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- Draft -

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

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ABSTRACT

Evaporative emissions due to changes in ambient temperature are an important source of hydrocarbons. These diurnal emissions were described as daily averages in an earlier report (M6.EVP.001). The current report proposes a model for distributing these emissions among the hours of the day. This document reports on both the methodology used to analyze data from real-time diurnal (RTD) tests on 270 vehicles and the results from those analyses. 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) 214-4939, or by mail to "MOBILE6 Review Comments", US EPA Assessment and Modeling Division, 2000 Traverwood Drive, 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.

An earlier draft of this document was released and posted on May 21, 1998 for stakeholder review. Comments were accepted for sixty (60) days, ending July 18, 1998. In response to those comments, we made substantial revisions to both our methodology and to this document.

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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,* 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 in Figure 1-1; however, most of the testing was performed using the 72 to 96 degree cycle.** In that 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 are delayed and do not start until after the daily temperature rise has already begun.

As illustrated in Figure 1-1, 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. Over the course of the remaining 15 hours, the temperature slowly returns to the daily low temperature. The three hourly temperature cycles used in this study are given in Appendix A. The most rapid increase in temperatures occurs during the fourth

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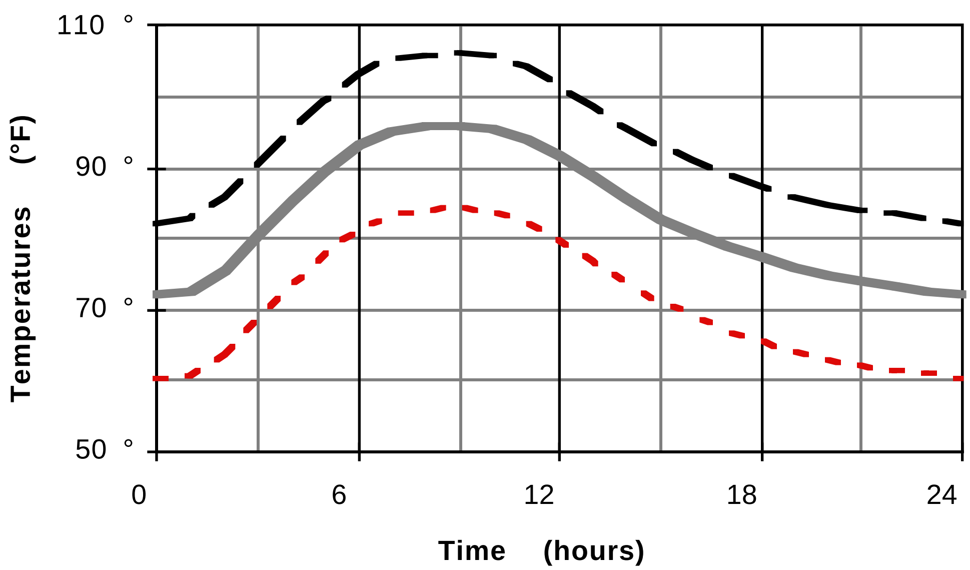
* Report numbered M6.EVP.001 is entitled "Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests."

** 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, entitled "Evaluating Multiple Day Diurnal Evaporative Emissions Using RTD Tests."

hour. For RTD tests that exceed 24 hours, the cycle is simply repeated. (Estimating the effects of alternate temperature profiles is discussed in Section 6.3.)

Figure 1-1

Temperature Cycles for Real-Time Diurnal (RTD) Testing



The previous document analyzed RTD test results from 270 vehicles. In this document, we analyze the hourly results from those same tests. This document reports on both the methodology used to analyze the data from these RTD tests and the results obtained from those analyses.

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 between 6 and 7 AM, while the maximum daily temperature typically occurred between 3 to 5 PM. Obviously, the local temperature curve depends on local conditions. However, for MOBILE6, EPA proposes to combine the GM and MOBILE5 time estimates and to assign the daily low temperature to 6 AM, and the daily high temperature to at 3 PM. Applying this proposal to the temperature cycles in Appendix A results in having the time zero correspond with 6 AM.

2.0 Stratifying the Test Fleet

It was necessary to stratify the test fleet for two reasons. First, different mechanisms are involved in producing the diurnal emissions for different groups of vehicles, thus, necessitating different analytical approaches. Second, the recruitment of test vehicles was intentionally biased to allow testing a larger number of vehicles that most likely had problems with their evaporative control systems. This stratified recruitment resulted in the necessity of separate analyses within each of the recruitment strata.

The test data used for these hourly analyses are the same data used in the aforementioned EPA draft report. 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" (i.e., 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, those two groups were analyzed separately in both reports.

The two testing parameters in the EPA programs that were found (in M6.EVP.001) to affect the 24-hour 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 24-hour 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 EPA 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).*

This stratification was used in both the analysis of the 24-hour diurnal emissions and in this current analysis (see Section 4.0).

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 (i.e., less than three percent).

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

* For only one of the fuel delivery system/model year range groupings (i.e., pre-1980 carbureted vehicles) were 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.

carbureted vehicles. This should be a reasonable assumption since any actual differences between the emissions of 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 actually measure the combination (sum) of two types of evaporative emissions:

1) "Resting loss" emissions are always present and 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 ambient temperature.

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

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

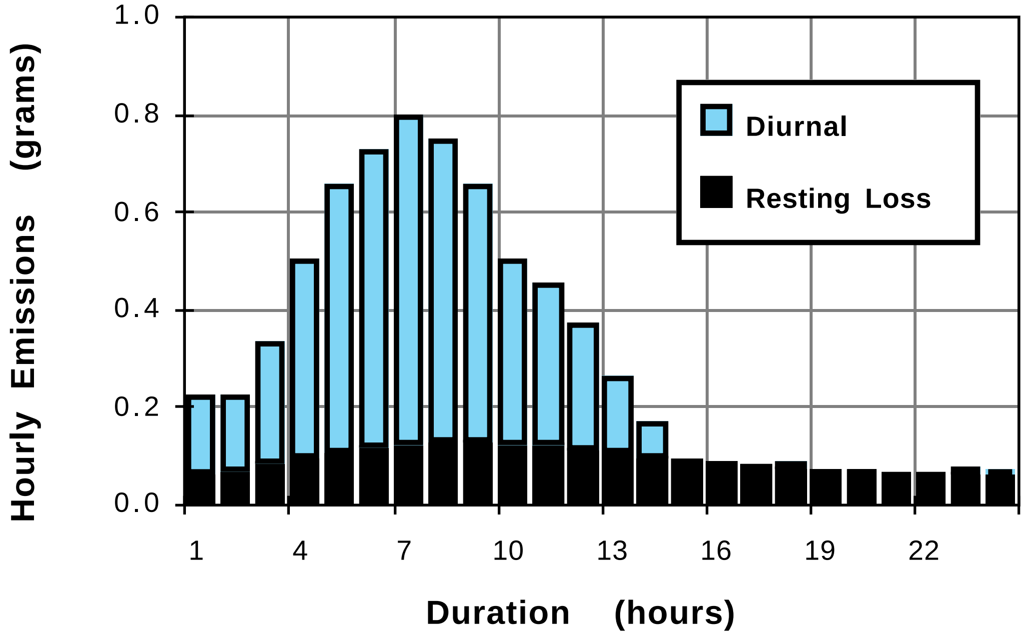
   The 24-hour diurnal emissions were calculated by first adjusting the resting loss value for each hour's ambient temperature, and then subtracting that temperature-adjusted resting loss estimate from the full 24-hour RTD test results.

A special case of each of these two categories consists of evaporative emissions from vehicles that have significant leaks of liquid gasoline. We defined these "gross liquid leakers" as vehicles with resting loss emissions exceeding 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 <u>not</u> gross liquid leakers. For this example, we averaged the RTD hourly results from 69 1986-95 model year, FI vehicles that had passed both the pressure and purge tests. All were tested over the 72° to 96° cycle using a 6.8 RVP gasoline. We then plotted the temperature-adjusted hourly resting loss and diurnal emissions.

Figure 3-1

An Example of Hourly RTD Emissions



This example represents the hourly resting loss and diurnal emissions of the mean of a single stratum. Each combination of the five parameters discussed in Section 2.0 can produce a different graph. 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 construct 86 graphs for which there are any data (58 are based on the average of no more than four RTD tests). EPA chose to consolidate those strata into the smaller number of groups that were actually used. The selection of both the categorical variables (used to form the strata) and the analytical variables is discussed in the following section.

