parameters. Thus, all that is necessary to obtain the hourly diurnal emissions is to multiply percentages in Table 4-2 by the full day's diurnal (calculated in Appendix C) for non-leakers. For gross liquid leakers, the equation following Table 5-2 will generate the hourly diurnal emissions.

7.2 Assumptions for Interrupted Diurnals

The discussion of interrupted diurnals (in Section 6) requires a number of assumptions.

First, interrupting the diurnal with a trip will result in an increase in fuel tank temperature. However, the amount of that temperature rise is dependent not only upon the duration of the trip (see footnote on page 14) but also on other parameters (e.g., fuel delivery system, fuel tank design, fuel tank materials, air flow, etc.). Similarly, the time necessary for the elevated fuel temperature to decrease to equal the rising ambient temperature is dependent on factors such as the actual temperature cycle (see the discussion on temperature cycles in Section 6.2), fuel tank design, fuel tank materials, and air flow. EPA proposes to continue the approach used since MOBILE4.1 of assuming that exactly two hours is necessary to stabilize the temperatures. (Also, this approach of rounding off the vehicle activity periods to whole hours is also consistent with the vehicle activity data that will be used in MOBILE6.)

8.0 Other Assumptions

In this report, EPA proposes using the total 24-hour diurnal emissions as a basis for calculating the diurnal emission from each individual hour. Another set of assumptions indirectly affected the calculation of hourly emissions by directly affecting the calculation of the full (24-hor) diurnal emission.

8.1 Temperature Ranges

All of the tests used in this analysis were performed using one of the three temperature cycles in Appendix A. This results in all of the resting loss data being measured at only three temperatures (i.e., 60, 72, and 82 °F). In Appendix F, we presented regression equations (developed in M6.EVP.001) to estimate hourly resting loss emissions at theoretically any temperature. We will limit that potentially infinite temperature range as we did in the previous version of MOBILE, specifically:

1) We will assume, for vehicles other than gross liquid leakers, there are no resting loss emissions when the temperatures are below or equal to 40°F. (This assumption was used consistently for all evaporative emissions in MOBILE5.)

   For temperatures between 40°F and 50°F, EPA proposes to interpolate between an hourly resting loss of zero and the value predicted in Appendix F for 50°F.

2) We will assume, for vehicles other than gross liquid leakers, that when the ambient temperatures are above 105°F that the resting loss emissions are the same as those calculated at 105°F.

Since vehicles classified as gross liquid leakers were not handled separately in MOBILE5, we will now make a new assumption concerning the resting loss emissions of those vehicles as relates to temperatures. Specifically:

3) For the vehicles classified as gross liquid leakers, we will assume the resting loss emissions are completely independent of temperature, averaging 8.84 grams per hour.

In a similar fashion, the equations developed in this report to estimate hourly diurnal emissions theoretically could also be applied to any temperature cycle. EPA proposes to limit those functions by making the following assumptions:

1) Regardless of the increase in ambient temperatures, there are no diurnal emissions until the temperature exceeds 40°F. (This assumption was used consistently for all evaporative emissions in MOBILE5.)

   For a temperature cycle in which the daily low temperature is below 40°F, EPA proposes to calculate the diurnal emissions for that day as an interrupted diurnal that begins when the ambient temperature reaches 40 °F.

2) The 24-hour diurnal emissions will be zero for any temperature cycle in which the difference between the daily high and low temperatures (i.e., the "diurnal temperature range") is no more than zero degrees Fahrenheit. For temperature cycles in which the diurnal temperature range is between zero and ten degrees Fahrenheit, the 24-hour diurnal emissions will be linear interpolation of the predicted value for the ten-degree cycle and zero.

8.2 Estimating Vapor Pressure

EPA is proposing to use the fuel's RVP and the Clausius-Clapeyron relationship to calculate the fuel's vapor pressure at each ambient temperature (see Figure B-1). This approach is the equivalent of attempting to draw a straight line based on only a single point since RVP is the vapor pressure calculated at a single temperature (100° F). Since two different fuels could have the same vapor pressure at a single temperature, it is possible for two fuels to have the same RVP but different vapor pressure to temperature curves. However, the two vapor pressure curves would yield similar results near the point where they coincide (i.e., at 100° F). Thus, at temperatures where ozone exceedences are likely to occur, this assumption should produce reasonable estimates of diurnal emissions.

