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Technical Report

Fuel Volatility Effects on Exhaust Emissions

By

Celia Shih

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Test and Evaluation Branch
Emission Control Technology Division
Office of Mobile Sources
Office of Air and Radiation
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1.0 BACKGROUND

In MOBILE4, the effects of fuel volatility, expressed as Reid Vapor Pressure (RVP) in pounds per square inch (psi), on vehicles' exhaust emissions were modeled using data from EPA's Emission Factor Programs (EFP) conducted in Ann Arbor and test programs performed by Automotive Testing Laboratories, Inc. (ATL) at East Liberty, Ohio. The results of these test programs were summarized in two reports [1,2]. The American Petroleum Institute (API) submitted some of their test data (see discussions in Data Sources section below) before the release of MOBILE4. These data were reviewed and found not to be contradictory to the MOBILE4's assumptions. The algorithm used in MOBILE4 has been documented [3], and is summarized in the following paragraphs:

(1) When ambient temperatures are less than 41°F, it is assumed that there is no RVP effect on vehicles' exhaust emissions. This assumption is applied to all model years and all gasoline-powered vehicle types.

(2) There were no data to characterize the RVP effects on exhaust emissions for fuel volatilities less than the certification level of 9.0 psi, especially with ambient temperatures below 75°F. The MOBILE4 model has assumed that the effects of low RVP fuels on exhaust emissions were the same as those of 9.0 psi fuel (i.e., no effect).

(3) Vehicles tested at ambient temperatures of 75°F and up have shown exhaust emissions increases when the fuel volatility is higher than the certification level of 9.0 psi. Therefore, various RVP adjustment factors are used for different vehicle types and model year groups. For example, adjustments are made to exhaust HC and CO composite emissions for 1970-79 light-duty gasoline-powered vehicles (LDGVs), 1970-80 LDGT1s, and 1979-80 LDGT2s when the ambient temperature is higher than 40°F. A different set of correction factors is used to adjust exhaust HC and CO composite emissions for 1980+ LDGVs, 1981+ LDGT1s/LDGT2s, and 1985+ HDGVs at ambient temperatures between 41°F and 75°F. For ambient temperatures higher than 75°F, and model years 1980+ LDGVs, 1981+ LDGT1s/LDGT2s, and 1985+ HDGVs, a combined temperature and fuel volatility correction factor is used for each bag of the FTP exhaust emissions.

The purpose of this report is to assemble all data available as of May 1, 1990 to re-evaluate these MOBILE4 assumptions, especially in the areas of low RVP fuels (less than 9.0 psi) at temperatures less than 75°F.

2.0 DATA SOURCES

2.1 Pre-1980 Vehicles

(1) In 1975, Chevron Research [4] tested a total of seven vehicles (model years 1973 to 1976) at two fuel volatility levels and at two ambient temperatures using a randomized test sequence. The two fuels were the equivalent of 8.5 and 6.5 psi RVP*. The two ambient temperatures were 75 and 55°F, with relative humidities of 42 and 73 percent, respectively. One of the test vehicles was tested twice, once with the original carburetor and once with a replacement carburetor. All other vehicles were tested in "as-received" condition after their ignition and emission control systems were checked and failed components repaired. Out of 32 tests ("8" vehicles x 2 fuel RVPs x 2 temperatures), 20 were run in replicates with the average emissions listed in their report. Descriptions of the test vehicles are included in Table A1 of the Appendix to this report. Note that they were all California vehicles.

(2) In 1979, Exxon Research and Engineering Company [5] tested a total of eight 1974 through 1977 model year vehicles at six levels of fuel RVP and at the FTP ambient temperature of 75°F. The test fuels used were 11.8, 9.4, 9.1, 8.8, 6.8, and 6.6 psi RVP. There were two 9.1 psi fuels used in the program: one being a "high octane Indolene" used for certification, and one being a 50-50 blend of 6.5 and 11.8 psi fuels, with many more tests on the latter fuel than the former. At each fuel volatility level, most of the vehicles were tested two or three times. Among the test fleet, three of them were California vehicles, and two of them had their engines overhauled previously. Descriptions of the test vehicles are given in Table A2 of the Appendix.