4.0 Hourly Diurnal Emissions

4.1 Characterizing Hourly Diurnal Emissions by Strata

In Table 4-1 (below), to normalize the hourly diurnal emissions (which can vary substantially), we divided each hour's diurnal emissions by the full (i.e., total 24-hour) diurnal

Table 4-1

Distribution of Hourly Diurnal Emissions Within the Strata Containing at Least 10 Tests

Purge / Pressure Category	temp cycle	MYR Range	Fuel Meter	Cnt	RVP	--- Hour During Which --- Total Hourly Reaches Percent of Full-Day 25%	50%	75%	Max Diurnal Occur
Fail ONLY Purge	60.TO.84	86-95	FI	12	6.8	3.90	5.40	7.38	5
		86-95	FI	17	9.0	4.16	5.89	7.86	6
	72.TO.96	80-85	CARB	11	6.8	4.24	6.50	8.83	7
		86-95	FI	19	6.8	3.52	5.50	7.65	6
		86-95	FI	17	9.0	4.50	6.35	8.02	7
	82.TO.106	86-95	FI	16	6.8	3.99	5.74	7.70	6
		86-95	FI	12	9.0	5.01	6.71	8.58	7
Fail Pressure	60.TO.84	86-95	FI	11	6.8	4.06	5.73	7.54	7
		86-95	FI	19	9.0	4.08	5.60	7.15	6
	72.TO.96	Pre-80	CARB	33	6.8	4.39	6.28	8.35	6
		80-85	CARB	10	6.8	4.18	6.04	8.10	6
		86-95	FI	20	6.8	4.31	6.04	8.09	6
		86-95	FI	19	9.0	4.37	6.06	7.84	6
	82.TO.106	86-95	FI	17	6.8	4.26	5.98	7.79	7
		86-95	FI	12	9.0	4.57	6.29	7.90	7
Passing Both	60.TO.84	86-95	FI	16	6.8	4.06	7.10	9.73	8
		86-95	FI	32	9.0	5.49	7.88	10.36	8
	72.TO.96	Pre-80	CARB	11	6.8	6.32	8.46	10.85	8
		80-85	CARB	38	6.8	4.98	7.00	9.19	7
		86-95	CARB	10	6.8	5.36	7.72	10.10	9
		86-95	FI	70	6.8	4.62	6.73	8.98	7
		86-95	FI	31	9.0	6.43	8.36	10.46	8
	82.TO.106	86-95	FI	25	6.8	4.59	6.97	9.56	7
		86-95	FI	22	9.0	6.73	8.06	9.72	8

emissions within each of the strata described in Section 3.0. Twenty-four of those strata were represented by at least ten tests. Within each of those 24 strata, we estimated (by interpolation) the time at which the cumulative hourly diurnal emissions totaled 25, 50, and 75 percent of the full-days diurnal emission. We also identified the test hour during which the day's highest (i.e., peak) hourly diurnal emission occurred. No attempt was made (in Table 4-1) to estimate the overall mean values.

A visual inspection of these results in Table 4-1 suggests that:

- These strata do not yield a complete representation of the various technologies (i.e., not all of the combinations of fuel delivery systems and model year ranges are present), specifically:

    - • The only strata containing fuel injected vehicles are exclusively composed of the 1986-95 model year vehicles.

    - • The only strata containing the Pre-1980 or the 1980-85 model year vehicles are exclusively composed of the carbureted vehicles.

  Thus, we cannot treat as independent variables both the type of fuel delivery system and the model year range. Therefore, EPA proposes to select the type of fuel delivery system (i.e., carbureted versus fuel injected) as the stratifying variable.

- The emissions distribution as indicated by the "four critical times" (i.e., the number of hours into the tests that the maximum hourly diurnal emissions occur as well as the number of hours into the tests necessary for the cumulative hourly diurnal emissions to total 25, 50, and 75 percent of the full 24-hour diurnal) appear to be effected by both the temperature cycle and the fuel RVP, specifically:

    - • The higher temperature cycles often correspond (but not consistently) with a delay in the occurrence of some of the four critical times in the distributions.

    - • For the strata of vehicles that passed the pressure test (either "Fail ONLY Purge" or "Passing Both"), a higher fuel RVP corresponds with delaying the occurrence of all four critical times in the corresponding distributions.

In the earlier analyses (M6.EVP.001), EPA used the RVP to estimate the vapor pressure (VP) of the fuel at each point in the temperature cycle. If we calculate the mean of the VP at the highest and lowest temperatures, then that midpoint value incorporates both the temperature cycle and the fuel RVP. EPA proposes to use that value (in kiloPascals) as one of the potential variables. (This variable serves to distinguish among the three temperature cycles in Appendix A. If RTD testing is performed over different cycles, then this variable may need to be modified.)

- There appears to be differences among the three purge / pressure categories, specifically:

  - • • As noted above, the four critical times in the distributions appear to be affected by the fuel RVP in the strata that passed the pressure test. However, for the strata of vehicles that failed the pressure test, those times are fairly insensitive to differences in fuel RVP.

  - • • For the strata of vehicles that passed both the purge and pressure tests, the occurrence of all four critical times in the corresponding distributions are delayed (relative to the strata of vehicles the failed only the purge test).

  Based on these observations, EPA proposes to estimate the hourly diurnal emissions separately for each of the three purge / pressure categories.

Therefore, EPA proposes to model the hourly diurnal emissions (as percentages of the full day diurnal):

- separately for the category of "gross liquid leakers" (see Section 4.2.3),
- separately for each of the six combinations of fuel delivery system (i.e., fuel injected versus carbureted) and purge / pressure category,
- using VP to distinguish among the temperature cycles and the fuel RVP (for vehicles that are not "gross liquid leakers"), and
- using variables that describe the change in ambient temperature (discussed on the following page).

These proposals result in modeling the hourly diurnal emissions separately within each of the following seven strata:

1) carbureted vehicles (**not** "gross liquid leakers") that pass both the purge and pressure tests,
2) carbureted vehicles (**not** "gross liquid leakers") that fail the pressure test,
3) carbureted vehicles (**not** "gross liquid leakers") that fail only the purge test,
4) FI vehicles (**not** "gross liquid leakers") that pass both the purge and pressure tests,
5) FI vehicles (**not** "gross liquid leakers") that fail the pressure test,
6) FI vehicles (**not** "gross liquid leakers") that fail only the purge test, and
7) the vehicles classified as "gross liquid leakers" (see Section 4.2.3).

Those seven strata can be illustrated in the following table. The numbering of the cells within the table (**1** through **7**) coincides with both the numbering in the preceding list as well as with the numbering of the seven equations in Section 4.2.

	Passing Both Purge and Pressure	Failing the Pressure Test	Failing ONLY the Purge Test	Gross Liquid Leakers
Carbureted	**(1)**	**(2)**	**(3)**	**(7)**
Fuel Injected	**(4)**	**(5)**	**(6)**	

As stated in Section 3.0, the diurnal emissions are the pressure-driven emissions resulting from the daily increase in the temperature of both the fuel and the vapor. Although the fuel temperature is not a readily available variable, it does follow the daily cycle of the ambient temperature. On 80 of the 119 vehicles that EPA tested using the RTD cycles, EPA measured both the ambient temperature and the fuel tank temperature. We then shifted the graph of the tank temperatures to minimize the sum of the squares of the temperature differences. The amounts of those shifts are the times (in minutes) by which the fuel tank temperatures lagged behind the corresponding ambient temperatures. Those shifts are given below:

Ambient Temperature Cycle	Lag Time (minutes)
60 to 84° Cycle	44.4
72 to 96° Cycle	67.0
82 to 106° Cycle	108.4

Since the changes in fuel temperature can lag by one to two hours behind the corresponding changes in the ambient temperature, EPA considered the following three variables (and multiplicative combinations of them to allow for interactions) in modeling the hourly diurnal emissions:

- the change in ambient temperature during that specific hour,
- the change in ambient temperature during the previous hour, and
- the total change in temperature from the start of the cycle until the start of the previous hour.

Since all three of those temperature terms are actually differences of temperatures, it was not necessary to convert the temperature units from Fahrenheit to an absolute temperature. For the three temperature cycles used, these three temperature variables are given in Appendix A.

4.2 Calculating Hourly Diurnal Emissions by Strata

EPA proposes to estimate the mean hourly diurnal emissions by multiplying the full day's diurnal emissions (estimated in the previous report (M6.EVP.001 and reproduced in Appendix C) by the hourly percentages predicted in Sections 4.2.1 through 4.2.3 of this report.

4.2.1 Carbureted Vehicles

As noted in the discussion associated with Table 4-1, within each of the various strata of carbureted vehicles, the only combination of temperature cycle and fuel RVP represented by at least 10 tests was that of the 72 to 96 degree cycle using the 6.8 RVP fuel. That condition persisted even after eliminating the model year groupings as a stratifying factor. EPA, therefore, had the option of either performing analyses based on a small number of carbureted vehicles or applying the results of the analyses of the FI vehicles directly to the carbureted vehicles. EPA decided to proceed using the limited test results on carbureted vehicles. The distribution of the tests is given on the following page in Table 4-2.