8.3 Heavy-Duty Vehicles (HDGVs)

The analyses in this report were based only on RTD tests of light-duty gasoline-powered vehicles (LDGVs) and light-duty gasoline-powered trucks (LDGTs). Since the data did not indicate a significant difference between the RTD emissions from LDGVs and LDGTs, they were combined in a single group of analyses.

Since no RTD testing was performed on any HDGVs, we will use the same approach that was used in the earlier version of MOBILE. That is, the ratio of diurnal emissions of the HDGVs to those of the LDGTs is a sales weighted average of the corresponding evaporative emission standards. Translating that sentence into an equation yields:

$$DI_{HDGV} = DI_{LDGT} * [(1.5 * 0.875) + (2.0 * 0.125)]$$
$$= 1.5625 * DI_{LDGT}$$

Where, DI_{HDGV} is the full day's diurnal emissions from the HDGVs.

DI_{LDGT} is the full day's diurnal emissions from the corresponding LDGTs.

EPA proposes to use this equation to estimate the mean of the 24-hour diurnal emissions from HDGVs. EPA also proposes to calculate the hourly diurnal emissions by multiplying that estimated 24-hour diurnal emission value by the percentages in Table 4-2 to predict the hourly diurnal emissions from HDGVs.

EPA proposes to use the corresponding formula for resting losses (obviously changing **DI** to "hourly resting losses").

8.4 High Altitude Evaporative Emissions

EPA proposes to continue to use the multiplicative adjustment factor of **1.30** (from previous version of MOBILE) to adjust both the hourly resting loss and 24-hour (and hourly) diurnal emissions for high altitude.

8.5 Motorcycles (MC)

RTD evaporative emission tests were not performed on motorcycles (MC). In MOBILE5, the resting loss and diurnal emissions from motorcycles were modeled using carbureted vehicles equipped with open-bottom canisters. EPA proposes to continue that approach to continue in MOBILE6.

We first identified the 109 RTD tests of carbureted vehicles equipped with open-bottom canisters (all 1988 or earlier model years), and calculated both the hourly resting loss (associated with the test's low temperature) and the full-day's diurnal for each of those 109 tests. The diurnal emissions were then regressed against both the vapor pressure product term (from Section 4.2) and the age of each test vehicle. As illustrated in Table 8-1, each of those variables is statistically significant. MOBILE6 will use the linear regression equation generated by that analysis to calculate the full day's diurnal emissions.

Table 8-1

Regression of Diurnal Emissions (Simulated Motorcycle Fleet)

Dependent variable is: **Diurnal**
No Selector

R squared = 59.0%   R squared (adjusted) = 58.3%
s = 10.20 with 109 - 3 = 106 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	15892.9	2	7946.46	76.4
Residual	11024.5	106	104.005	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-36.7971	4.5620	-8.07	0.0001
age	0.855491	0.1894	4.52	0.0001
VP_Product	0.058251	0.0051	11.5	0.0001

Translating that regression analysis into an equation yields:

24-Hour Diurnal Emissions (grams) for Motorcycles

= -36.7971 + (0.855491 * Vehicle_Age)

+ (0.058251 * VP_Product_Term)

EPA proposes to use this equation to estimate the mean of the 24-hour diurnal emissions from motorcycles.

For MOBILE6, EPA proposes to multiply the estimated 24-hour diurnal emissions from those vehicles (calculated from the preceding equation) by the percentages in Table 4-2 to predict the hourly diurnal emissions from motorcycles.

Similarly, the hourly resting loss emissions were regressed against both the temperature at which those values were calculated (i.e., the daily low temperature) and the age of each test vehicle. As illustrated in Table 8-2, only the vehicle age is statistically significant. It is possible that temperature was not found to be statistically significant simply due to the fact that most of the resting loss emissions were calculated at a single temperature (72 °F). Since temperature <u>should</u> be an important factor in determining resting loss emissions, EPA proposes to use for MOBILE6 the linear regression equation generated by the analysis (in Table 8-2) that uses <u>both</u> variables.