(3) In 1988, the California Air Resources Board (CARB) included one model year 1978 vehicle in their five-car evaluation project [6] with two fuel volatilities at FTP ambient temperature of 75°F. The two test fuels were 8.6 and 7.2 psi RVP. Each vehicle was tested twice at each fuel volatility level. Description of this test vehicle is included in Table A3 of the Appendix.

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* With 11.8 and 8.3 Front End Volatility Index (FEVI) rating volatilities, respectively. This FEVI rating volatility is defined as [RVP + 0.13 * (% evaporated at 158°F)].

2.2. Post-1980 Vehicles

(1) In 1988, Chevron Research conducted two test programs in an effort to evaluate the effects of reduced RVP on exhaust emissions [7,8]. The first portion of the program involved a total of fourteen vehicles tested during two phases, each comparing exhaust emissions with two different RVP fuels [4]. In Phase I, 11.4 and 8.1 psi fuels were used with an ambient temperature of 43°F. In Phase II, 8.4 and 6.1 psi fuels were used with an ambient temperature of 55°F. Descriptions of the test vehicles are included in Table B1 of the Appendix. Note that all were California vehicles.

(2) Four of the test vehicles in the 1988 CARB five-car evaluation project (discussed in A.3 above) were 1981+ model year vehicles, as described in Table A3 of the Appendix.

(3) In 1987, ATL, under the sponsorship of API, tested six vehicles at four fuel volatility levels and at three ambient temperatures [9] using a randomized test sequence. The four fuels were 10.5, 9.0, 8.0, and 6.5 psi in fuel RVP. The ambient temperatures were 42, 55, and 80°F. Out of 72 tests (6 vehicles x 4 fuels x 3 temperatures), all were run twice, with 4 tests run three times. Descriptions of these six vehicles are included in Table B2 of the Appendix.

(4) In addition to those EFP data included in MOBILE4 analyses [1,2,3], EPA has since tested ten model year 1987 fuel-injected vehicles at ambient temperature of 50°F and at three fuel volatility levels: 14.6, 11.7, and 9.0 psi RVP. Descriptions of these ten vehicles are included in Table B3 of the Appendix.

3.0 DATA ANALYSIS

The following criteria were used in analyzing the data:

(1) Each test program was analyzed separately.

(2) Within each test program, data from each ambient temperature level were examined.

(3) Since the sample sizes were relatively small (at each temperature level and for each test program), a statistical significance level of 0.10 was used.

(4) One of the test vehicles from the 1975 Chevron program (1973 Pontiac Catalina) was treated as if it were two vehicles, since it was tested with the original carburetor and tested again with a replacement carburetor (see A.1, section 2.0).

(5) Between the two 9.1 psi fuels used in the Exxon program (as discussed in A.2, section 2.0), emissions from the "high octane Indolene" were used in this analysis, since this is the type of fuel used for certification.

(6) The model year 1978 vehicle tested by CARB was separated from the other four 1983+ vehicles in the analysis, since it was built to comply with a different evaporative emission standard.

(7) One of the test vehicles from the 1988 Chevron program (1983 Toyota SR-5 pickup) was excluded from the current analysis, as the vehicle was of a different type (LDGT1).

Three types of statistical procedure were used to examine the impact of fuel volatility on exhaust emissions: paired-t test, student-t test, and regression analysis. Descriptions of the statistics and results are summarized in the following sections.