Table 4-2

Distribution of RTD Tests of Carbureted Vehicles

Purge/Pressure Category	temperature cycle	RVP	Number of Tests
Fail ONLY Purge	60 to 84	6.8	4
		9.0	6
	72 to 96	6.8	19
		9.0	6
	82 to 106	6.8	5
		9.0	4
Fail Pressure	60 to 84	6.8	4
		9.0	8
	72 to 96	6.8	45
		9.0	8
	82 to 106	6.8	6
		9.0	4
Passing Both	60 to 84	6.8	4
		9.0	9
	72 to 96	6.8	59
		9.0	9
	82 to 106	6.8	6
		9.0	4

EPA chose to use stepwise* linear regressions to identify the variables that were the most influential in determining the shape of the hourly diurnal emissions. The mean hourly diurnal emissions were calculated within each of the 18 sub-stratum determined by the purge/pressure category, the temperature cycle, and fuel RVP. The emissions were positive for hours one through 18, and were zero for hours 19 through 24. The emissions for each hour were divided by the full (i.e., total 24-hour) diurnal emissions to calculate the percentage (ratio) of the total diurnal the percentage for hour 19 always zero). Therefore, each

* The stepwise regression process first uses the Pearson Product-Moment to select the independent variable that has the highest correlation with the "**Ratio of Hourly Diurnal**." The difference between the best linear estimate using that variable and that "**Ratio of Hourly Diurnal**" (i.e., the residuals) is then compared with the set of remaining variables to identify the variable having the next highest correlation. This process continues as long as the "**prob**" values do not exceed 5%, thus, creating a sequence of variables in descending order of statistical correlation.

purge/pressure stratum contained 19 hourly percentages for each of six combinations of temperature cycles and fuel RVP (for a total of 114 results). Within each purge/pressure stratum, a stepwise linear regression of those 114 hourly diurnal ratios was performed to estimate the "**Ratio of Hourly Diurnal**" as a linear function of the temperature variables (from page 10) and multiplicative combinations of them, as well as, multiplicative combinations of them with the VP term (calculated as the midpoint of the VP at the highest and lowest temperatures of the day in kiloPascals). The stepwise regression process produced the following three equations that predict the ratios of hourly diurnal emissions from **carbureted** vehicles:

For **Carbureted Vehicles Passing Both Purge and Pressure Tests:** **(1)**

Ratio of Hourly Diurnal = 0.007032

**+ 0.000023 * [(Midpoint VP) *
(Change in Ambient During Previous Hr)
(Change in Ambient Prior to Previous Hr)]**

+ 0.003586 * (Change Prior to Previous Hr)

- 0.001111 * (Sqr of Change During Previous Hr)

For **Carbureted Vehicles Failing the Pressure Test:** **(2)**

Ratio of Hourly Diurnal = 0.010549

**+ 0.001138 * [(Change During Previous Hr) *
(Change in Ambient Prior to Previous Hr)]**

+ 0.001758 * (Change Prior to Previous Hr)

+ 0.001765 * (Sqr of Change During Current Hr)

For **Carbureted Vehicles Failing ONLY the Purge Test:** **(3)**

Ratio of Hourly Diurnal = 0.006724

**+ 0.000023 * [(Midpoint VP) *
(Change in Ambient During Previous Hr)
(Change in Ambient Prior to Previous Hr)]**

+ 0.003966 * (Change Prior to Previous Hr)

- 0.001122 * (Sqr of Change During Previous Hr)

**+ 0.000019 * [(Midpoint VP) *
(Sqr of Change During Current Hr)]**

**- 0.000018 * [(Midpoint VP) *
(Change Prior to Previous Hr)]**

More details can be found in Appendix D which contains the regression tables and graphs comparing the actual and predicted hourly ratios. The solid lines in each of the graphs in Appendix D are not regression lines; they are unity lines. (That is, if the predicted values exactly matched the actual values, then the points of predicted versus actual pairs would exactly lie on those lines.) EPA proposes to use equations (1) through (3) to predict the ratios of hourly diurnal emissions of the carbureted vehicles that were not gross liquid leakers. EPA then proposes to multiply those percentages by the full (24-hour) diurnals estimated by using the corresponding equations in Appendix C to obtain the hourly emissions (in grams of HC).

4.2.2 Strata of FI Vehicles

The distribution of the tests of fuel injected vehicles is given below in Table 4-3. This table is similar to the previous table on the distribution of the tests of carbureted vehicles (Table 4-2).

Table 4-3

Distribution of RTD Tests of FI Vehicles

Purge/Pressure Category	temperature cycle	RVP	Number of Tests
Fail ONLY Purge	60 to 84	6.8	15
		9.0	21
	72 to 96	6.8	21
		9.0	21
	82 to 106	6.8	18
		9.0	16
Fail Pressure	60 to 84	6.8	13
		9.0	21
	72 to 96	6.8	23
		9.0	21
	82 to 106	6.8	18
		9.0	14
Passing Both	60 to 84	6.8	17
		9.0	33
	72 to 96	6.8	73
		9.0	33
	82 to 106	6.8	26
		9.0	22

For the strata of fuel injected vehicles, the analytical approach was similar to that used for the carbureted vehicles. That is, the mean hourly diurnal emissions were calculated within each of the 18 sub-stratum determined by the purge/pressure category, the temperature cycle, and fuel RVP. The emissions were positive for hours one through 18, and were zero for hours 19 through 24. The percent of the total diurnal emissions represented by each hour was calculated for hours one through 19 (with the percentage for hour 19 always zero). Therefore, each purge/pressure stratum contained 19 hourly percentages for each of six combinations of temperature cycles and fuel RVP (for a total of 114 results).

Within each of the three purge/pressure strata, a stepwise linear regression of those 114 hourly diurnal ratios was performed to estimate the "**Ratio of Hourly Diurnal**" as a linear function of the temperature variables (from page 10) and multiplicative combinations of them, as well as, multiplicative combinations of them with the VP term (calculated as the midpoint of the VP at the highest and lowest temperatures of the day in kiloPascals). The stepwise regression process produced the following three equations that predict the ratios of hourly diurnal emissions from **fuel injected** vehicles:

For **Fuel Injected Vehicles Passing Both Purge and Pressure Tests:** **(4)**

Ratio of Hourly Diurnal = 0.008001

+ 0.001961 * (Change Prior to Previous Hr)

+ 0.000535 * [(Change During Previous Hr) * (Change in Ambient Prior to Previous Hr)]

- 0.000060 * [(Midpoint VP) * (Sqr of Change During Previous Hr)]

+ 0.005964 * (Change During Current Hr)

+ 0.000056 * [(Midpoint VP) * (Change in Ambient Prior to Previous Hr)]

For **Fuel Injected Vehicles Failing the Pressure Test:** **(5)**

Ratio of Hourly Diurnal = 0.006515

+ 0.001194 * [(Change During Previous Hr) * (Change in Ambient Prior to Previous Hr)]

+ 0.001963 * (Change Prior to Previous Hr)

+ 0.001329 * (Sqr of Change During Current Hr)

+ 0.000574 * (Sqr of Change During Previous Hr)

For **Fuel Injected Vehicles Failing ONLY the Purge Test:** **(6)**

Ratio of Hourly Diurnal = 0.007882

+ 0.000855 * [(Change During Previous Hr) * (Change in Ambient Prior to Previous Hr)]

+ 0.000084 * [(Midpoint VP) * (Change in Ambient Prior to Previous Hr)]

+ 0.006960 * (Sqr of Change During Current Hr)

- 0.000160 * [(Midpoint VP) * (Sqr of Change During Current Hr)]

- 0.001172 * (Change Prior to Previous Hr)

+ 0.000118 * [(Midpoint VP) * (Change in Ambient During Current Hr)]

+ 0.000825 * (Sqr of Change During Previous Hr)

More details can be found in Appendix D which contains the regression tables and graphs comparing the actual and predicted hourly ratios. The solid lines in each of the graphs in Appendix D are unity lines. (That is, if the predicted values exactly matched the actual values, then the points of predicted versus actual pairs would exactly lie on those lines.) EPA proposes to use equations **(4)** through **(6)** to predict the ratios of hourly diurnal emissions of the fuel injected vehicles that were not gross liquid leakers.

In the observations following Table 4-1, it was noted that the shape of the hourly distribution curve (i.e., the ratios not the actual magnitude) for FI vehicles that failed the pressure test seemed insensitive to changes in the fuel RVP. The regression in Appendix D confirms that observation. The regression table indicates that more than 95 percent of the variability in the hourly diurnal emissions can be explained using only the variables involving changes in the temperature. (A similar condition holds true for carbureted vehicles that failed the pressure test.)

4.2.3 "Gross Liquid Leaker" Vehicles

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

- the large differences in both 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 4.2.1 and 4.2.2 were repeated for the vehicles identified as being gross liquid leakers. The hourly RTD results for those test vehicles are given in Appendix E. 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 E, we attempt to compensate (as explained in the footnote in Appendix E) 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 which is the average RTD emissions of hours 19 through 24) from each hour's modified RTD emissions, and then dividing by the total diurnal to yield the hourly percentages in Table 4-4 on the following page.