Table 8-2

Regression of Hourly Resting Loss Emissions (Simulated Motorcycle Fleet)

Dependent variable is: **Hourly Resting Loss**
No Selector

R squared = 5.6% R squared (adjusted) = 3.8%
s = 0.1346 with 109 - 3 = 106 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.114078	2	0.057039	3.15
Residual	1.92123	106	0.018125	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.044345	0.1572	0.282	0.7784
age	0.006134	0.0025	2.45	0.0159
Temperature	0.000859	0.0022	0.399	0.6909

Translating that regression analysis into an equation yields:

Hourly Resting Loss Emissions (grams) for Motorcycles
= 0.044345 + (0.006134 * Vehicle_Age)
+ (0.000859 * Temperature)

EPA proposes to use this equation to estimate the hourly resting loss emissions from motorcycles.

8.6 Pre-Control Vehicles

Non-California vehicles prior to the 1972 model year were not required to meet an evaporative emission standard. These uncontrolled vehicles would simply vent vapors to the atmosphere as pressure built up. Since that situation is similar to that of a controlled vehicle with a vapor leak, we hypothesized that the resting loss and diurnal evaporative emissions of the pre-1972 vehicles would be comparable to the emissions of the pre-1980 vehicles that had failed the pressure test.

To characterize the hourly resting loss emissions from these pre-control vehicles, we proceeded in a similar fashion to the approach in Section 8 of M6.EVP.001. We first identified the <u>two</u>

pre-1980 vehicles in our study that both had failed the pressure test and were tested over the full range of fuels and temperature cycles. Possibly due to that small sample size, a regression of those data produced a slope of resting loss versus temperature that was not statistically different from zero. Since most of the RTD tests (i.e., 37 of 47) that were performed on the 34 candidate vehicles were run over the same temperature cycle (i.e., 72 to 96 degrees), the variable "temperature" would not make a useful independent variable to analyze those 47 resting loss results. We, therefore, decided to use the same slope (0.002812) that was developed in that earlier report. However, the variable "age" was found to be statistically significant. Combining the results of regressing the data against age with the previously calculated temperature slope yields the following equation:

$$\begin{aligned} \textbf{Hourly Resting Loss (grams)} = & -0.768438 \\ & + (0.002812 * \textbf{Temperature}) \\ & + (0.040528 * \textbf{Vehicle Age in Years}) \end{aligned}$$

EPA proposes to use this equation to estimate the hourly resting loss emissions from pre-control vehicles.

To characterize the full day's diurnal emissions from these pre-control vehicles, we proceeded in a similar fashion to the approach in the previous report. In the preceding paragraph we noted that only two of the candidate vehicles (i.e., pre-1980 vehicles that failed the pressure test) were tested over the full range of fuels and temperature cycles. Attempting to analyze the resting loss emissions of those two vehicles as a function of temperature did not produce usable results. However, the corresponding analysis for diurnal emissions as a function of the vapor pressure product term produced satisfactory results, as shown in Table 8-3.

Table 8-3

Regression of Diurnal Emissions
(Simulated Pre-Control Fleet)
(Based on Two Vehicles)

Dependent variable is: **Diurnal**
No Selector

R squared = 92.3% R squared (adjusted) = 90.4%
s = 5.503 with 6 - 2 = 4 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	1456.41	1	1456.41	48.1
Residual	121.136	4	30.284	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-6.52265	6.175	-1.06	0.3504
VP_Product	0.05115	0.0074	6.93	0.0023

As previously stated, the diurnal emissions from these tests are almost exclusively from tests performed over a single temperature cycle using a single fuel RVP (i.e., 6.8 psi RVP fuel over the 72 to 96 degree cycle). Thus, using a variable for vapor pressure with the full set of 47 tests would not be productive. However, as with the resting loss emissions, we used the preceding coefficient (0.05115) to estimate diurnal emissions (based on the vapor pressures) and then regressed the calculated residuals against vehicle age. These two regression analyses yield the following equation:

24-Hour Diurnal (grams) = -40.67512
+ (0.05115 * VP_Product_Term)
+ (1.41114 * Vehicle_Age_in_Years)

EPA proposes to use this equation to estimate the 24-hour diurnal emissions from pre-control vehicles.