3.1 Paired-t Test

The paired-t test is a statistical procedure used to examine the effects (exhaust emissions) of a certain treatment (fuel volatility) which has been applied to the same sample population (test vehicle) under similar conditions (i.e., at the same ambient temperature, FTP speed cycle, etc.). This is a more powerful statistical tool than the commonly used student-t test to be discussed later. In general, the statistic used in paired-t test has the form [10]:

$$T = D / s(D)$$

where: D = mean of the differences D_i, for $i = 1,2,\ldots,n$,
s(D) = standard deviation of the differences.

This T statistic is distributed as a t-distribution with (n-1) degrees of freedom. The hypothesis is that the mean of the differences (D) equals zero. This hypothesis is to be rejected if the absolute value of T is greater than a critical value estimated from the t-distribution, based on a significance level of 0.10 and sample size n.

For each pollutant, D_i was calculated as the difference between emissions from a high RVP fuel and those from a low RVP fuel on each vehicle at a given temperature:

$$D_i = E_{High\ RVP} - E_{Low\ RVP}$$

If replicate tests on a given vehicle were available, the average of the emissions measured on each test were used. Means and standard deviations of the differences (D_i) at each temperature level from each test program were calculated and summarized. Results from pre-1980 vehicles are presented in Table 1, and results from 1980+ vehicles are shown in Table 2.

Also listed in Tables 1 and 2 are the probabilities calculated from the t-distribution. Probabilities designate the numerical value associated with the chances that D being different from zero are caused by random error. Therefore, if the probability value is less than or equal to 0.10, this implies that D is significantly different from zero, or that the difference between emissions from a high and from a low RVP fuel is statistically significant.

The average percent emission change is calculated from the percent emission change for each vehicle:

$$D_i / E_{High\ RVP} * 100.0$$

Therefore, a negative average percent emission change would indicate that on the average the emissions are increased by using a lower RVP fuel.

In evaluating paired-t test results, it should be noted that the effect of fuel volatility on exhaust emissions is significant if and only if there is consistency among all statistics being evaluated.

For example, a determination that a lower RVP fuel (say 6.5 psi compared to 8.0 psi) would increase exhaust HC emissions at 55°F, results from pairs of test results at these two fuel volatility levels from the API/ATL program, where:

(1) the means (D's) of the exhaust HC emission differences are negative,

(2) the probabilities that D's being equal to zero are less than or equal to the chosen significance level,

(3) the average percent emission change values are negative (consistent with the mean emission differences), and,

(4) there is a consistent trend in the occurrences of the above three criteria at similar temperature levels and across the test programs. For example, if the exhaust HC emission differences for 8.4 vs. 6.1 psi RVP fuels were significant at 55°F from the Chevron test program, it is logical to expect that the emission differences for similar volatility levels (8.0 vs. 6.5 psi RVP fuels) should also be significant at similar temperatures (55°F) from the API/ATL test program.

3.1.1. Pre-1980 Vehicles

On examining test results from pre-1980 vehicles, the 1978 vehicle tested by CARB at 75°F showed very large percent emission increases from using a lower RVP fuel. Since this was the only pre-1980 vehicle tested by CARB, and the only 8.6 vs. 7.2 psi RVP emission levels, no statistical comparison can be made, and thus no conclusion can be drawn.

For other pre-1980 vehicles, as can be seen from Table 1, the majority of the paired-t significance levels are greater than 0.10, with the following exceptions:

Test Program	°F	Fuel RVPs (psi)	Pollutant(s) that showed Significant Differences
Chevron	55	11.8/8.3	HC,CO
Exxon	75	11.8/6.6	NOx
Exxon	75	8.8/6.6	HC,NOx
Exxon	75	6.8/6.6	NOx

This implies that, except for the above cases, there is no significant difference in emissions when different volatility fuels are used.