Table 4-4

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 stepwise linear regression of those hourly diurnal ratios (for hours 1 through 19) was performed to estimate the "**Ratio of Hourly Diurnal**" as a linear function of the temperature variables (from page 10) and multiplicative combinations of them, as well as, multiplicative combinations of them with the VP term (calculated as the midpoint of the VP at the highest and lowest temperatures of the day in kiloPascals). The stepwise regression process produced the following equation that predict the ratios of hourly diurnal emissions from vehicles with **gross liquid leaks**:

For **"Gross Liquid Leaker" Vehicles:** **(7)**

Ratio of Hourly Diurnal = 0.021349

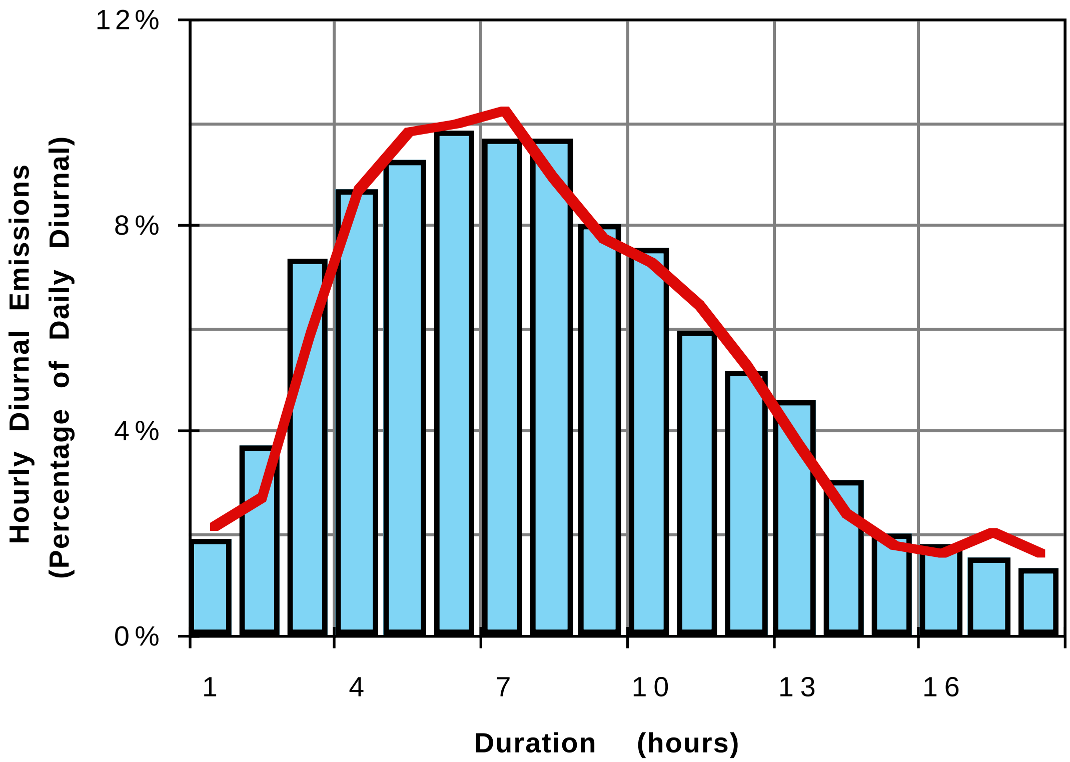
+ 0.010137 * (Change During Previous Hr)

+ 0.002065 * (Change Prior to Previous Hr)

More details can be found in Appendix D which contains the regression table and graph comparing the actual and predicted hourly ratios. A second graph comparing the actual and predicted hourly ratios appears in Figure 4-1 in which equation **(7)** is plotted as a solid line and the data from Table 4-4 as a bar chart. Based on those two graphs which depict close matches between the predicted and actual ratios of hourly diurnal emissions, EPA proposes to use equation **(7)** to predict the ratios of hourly diurnal emissions of the gross liquid leakers.

Figure 4-1

Distribution of Hourly Diurnal Emissions from "Gross Liquid Leakers"



In the earlier report (from Section 10.2 of M6.EVP.001), it was determined that the mean 24-hour diurnal emissions from "gross liquid leakers" (for any of the three temperature cycles in Appendix A and independent of the fuel RVP) was 104.36 grams. Multiplying the hourly ratios in equation **(7)** by that value produces, on the following page, equation **(7a)** which predicts the mean hourly diurnal emissions (in grams of HC) for vehicles that are gross liquid leakers.

For **"Gross Liquid Leaker" Vehicles:** **(7a)**

Hourly Diurnal Emissions (grams of HC) =

+ 2.22798

+ 1.057897 * (Change During Previous Hr)

+ 0.215503 * (Change Prior to Previous Hr)

In that earlier report, we predicted the full 24-hour diurnal emissions from vehicles that were <u>not</u> gross liquid leakers for all temperature cycles in which the hourly changes in temperatures are proportional to the cycles in Appendix A. Unfortunately, the corresponding data on the "gross liquid leakers" were limited (i.e., practically all of the tests were performed using the same temperature cycle), and we did not make similar predictions for the gross liquid leakers. However, if we apply equation **(7a)** to each hour of any temperature cycle (with the hourly changes in temperatures proportional to the cycles in Appendix A) and then add these hourly predictions together, we obtain equation **(7b)**:

Total 24-Hour Diurnal Emissions (grams) **(7b)**

= 40.10367 + (2.616201 * Diurnal_Temperature_Range)

Where the **Diurnal_Temperature_Range** is the difference of the daily high temperature minus the daily low temperature.

Note, equation **(7b)** predicts a 24-hour total diurnal emission of 40.10 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 for gross liquid leakers as increasing linearly from zero to 66.27 grams (i.e., the value predicted by the equation for a diurnal temperature range of 10 degrees).

Of the seven regression analyses performed (and displayed in Appendix D), the simplest equation (in terms both of number of variables and complexity of the variables) is the equation that predicts the hourly diurnal emissions of gross liquid leaking vehicles. This most likely results from the simplicity of the primary mechanism that produces the emissions for the vehicles in this stratum (i.e., a significant leakage of liquid fuel).

4.2.4 Summarizing All Strata

Examining the seven stepwise regression analyses in Appendix D (one for each of the strata identified on page 10), we note that not every possible variable described on page 11 (along with their multiplicative combinations) were found to be statistically significant in one or more of those analyses; only 11 variables and products of variables were found to be statistically significant:

- Delta (change) in previous hour's temperature,
- Delta (change) in current hour's temperature,

- Total (change in temperature) prior to previous hour,
- Square of the delta in previous hour's temperature,
- Square of the delta in current hour's temperature,
- Product of the delta in previous hour's temperature times the total (change in temperature) prior to the previous hour,
- Product of the VP times the delta in current hour's temperature,
- Product of the VP times the total prior to the previous hour,
- Product of the VP times the square of the delta in previous hour's temperature,
- Product of the VP times the square of the delta in current hour's temperature, and
- Product of the VP times the delta in previous hour's temperature times the total prior to the previous hour.

On further examination of Appendix D, we note that some of those variables are statistically significant in most of the strata:

- The total (change in temperature) prior to the previous hour, possibly combined with its interaction (i.e., product) with the midpoint VP, is statistically significant in all seven strata.
- The product of the delta in previous hour's temperature times the total (change in temperature) prior to the previous hour, possibly combined with its interaction (i.e., product) with the midpoint VP, is statistically significant in the six strata that do not include gross liquid leakers.
- The square of the delta in the previous hour's temperature, possibly combined with its interaction (i.e., product) with the midpoint VP, is statistically significant in the five strata that do not include either gross liquid leakers or carbureted vehicles that failed the pressure test.
- The square of the delta in the current hour's temperature, possibly combined with its interaction (i.e., product) with the midpoint VP, is statistically significant in the four strata of vehicles that failed either the pressure or the purge test but which are not gross liquid leakers.

This "universality" of the variable "total (change in temperature) prior to the previous hour" will be the basis for a critical assumption in estimating interrupted diurnals (in Section 5.2)

5.0 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.

5.1 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, uses a 6.8 RVP fuel, and experiences a daily temperature profile of the standard 72° to 96° F cycle from Appendix A). For those conditions, we will assume the following vehicle activity:

1. The vehicle soaks overnight and into the early morning.

2. Shortly after 9 AM (corresponding to the fourth hour of the RTD test), the vehicle is driven for 30 minutes. The vehicle reaches its destination and is parked by 10 AM. (That is, the entire drive takes place during the fourth hour of the RTD test.)

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 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). 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 rose by about 20 degrees Fahrenheit*. After the vehicle stops and until this elevated fuel temperature drops to become equal to 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, in MOBILE the entire hot soak emissions will be credited to the first hour (see reports M6.EVP.004 and M6.FLT.004). Thus, in this example, from 11 AM to noon, only resting losses will be calculated.