For MOBILE6, EPA proposes to multiply the estimated 24-hour diurnal emissions from those vehicles (calculated from the above equation) by the percentages in Table 4-2 to predict the hourly diurnal emissions from those pre-control vehicles.

8.7 Duration of Diurnal Soak Period

The analyses in this report were based on diurnals of 24 hours or less in length. In the real-world, the soak period could run for longer periods of time. Estimating diurnal emissions when the soak period is a multiple of 24 hours will be analyzed in report number M6.EVP.003.

EPA's proposal on how to classify a diurnal that follows an interrupted diurnal is based on EPA's hypothesis of why a single-day diurnal is different from a multiple-day diurnal. EPA believes that as the days progress (during a multiple day diurnal), the vehicle's evaporative canister becomes more heavily loaded (with a possible back purge occurring during the night hours). Therefore, if the first day's less than full diurnal is almost equivalent to a 24-hour diurnal, EPA proposes to treat the subsequent days as if the first day's diurnal were a complete diurnal. From Appendix E, the regression equation predicts that (interrupted) diurnals that begin no earlier than 9 AM, produce less than one-half the emissions of the corresponding full day's diurnal. Therefore, If a vehicle's first day's incomplete diurnal begins no later than 8 AM, EPA proposes to treat the subsequent days as if the first day's diurnal were a complete diurnal.

8.8 1996 and Newer Model Year Vehicles

Starting with the 1996 model year, EPA began certifying some of the new LDGVs and LDGTs using the RTD test. Estimating the resting loss and diurnal emissions from these vehicles will be analyzed in report number M6.EVP.005.

For MOBILE6, EPA proposes to multiply the estimated 24-hour diurnal emissions from those vehicles (to be calculated in M6.EVP.005) by the percentages in Table 4-2 to predict the hourly diurnal emissions from those vehicles.

Appendix A

Temperature Cycles (°F)

Hour	---Temperatures Cycling Between --- 60°-84°F	72°-96°F*	82°-106°F	Change in Temperature
0	60.0	72.0	82.0	- - -
1	60.5	72.5	82.5	0.5
2	63.5	75.5	85.5	3.0
3	68.3	80.3	90.3	4.8
4	73.2	85.2	95.2	4.9
5	77.4	89.4	99.4	4.2
6	81.1	93.1	103.1	3.7
7	83.1	95.1	105.1	2.0
8	83.8	95.8	105.8	0.7
9	84.0	96.0	106.0	0.2
10	83.5	95.5	105.5	-0.5
11	82.1	94.1	104.1	-1.4
12	79.7	91.7	101.7	-2.4
13	76.6	88.6	98.6	-3.1
14	73.5	85.5	95.5	-3.1
15	70.8	82.8	92.8	-2.7
16	68.9	80.9	90.9	-1.9
17	67.0	79.0	89.0	-1.9
18	65.2	77.2	87.2	-1.8
19	63.8	75.8	85.8	-1.4
20	62.7	74.7	84.7	-1.1
21	61.9	73.9	83.9	-0.8
22	61.3	73.3	83.3	-0.6
23	60.6	72.6	82.6	-0.7
24	60.0	72.0	82.0	-0.6

* The temperature versus time values for the 72-to-96 cycle are reproduced from Table 1 of Appendix II of **40 CFR 86**.

These three temperature cycles are parallel (i.e., identical hourly increases/decreases). The temperatures peak at hour nine. The most rapid increase in temperatures occurs during the fourth hour (i.e., a 4.9° F rise).

For cycles in excess of 24 hours, the pattern is repeated.

Appendix B

Vapor Pressure

Using the Clausius-Clapeyron Relationship

The Clausius-Clapeyron relationship is a reasonable estimate of vapor pressure over the moderate temperature range (i.e., 60° to 106°F)* being considered for adjusting the diurnal emissions. This relationship assumes that the logarithm of the vapor pressure is a linear function of the reciprocal (absolute) temperature.