4. At noon, we assume the fuel temperature has cooled to the ambient temperature of 93.1° F (from the temperature profile). The hourly diurnal emission will resume but in the modified form of an "interrupted diurnal" due to the effects of the drive on canister loading and fuel temperature. To modify the hourly diurnal emissions, we will make the following assumption:

   - The pressure that is driving the 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 not risen above 93.1° F, there would have been no further diurnal emissions for the remainder of that day, only resting loss emissions.

   - This suggests that the interrupted diurnal emissions will end once the ambient temperature returns to its starting point (i.e., 93.1° F in this example).

   - From the temperature profile, the ambient temperature will return to 93.1° at 5:25 PM. We will assume that after 5:25 PM, there are only resting loss emissions.

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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 duration, fuel tank temperature increases as a function of the trip duration. 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.

Therefore, we need to modify the estimated hourly diurnal emissions so that the modified values are zero after 6 PM (i.e., from test hour 13 through 24). In the following section (Section 5.2), EPA proposes a method of modifying the hourly diurnal emissions following such an interruption to the soak period.

5.2 Calculating Emissions of an Interrupted Diurnal

Based on the discussions in the preceding sections, EPA proposes to make the following three key assumptions in estimating interrupted diurnals:

- The ambient temperature at the beginning of the interrupted diurnal (i.e., the end of the hot soak) will be used as the starting temperature for that interrupted diurnal.
- In Section 4.2.4, we commented on the "universality" of the variable "total (change in temperature) prior to the previous hour." In those analyses of diurnals that were not interrupted, that variable was calculated by subtracting the daily low temperature (i.e., the starting temperature of the full day's diurnal) from the temperature at the start of the previous hour. EPA proposes for interrupted diurnals that the daily low temperature in that subtraction be replaced with that new starting temperature.
- The estimate of hourly diurnal emissions from that interrupted diurnal will be modified so that they cease once the ambient temperature drops below that new starting temperature.

In the preceding paragraphs, we analyzed one theoretical situation in which the diurnal emissions (following the morning drive) resumed at noon when the ambient temperature reached 93.1°F and, then, continued until the temperatures declined to that 93.1°F (at 5:25 PM). Using the 72° to 96° F temperature cycle given in Appendix A, we can repeat those calculations for interrupted diurnals that begin at each hour of the day. Those results appear in Table 5-1 (on the following page).

While the starting temperatures (the second column in Table 5-1) would vary with the daily temperature cycle, the time at which each (interrupted) diurnal ends would be unchanged for any of the three temperature cycles in Appendix A or for any cycle based on those three. Table 5-1, therefore, provides the time intervals during which diurnal emissions could occur following an interruption to the soak period.

Table 5-1

Starting and Ending Times and Temperatures For Interrupted Diurnals For the 72° to 96° Fahrenheit Cycle

Diurnal Begins: Time	Diurnal Begins: Temperature	Time Diurnal Ends
Midnight thru 6 AM*	72.0°	Midnight**
7:00 AM	72.5°	Midnight**
8:00 AM	75.5°	Midnight**
9:00 AM	80.3°	10:18PM
10:00 AM	85.2°	8:06PM
11:00 AM	89.4°	6:44PM
Noon	93.1°	5:25PM
1:00 PM	95.1°	4:17PM
2:00 PM	95.8°	3:24PM
3 PM thru Midnight	N/A***	N/A***

Therefore, EPA will modify the predicted hourly emissions of full day's diurnals (from equations **(1)** through **(7)**) using the following four-step process:

1.) In each of the seven regression equations (in Sections 4.2.1 through 4.2.3), the variable "**Change Prior to Previous Hr**" appears. For an interrupted diurnal, that variable is calculated by subtracting the temperature at the start of the interrupted diurnal from the temperature at the beginning of the previous hour. This step will produce an estimate of the percent of the full day's diurnal occurring each hour of the interrupted diurnal.

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* In Section 4.2.1, it was noted that diurnal emissions are zero for hours 19 through 24 (i.e., midnight through 6AM). Thus, any diurnal that begins between midnight and 6AM effectively begins at 6AM, and that diurnal is actually a full 24-hour diurnal.

** In the previous footnote, it was noted that diurnal emissions are zero after midnight. Thus, even if the ambient temperature has not returned to the temperature at which the (interrupted) diurnal began, the diurnal effectively ends by the following midnight.

*** Any interrupted diurnal that begins while the ambient temperatures are declining (i.e., 3 PM or later) does not exist (has zero emissions).

2.) Those hourly percentages would then be modified so that any negative estimates would be changed to zero, and any estimates for hours beyond the "**Time Diurnal Ends**" column in Table 5-1 would be replaced by zero.

3.) The total 24-hour diurnal emissions are then predicted using the regression equations from Appendix C.

4.) Finally, the hourly (interrupted) diurnal emissions are estimated by multiplying the predicted full 24-hour diurnal emissions by the individual hourly percentages.

To illustrate the use of this four-step process, we return to the example in Section 5.1.

- Both Table 5-1 and the discussion at the end of Section 5.1 indicate that the interrupted diurnal emissions would begin at noon and continue until 6 PM. For each of those six hours, we can use Appendix A to construct a table of hourly temperatures and changes in temperatures. (We will assume that the changes in temperature prior to noon are zero.) Those temperature values are given in Table 5-2 on the following page.

- Using the changes in temperature in Table 5-2 we use equation **(4)** (to estimate hourly emissions from FI vehicles that pass both the pressure and purge tests) to calculate the estimated percentages of the full 24-hour diurnal emissions that occur each hour of this interrupted diurnal. Those hourly fractions are given (as percentages) in the seventh column of Table 5-2.

- For the purpose of that example, we assumed a 1986-95 model year, FI vehicle that passed both the purge and pressure tests, that used a 6.8 RVP fuel, and where the daily temperature profile was the standard 72° to 96° F cycle from Appendix A. The equation in Appendix C predicts the full 24-hour diurnal in this case would be 2.55 grams (per day).

- Multiplying the predicted full 24-hour diurnal (2.55 grams) emissions by the six hourly percentages then produces the estimated hourly emissions (in grams) which appear as the eighth column of Table 5-2. (The negative value for the second hour is then rounded up to zero.)

Table 5-2

Example of Calculating Hourly Diurnal Emissions From an Interrupted Diurnal

Time Of Day	Initial Temp (°F)	Final Temp (°F)	Change in Previous Hr Temp	Change in Current Hr Temp	Change Prior to Previous	Hourly Diurnal (pct)	Hourly Diurnal (grams)
Noon - 1PM	93.1	95.1	0	2.0	0	0.80%	0.020
1PM - 2PM	95.1	95.8	2.0	0.7	0.0	-0.06%	0.000
2PM - 3PM	95.8	96.0	0.7	0.2	2.0	1.16%	0.030
3PM - 4PM	96.0	95.5	0.2	-0.5	2.7	1.35%	0.034
4PM - 5PM	95.5	94.1	-0.5	-1.4	2.9	1.23%	0.031
5PM - 6PM	94.1	91.7	-1.4	-2.4	2.4	0.66%	0.017

EPA believes that while this approach is not perfect (as evidenced by the prediction of negative emissions during the second hour that needed to be rounded up to zero), it does provide a reasonable estimate of hourly diurnal emissions during an interrupted diurnal; therefore, EPA proposes to use this method in MOBILE6.

6.0 Assumptions Related to Hourly Emissions

Several basic assumptions related to estimating hourly emissions were made in this analysis due to the lack of test data.

6.1 Distribution of Hourly Diurnal Emissions

In Section 4, the key assumption is that once the hourly diurnal emissions are divided by the full 24-hour diurnal emissions, the distribution (within each of the seven strata identified on page 10) of those fractions is a function of the temperature change variables and the midpoint VP.

As a direct result of that assumption, the hourly diurnal emissions (in grams) can be predicted by simply multiplying the estimated full 24-hour diurnal emissions (from Appendix C) by the fractions calculated in Section 4.2. EPA proposes using those products to estimate the diurnal emission from each individual hour.

6.2 Assumptions for Interrupted Diurnals

The discussion of interrupted diurnals (in Sections 5.1 and 5.2) requires a number of assumptions. Three of these assumptions are stated at the beginning of Section 5.2.

The fourth assumption deals with estimating how much time must elapse following the driving cycle for the diurnal to resume. It is an accepted fact that interrupting the diurnal with a trip will result in a temporary increase in fuel tank temperature. The time required after the trip for the fuel temperature to return to (i.e., achieve equilibrium with) the ambient temperature depends on many factors (e.g., duration of the trip, fuel delivery system, fuel tank design, fuel tank materials, air flow, etc.). However, 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.)

6.3 Temperature Ranges

All of the tests used in this analysis were performed using one of the three temperature cycles in Appendix A. Thus, all of the resting loss data were measured at only three temperatures (i.e., 60, 72, and 82 °F). In Appendix F, we present regression equations (developed in M6.EVP.001) to estimate hourly resting loss emissions at 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 9.16 grams per hour. (from report number M6.EVP.009, entitled "Evaporative Emissions of Gross Liquid Leakers in MOBILE6").

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 the linear interpolation of the predicted value for the ten-degree cycle and zero.

6.4 Estimating Vapor Pressure

EPA proposes using 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 relationships between the vapor pressure and the temperature. 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.

6.5 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, vehicles could soak for longer periods of time. Estimating diurnal emissions when the soak period is a multiple of 24 hours will be analyzed in report M6.EVP.003. For the purpose of this analysis, a full 24-hour diurnal takes place between 6 AM and 6 AM of the following day (with hourly diurnal emissions of zero between midnight and 6 AM). If a diurnal period extends beyond 6 AM, then the emissions during the hours beyond 6 AM will be calculated using equations **(1)** through **(7)** (in Sections 4.2.1 through 4.2.3).

EPA's proposal on classifying a diurnal that follows a diurnal of less than 24 hours is based on EPA's hypothesis of why a single-day diurnal is different from a multiple-day diurnal. EPA believes that as the time progresses (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 interrupted diurnal is almost equivalent to a full 24-hour diurnal, EPA proposes to treat the subsequent days as if the first day's diurnal were a complete (i.e., a full-day) diurnal.

To determine the meaning of an interrupted diurnal being "almost equivalent" to a full 24-hour diurnal, we applied the equations **(1)** through **(6)** to various combinations of fuel RVP, temperature cycle, and starting time of an interrupted diurnal. This analysis determined that:

- Interrupted diurnals that began at 10 AM (i.e., the start of the fourth hour of the RTD test) exhibited only about one-third of the emissions of the full 24-hour diurnal.
- Interrupted diurnals that began at 9 AM (i.e., the start of the third hour of the RTD test) exhibited only about one-half of the emissions of the full 24-hour diurnal.
- Interrupted diurnals that began no later than 8 AM (i.e., at least by the start of the second hour of the RTD test) exhibited at least 80 percent of the emissions of the full 24-hour diurnal.

Based on these observations, if a vehicle's first day's incomplete (i.e., interrupted) 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. Otherwise, we treat the subsequent day as the first day of the diurnal.

Appendix A

Temperature Cycles (°F)

Hour	Temperatures Cycling Between 60-84°F	72-96°F*	82-106°F	Change in Previous Hr Temp (°F)	Change in Current Hr Temp (°F)	Change Prior to Previous Hr
0	60.0	72.0	82.0	---	---	---
1	60.5	72.5	82.5	0.0	0.5	0.0
2	63.5	75.5	85.5	0.5	3.0	0.5
3	68.3	80.3	90.3	3.0	4.8	3.5
4	73.2	85.2	95.2	4.8	4.9	8.3
5	77.4	89.4	99.4	4.9	4.2	13.2
6	81.1	93.1	103.1	4.2	3.7	17.4
7	83.1	95.1	105.1	3.7	2.0	21.1
8	83.8	95.8	105.8	2.0	0.7	23.1
9	84.0	96.0	106.0	0.7	0.2	23.8
10	83.5	95.5	105.5	0.2	-0.5	24.0
11	82.1	94.1	104.1	-0.5	-1.4	23.5
12	79.7	91.7	101.7	-1.4	-2.4	22.1
13	76.6	88.6	98.6	-2.4	-3.1	19.7
14	73.5	85.5	95.5	-3.1	-3.1	16.6
15	70.8	82.8	92.8	-3.1	-2.7	13.5
16	68.9	80.9	90.9	-2.7	-1.9	10.8
17	67.0	79.0	89.0	-1.9	-1.9	8.9
18	65.2	77.2	87.2	-1.9	-1.8	7.0
19	63.8	75.8	85.8	-1.8	-1.4	5.2
20	62.7	74.7	84.7	-1.4	-1.1	3.8
21	61.9	73.9	83.9	-1.1	-0.8	2.7
22	61.3	73.3	83.3	-0.8	-0.6	1.9
23	60.6	72.6	82.6	-0.6	-0.7	1.3
24	60.0	72.0	82.0	-0.7	-0.6	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, fuels with similar Reid vapor pressures (RVP) were tested, and their vapor pressures (in kiloPascals) 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 kiloPascals).

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:

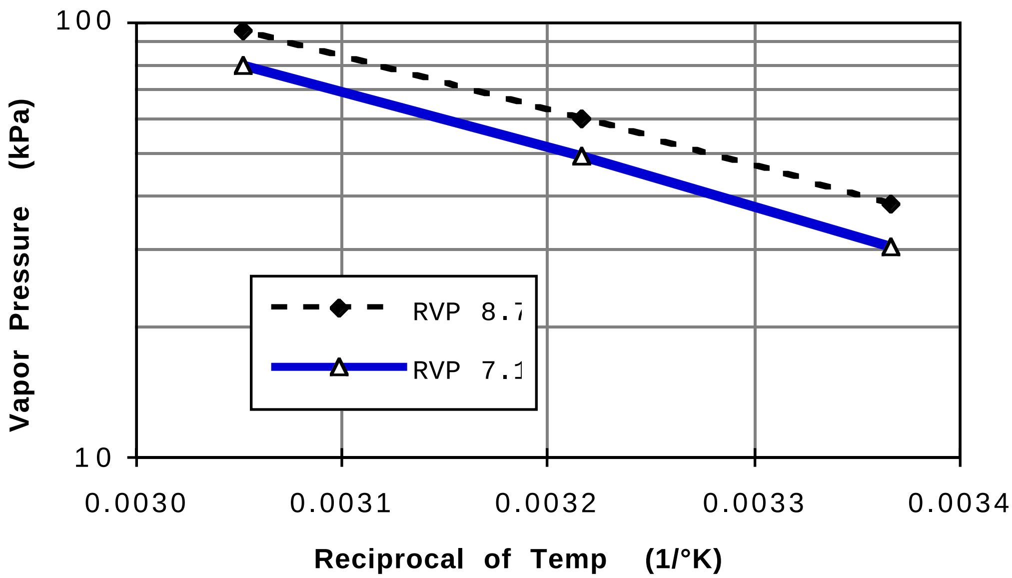
Ln(VP) = A + (B / Absolute Temperature), where:

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:

B = -3565.2707 + (70.5114 * RVP)

and

A = Ln(6.89286 * RVP) - (**B** / 310.9)

Appendix C

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

(Reproduced from M6.EVP.001)

In each of the following 18 strata, 24-hour diurnal emissions are modeled using four constants:

A ,B, C, D. Where,

24-Hour Diurnal (grams) =
= A
+ B * RVP (in psi)
+ C * [(Mean VP) * (Change in VP)]
+ D * [(Mean VP) * (Change in VP)]^2 / 1,000

For each of the 9 strata, the four constants used to model diurnal emissions are given below in the following table. Within each cell of this table, the four constants are listed vertically (i.e., with "A" at the top and "D" at the bottom).

Fuel Delivery	Model Year Range	Fail Pressure Test	Fail Only Purge Test	Pass Both Purge and Pressure
Carbureted	1972-79*	-0.29374 -0.62160 0.039905 0	21.94883 -2.23907 0 0.02990	21.13354 -2.42617 0 0.024053
	1980-1985	-1.22213 -0.62160 0.039905 0	16.69934 -2.23907 0 0.02990	15.50536 -2.42617 0 0.024053
	1986-1995**	18.97709 -1.81237 0 0.017098	13.90647 -2.14898 0.021368 0	8.37118 -0.767027 0 0.005934

* The **B**, **C**, and **D** values are based on 1980-85 carbureted vehicles.

** The **B**, **C**, and **D** values are based on 1986-95 FI vehicles.

Appendix C (Continued)

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

(Reproduced from M6.EVP.001)

In each of the following 18 strata, 24-hour diurnal emissions are modeled using four constants:

A ,B, C, D. Where,

24-Hour Diurnal (grams) =

$$= A + B * RVP\ (\text{in psi}) + C * [(\text{Mean VP}) * (\text{Change in VP})] + D * [(\text{Mean VP}) * (\text{Change in VP})]^2 / 1{,}000$$

Fuel Delivery	Model Year Range	Fail Pressure Test	Fail Only Purge Test	Pass Both Purge and Pressure
Fuel Injected	1972-79*	-0.29374 -0.62160 0.039905 0	21.94883 -2.23907 0 0.02990	21.13354 -2.42617 0 0.024053
	1980-1985	7.11253 -1.25128 0.036373 0	7.48130 -0.701002 0 0.010466	5.62111 -0.701002 0 0.010466
	1986-1995	14.19286 -1.81237 0 0.017098	9.93656 -2.14898 0.021368 0	5.85926 -0.767027 0 0.005934

* The three untested strata of Pre-1980 FI vehicles were represented using the Pre-1980 model year carbureted vehicles (which were themselves based on the 1980-85 model year carbureted vehicles).