In a previous EPA work assignment, similar RVP fuels were tested, and their vapor pressures (in kilo Pascals) at three temperatures were measured. The results of those tests are given in the following table:

Nominal RVP	Measured RVP	Vapor Pressure (kPa) 75° F	100° F**	130° F
7.0	7.1	30.7	49.3	80.3
9.0	8.7	38.2	60.1	96.5

** The VPs at 100° F are the fuels' RVPs (in kilo Pascals).

Plotting these six vapor pressures (using a logarithm scale for the vapor pressure) yields the graph (Figure B-1) on the following page.

For each of those two RVP fuels, the Clausius-Clapeyron relationship estimates that, for temperature in degrees Kelvin, the vapor pressure (VP) in kPa will be:

$$\ln(VP) = A + (B / \text{Absolute Temperature}), \text{ where:}$$

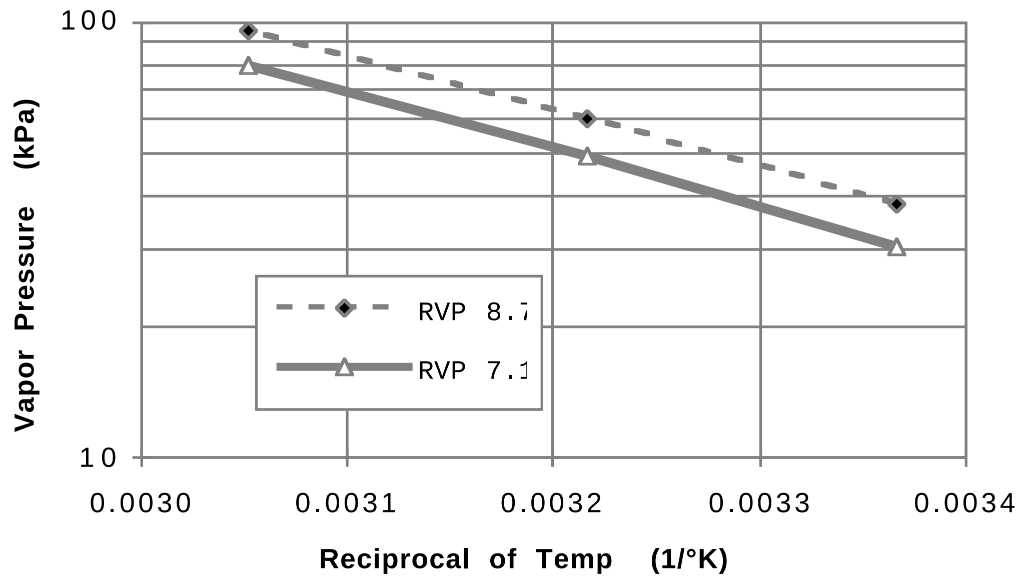
RVP	A	B
8.7	13.5791	-2950.47
7.1	13.7338	-3060.95

---

* C. Lindhjem and D. Korotney, "Running Loss Emissions from Gasoline-Fueled Motor Vehicles", SAE Paper 931991, 1993.

Figure B-1

Comparison of Vapor Pressure to Temperature



We will assume that the specific fuels used in the vehicles that were tested in this analysis had vapor pressure versus temperature curves similar to the curves for these to two test fuels. Extrapolating the trends in either the "A" or "B" values to fuels with nominal RVPs of 6.3, 7.0, and 9.0 psi; and then requiring the lines (in log-space) to pass through the appropriate pressures at 100°F, yields the linear equations with coefficients:

RVP	A	B
6.3	13.810	-3121.05
6.8	13.773	-3085.79
9.0	13.554	-2930.67

We will use the above to estimate vapor pressures for the 6.3, 6.8, and 9.0 psi RVP fuels.

In general, given the fuel RVP, we can approximate **A** and **B** with these equations:

$$\mathbf{B} = -3565.2707 + (70.5114 * RVP)$$

and

$$\mathbf{A} = \ln(6.89286 * RVP) - (\mathbf{B} / 310.9)$$

Appendix C

Modeling 24-Hour Diurnal Emissions As Functions of Vapor Pressure (kPa)

In each of the following 18 strata, 24-hour diurnal emissions modeled using a triple of numbers:

A
B
C. Where,

24-Hour Diurnal (grams) = A + B * [(Mean VP) * (Change in VP)] + C * [(Mean VP) * (Change in VP)]^3 / 1,000,000

Fuel Delivery	Model Year Range	Fail Pressure Test	Fail Only Purge Test	Pass Both Purge and Pressure
Carbureted	Pre-1980	11.4367 0 0.026810	8.8657 0 0.026810	4.63506 0 0.026810
	1980-1985	-4.6034 0.0374 0	6.9618 0 0.018974	3.0719 0 0.014217
	1986-1995*	9.9392 0 0.009876	10.0559 0 0.005993	4.5033 0 0.002850
Fuel Injected	Pre-1980**	11.4367 0 0.026810	8.8657 0 0.026810	4.63506 0 0.026810
	1980-1985	0.2134 0.0326 0	4.3700 0 0.006868	3.9001 0 0.004744
	1986-1995	4.7661 0 0.009876	5.7386 0 0.005993	2.0690 0 0.002850

* "**C**" value based on 1986-95 FI vehicles.

** The untested stratum of Pre-1980 FI vehicles was represented using the Pre-1980 model year carbureted vehicles.

Appendix D

Hourly RTD Emissions (in grams) of Gross Liquid Leakers

	-------- Vehicle Number --------							
Hour	**5002**	**5082**	**9049**	**9054**	**9087**	**9111**	**Mean**	**Modified***
1	4.56	2.23	11.88	10.99	27.67	55.95	18.88	10.48
2	4.71	2.41	8.79	11.24	28.50	46.77	17.07	12.45
3	6.12	3.18	10.24	9.78	24.65	44.26	16.37	16.37
4	7.93	4.00	11.74	13.05	25.98	44.32	17.84	17.84
5	9.55	4.63	11.62	14.28	25.06	45.49	18.44	18.44
6	11.29	5.14	11.19	14.69	24.61	47.67	19.10	19.10
7	9.41	5.39	10.99	14.00	25.70	48.07	18.93	18.93
8	9.78	5.11	9.74	16.08	25.22	47.46	18.90	18.90
9	7.14	4.73	9.04	15.05	24.21	42.41	17.10	17.10
10	6.06	4.36	8.02	14.06	23.36	43.84	16.62	16.62
11	5.35	4.30	7.42	14.85	20.95	36.43	14.88	14.88
12	4.18	4.10	6.91	15.53	19.67	33.72	14.02	14.02
13	3.66	3.51	6.91	14.93	18.50	32.96	13.41	13.41
14	3.08	2.76	6.25	15.03	17.58	25.79	11.75	11.75
15	2.89	2.55	5.63	14.60	16.57	21.55	10.63	10.63
16	2.83	2.23	5.78	13.93	16.31	21.24	10.39	10.39
17	2.97	2.22	5.09	16.37	13.59	20.46	10.12	10.12
18	2.76	2.20	4.91	14.65	15.29	19.64	9.91	9.91
19	2.91	2.18	4.93	11.54	13.86	17.60	8.84	8.84
20	2.82	2.09	4.89	11.30	13.46	16.85	8.57	8.57
21	3.01	2.06	4.70	11.12	13.69	16.52	8.52	8.52
22	3.06	2.09	5.02	9.89	13.62	15.89	8.26	8.26
23	3.01	1.97	4.78	10.36	13.04	15.82	8.16	8.16
24	2.96	2.13	4.88	9.28	17.05	16.40	8.78	8.78

* Mean emissions for the first two hours have been "**MODIFIED**" to fit the pattern specified in Section 7.3.

Appendix E

Estimating Hourly Interrupted Diurnal Emissions

Diurnal Begins

Time:	6 AM*	7 AM	8 AM	9 AM	10 AM	11 AM	Noon	1 PM	2 PM
Temperature:	72.0°	72.5°	75.5°	80.3°	85.2°	89.4°	93.1°	95.1°	95.8°

Diurnal Ends

Time:	6:00AM	5:10AM	1:16AM	10:18PM	8:06PM	6:44PM	5:25PM	4:17PM	3:24PM
Duration (hr):	24.000	22.167	17.273	10.111	10.111	7.742	5.417	3.286	1.400