Appendix D

Regression of Ratio of Mean Hourly Diurnal Emissions Carbureted Vehicles Passing Both Purge and Pressure Tests

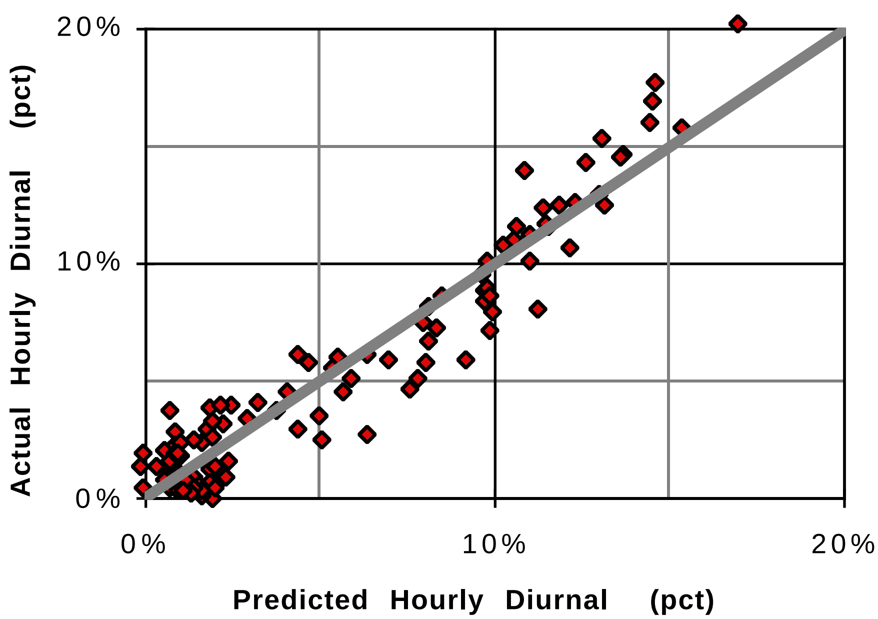
Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 91.6% R squared (adjusted) = 91.4%
s = 0.0146 with 114 - 4 = 110 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	0.257692	3	0.085897	400
Residual	0.023597	110	0.000215	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.007032	0.0033	2.15	0.0336
VP * Previous * Total Prior to Previous	0.000023	0.0000	23.1	≤ 0.0001
Total Prior to Previous	0.003586	0.0002	20.7	≤ 0.0001
Sqr_Delta Previous	-0.001111	0.0002	-5.01	≤ 0.0001

Plotting Predicted Versus Actual Values



Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emissions Carbureted Vehicles Failing the Pressure Test

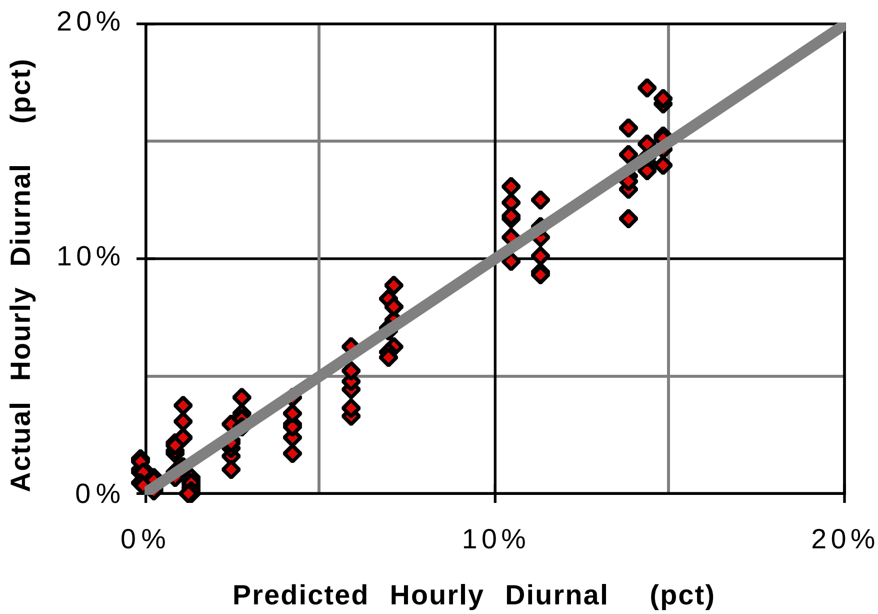
Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 95.1% R squared (adjusted) = 95.0%
s = 0.0119 with 114 - 4 = 110 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.300208	3	0.100069	710
Residual	0.015505	110	0.000141	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.010549	0.0029	3.60	0.0005
Previous * Total Prior to Previous	0.001138	0.0000	37.4	≤ 0.0001
Total Prior to Previous	0.001758	0.0001	11.8	≤ 0.0001
Sqr_Delta Current	0.001765	0.0002	10.4	≤ 0.0001

Plotting Predicted Versus Actual Values



Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emissions Carbureted Vehicles Failing ONLY the Purge Test

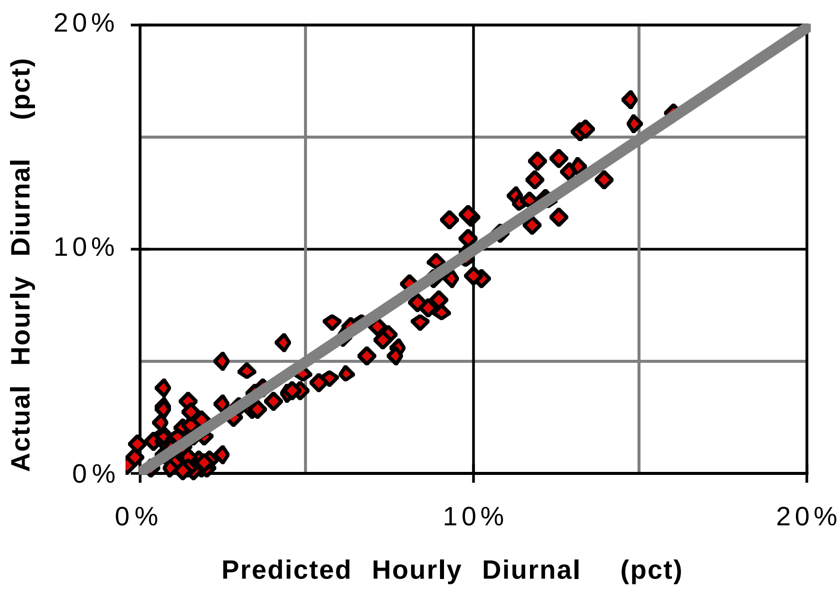
Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 93.5% R squared (adjusted) = 93.1%
s = 0.0124 with 114 - 6 = 108 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	0.236796	5	0.047359	308
Residual	0.01659	108	0.000154	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.006724	0.0030	2.23	0.0276
VP * Previous * Total Prior to Previous	0.000023	0.0000	27.1	≤ 0.0001
Total Prior to Previous	0.003966	0.0004	10.1	≤ 0.0001
Sqr_Delta Previous	-0.001122	0.0003	-4.05	≤ 0.0001
VP * Sqr_Delta Current	0.000019	0.0000	3.14	0.0022
VP * Tot Prior to Previous	-0.000018	0.0000	-2.24	0.0272

Plotting Predicted Versus Actual Values



Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emissions FI Vehicles Passing Both Purge and Pressure Tests

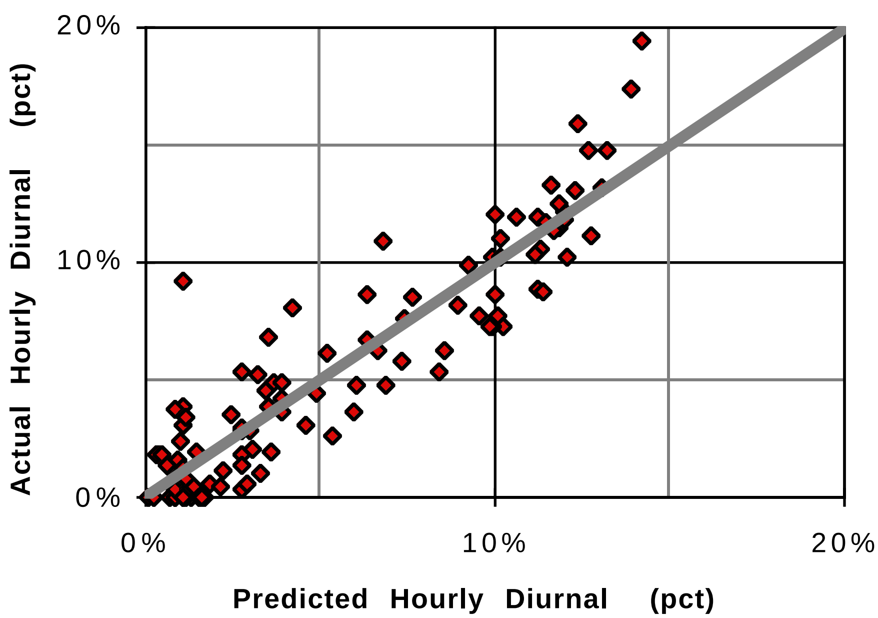
Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 85.2% R squared (adjusted) = 84.5%
s = 0.0188 with 114 - 6 = 108 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.220626	5	0.044125	124
Residual	0.03832	108	0.000355	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.008001	0.0046	1.75	0.0834
Total Prior to Previous	0.001961	0.0006	3.33	0.0012
Previous * Total Prior to Previous	0.000535	0.0000	5.61	≤ 0.0001
VP * Sqr_Delta Previous	-0.000060	0.0000	-8.75	≤ 0.0001
Delta Current	0.005964	0.0015	4.11	≤ 0.0001
VP * Tot Prior to Previous	0.000056	0.0000	4.47	≤ 0.0001

Plotting Predicted Versus Actual Values



Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emissions FI Vehicles Failing the Pressure Test

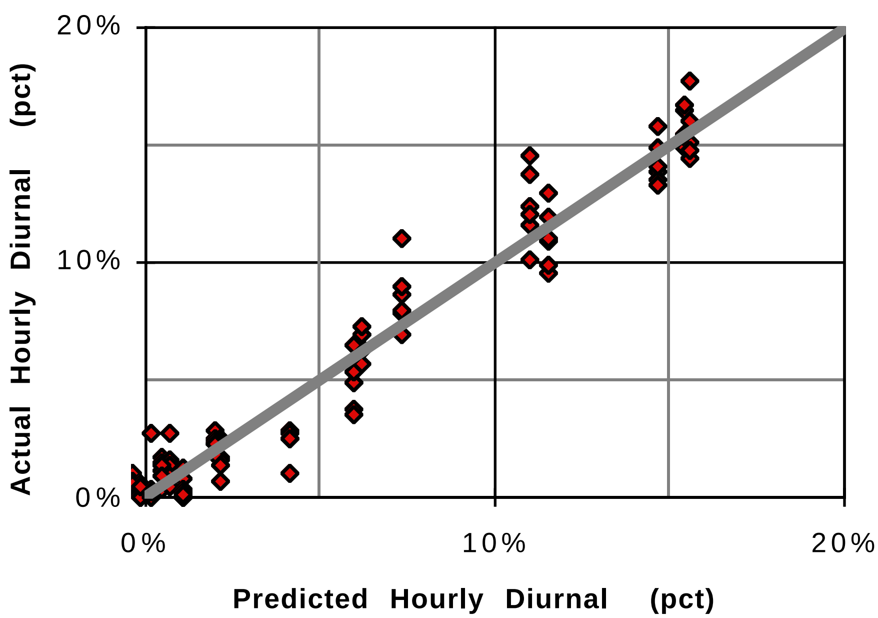
Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 95.9% R squared (adjusted) = 95.7%
s = 0.0118 with 114 - 5 = 109 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	0.350423	4	0.087606	634
Residual	0.015068	109	0.000138	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.006515	0.0029	2.25	0.0267
Previous * Total Prior to Previous	0.001194	0.0000	33.9	≤ 0.0001
Total Prior to Previous	0.001963	0.0002	12.9	≤ 0.0001
Sqr_Delta Current	0.001329	0.0003	5.04	≤ 0.0001
Sqr_Delta Previous	0.000574	0.0003	2.03	0.0449

Plotting Predicted Versus Actual Values



Appendix D (continued)
FI Vehicles Failing ONLY the Purge Test

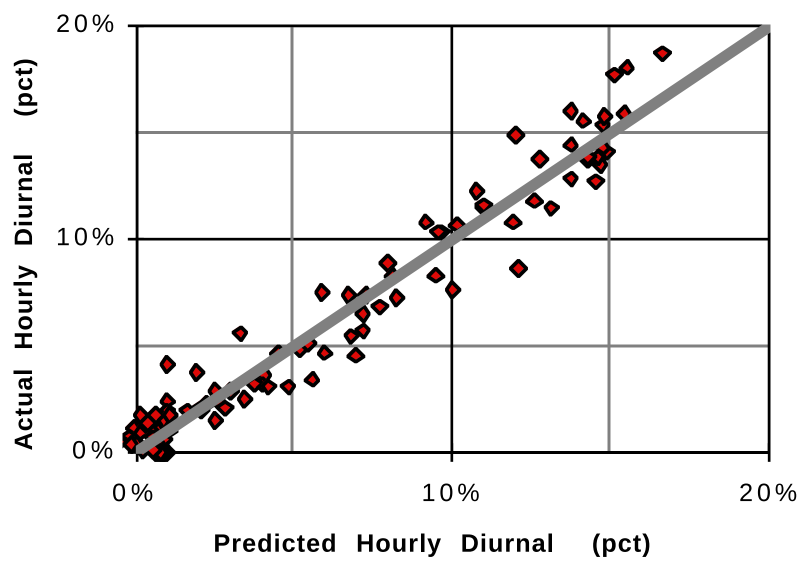
Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 95.6% R squared (adjusted) = 95.3%
s = 0.0120 with 114 - 8 = 106 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	43.7687	2	21.8844	50.8
Residual	1.29117	3	0.43039	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.007882	0.0030	2.66	0.0090
Previous * Total Prior to Previous	0.000855	0.0001	7.87	≤ 0.0001
VP * Tot Prior to Previous	0.000084	0.0000	8.82	≤ 0.0001
Sqr_Delta Current	0.006960	0.0007	10.7	≤ 0.0001
VP * Sqr_Delta Current	-0.000160	0.0000	-10.0	≤ 0.0001
Total Prior to Previous	-0.001172	0.0004	-2.88	0.0048
VP * Delta Current	0.000118	0.0000	2.98	0.0036
Sqr_Delta Previous	0.000825	0.0004	2.06	0.0419

Plotting Predicted Versus Actual Values



Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emissions "Gross Liquid Leaker" Vehicles

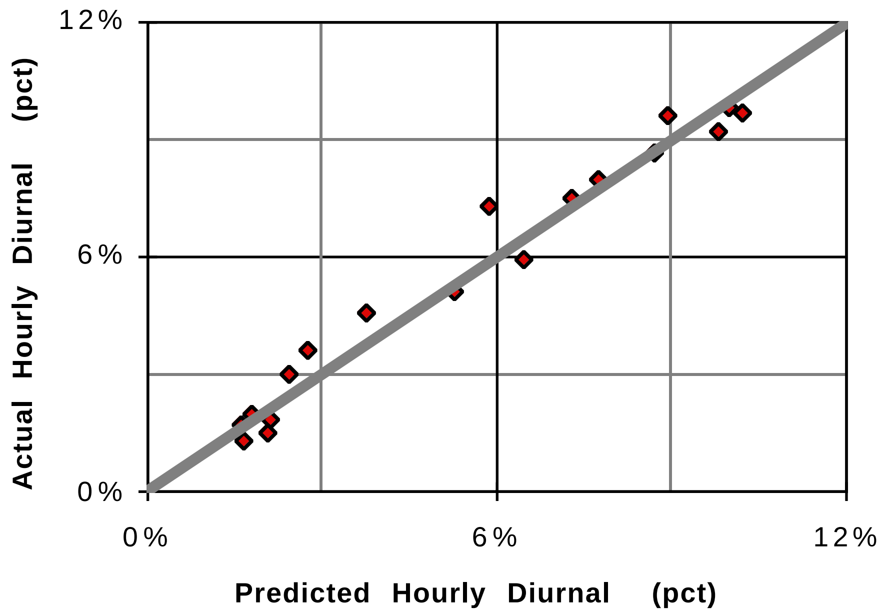
Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 96.2% R squared (adjusted) = 95.7%
s = 0.0070 with 19 - 3 = 16 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	0.019576	2	0.009788	200
Residual	0.000783	16	0.000049	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.021349	0.0032	6.67	≤ 0.0001
Delta Previous	0.010137	0.0006	16.90	≤ 0.0001
Total Prior to Previous	0.002065	0.0002	10.30	≤ 0.0001

Plotting Predicted Versus Actual Values



Appendix E

Hourly Real-Time Diurnal (RTD) Emissions (in grams) From Six 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**" (see Section 4.2.3) to fit the following assumed pattern:

- The diurnal emissions (i.e., RTD minus resting loss of 8.52) during the first hour were assumed to be one-half the diurnal emissions during the second hour.
- The diurnal emissions during the second hour were assumed to be one-half the diurnal emissions during the third hour.

Appendix F

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

In each of the following 12 strata, resting loss emissions (in grams 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 * Diurnal_Temperature_Range)

Where the **Diurnal_Temperature_Range** is the difference of the daily high temperature minus the daily low temperature.