	Time od Day	**Proportion of Full Day's Diurnal Allocated to Each Hour**								
1	**6-7AM**	1.89%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
2	**7-8AM**	2.45%	1.98%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
3	**8-9AM**	5.13%	5.09%	3.34%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
4	**9-10AM**	8.36%	8.65%	6.42%	3.43%	**0%**	**0%**	**0%**	**0%**	**0%**
5	**10-11AM**	11.24%	11.26%	8.82%	5.49%	2.81%	**0%**	**0%**	**0%**	**0%**
6	**11AM - Noon**	13.78%	13.79%	11.14%	7.47%	4.44%	2.43%	**0%**	**0%**	**0%**
7	**Noon - 1PM**	14.93%	12.57%	10.15%	6.86%	4.21%	2.53%	1.49%	**0%**	**0%**
8	**1-2PM**	13.08%	10.69%	8.53%	5.64%	3.42%	2.09%	1.37%	1.15%	**0%**
9	**2-3PM**	9.85%	9.88%	7.83%	5.11%	3.05%	1.87%	1.28%	1.13%	1.11%
10	**3-4PM**	6.69%	8.20%	6.36%	3.99%	2.29%	1.42%	1.09%	1.09%	**0%**
11	**4-5PM**	4.31%	5.72%	4.23%	2.41%	1.29%	0.90%	1.00%	**0%**	**0%**
12	**5-6PM**	2.97%	2.93%	1.91%	0.84%	0.47%	0.73%	1.41%	**0%**	**0%**
13	**6-7PM**	2.09%	0.95%	0.38%	0.04%	0.41%	1.31%	**0%**	**0%**	**0%**
14	**7-8PM**	1.32%	0.37%	0.08%	0.19%	1.03%	**0%**	**0%**	**0%**	**0%**
15	**8-9PM**	0.75%	0.44%	0.30%	0.64%	**0%**	**0%**	**0%**	**0%**	**0%**
16	**9-10PM**	0.53%	0.87%	0.70%	1.01%	**0%**	**0%**	**0%**	**0%**	**0%**
17	**10-11PM**	0.35%	0.73%	0.74%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
18	**11PM - Midnite**	0.26%	0.74%	0.90%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
19	**Midnite - 1AM**	0.00%	0.00%	0.00%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
20	**1- 2AM**	0.00%	0.00%	0.00%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
21	**2-3AM**	0.00%	0.00%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
22	**3-4AM**	0.00%	0.00%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
23	**4-5AM**	0.00%	0.00%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
24	**5-6AM**	0.00%	0.00%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

Percentage of Full Day's Diurnal Emissions:

100.0%	94.9%	71.8%	43.1%	23.4%	13.3%	7.6%	3.4%	1.1%

Number of Hours of Positive Diurnal Emissions:

18	17	16	13	10	8	6	3	1

* The diurnal that begins at 6 AM is the full (24-hour) diurnal.

Appendix F

Modeling Hourly Resting Loss Emissions As Functions of Temperature (°F)

In each of the following 12 strata, resting loss emissions (i
per hour) are modeled using a pair of numbers (A and B), where

Hourly Resting Loss (grams) = A + (B * Temperature in °F)

B = 0.002812 (for ALL strata) and

"A" is given in the following table:

Fuel Delivery	Model Year Range	Pass Pressure Test	Fail Pressure Test
Carbureted	Pre-1980	0.05530	0.07454
	1980-1985	-0.05957	-0.02163
	1986-1995	-0.07551	0.05044
Fuel Injected	Pre-1980*	0.05530	0.07454
	1980-1985	-0.09867	0.02565
	1986-1995	-0.14067	-0.10924

* The untested stratum (Pre-1980 FI vehicles) was represented using the Pre-1980 model year carbureted vehicles. (See report M6.EVP.001 for additional details.)

These equations can then be applied (in each stratum) to each of the hourly temperatures in Appendix A to obtain the resting loss emissions released in a 24 hour period. If we use an alternate temperature profile in which the hourly change in temperature is proportional to the cycles in Appendix A, we find that:

24-Hour Resting Loss (grams) = (24 * A) + (B * C)

Where **A** and **B** are given above, and where

C = 0.002632 + (24 * Low Temperature) + (11.3535 * Temperature Change)