At each temperature level, the average percent emission changes, either increasing or decreasing by using a lower RVP fuels, are also examined. The majority of the emission changes are small (say, within 10 percent), with the following exceptions:

Test Program	°F	Fuel RVPs (psi)	Pollutant(s) that showed 10% or more Emission Change: Increase	Decrease
Chevron	55	11.8/8.3	HC,CO	-
Exxon	75	11.8/6.8	-	CO
Exxon	75	11.8/6.6	-	CO
Exxon	75	9.4/9.1	-	CO
Exxon	75	9.4/6.8	-	CO
Exxon	75	9.4/6.6	-	CO
Exxon	75	9.1/8.8	NOx	-
Exxon	75	8.8/6.6	HC	NOx

Note that the percent emission changes from the Chevron program at 55°F for both HC and CO (11.8 vs. 8.3 psi RVP) and the Exxon program at 75°F (8.8 vs. 6.6 psi RVP) for HC and NOx were also statistically significant.

However, there is no consistency in the signs of the mean emission differences. For example, at 75°F, mean emission differences from the Chevron program at 11.8 vs. 8.3 psi RVP for both HC and CO are negative (i.e., the HC and CO emissions from the lower RVP fuel were higher than those from the higher RVP fuel). But from the Exxon program at the same temperature level and similar fuel volatility levels (11.8 vs. 8.8 psi), the mean HC and CO differences are positive (i.e., the HC and CO emissions from the lower RVP fuel were lower than emissions from the higher RVP fuel).

Therefore, it is concluded that, based on the current data from pre-1980 vehicles, the fuel volatility effect on vehicle's exhaust emissions at 75°F may not be significant and consistent. The Chevron test program data at 55°F (11.8 vs. 8.3 psi) showed both significant and consistent fuel volatility effect on exhaust HC and CO emissions.

3.1.2 1980+ Vehicles

For 1980 and later model year vehicles, as can be seen from Table 2, the majority of the paired-t probabilities are also greater than 0.10, with the following exceptions:

Test Program	°F	Fuel RVPs (psi)	Pollutant(s) that showed Significant Differences
API/ATL	42	9.0/8.0	NOx
EPA	50	14.6/11.7	NOx
EPA	50	14.6/9.0	NOx
Chevron	55	8.4/6.1	HC,CO,NOx
API/ATL	55	8.0/6.5	HC
API/ATL	80	10.5/9.0	HC
API/ATL	80	10.5/8.0	HC

At each temperature level, the average percent emission changes, either increasing or decreasing by using a lower RVP fuels, are also examined. The majority of the emission changes are within 10 percent, with the following exceptions:

Test Program	°F	Fuel RVPs (psi)	Pollutant(s) that showed 10% or more Emission Change Increase	Decrease
EPA	50	14.6/11.7	CO	-
EPA	50	14.6/9.0	-	NOx
Chevron	55	8.4/6.1	HC	-
API/ATL	80	10.5/9.0	-	CO
API/ATL	80	10.5/8.0	-	HC,CO
API/ATL	80	10.5/6.5	-	CO

At the 42/43°F temperature level, only NOx emissions from the API/ATL test program for 9.0 vs. 8.0 psi RVP fuels showed a statistically significant mean emission decrease. The average percent emission change values are all small (within ten percent increase or decrease). Therefore, it is concluded that at 42/43°F temperature level, there is no conclusive evidence of RVP effect on exhaust emissions.

At 50/55°F, only the 1988 Chevron program data (8.4 vs. 6.1 psi RVP fuels) showed significant mean emission differences (increases) for all three pollutants, and close to an eleven percent HC emission increase. For similar fuel volatility levels (at 8.0 vs. 6.5 psi fuels), the HC emission increases from API/ATL program was also significant. Therefore, by the consistency criterion, it is concluded that the fuel RVP effect on HC emissions at 50/55°F may be significant. There is no significant (and no consistent) RVP effect on CO or NOx emissions.

At the 75-80°F temperature range, the probability statistics showed significance for HC emissions reduction by reducing fuel volatilities from 10.5 to 9.0, and 10.5 to 8.0 psi RVP. However, the significance is lessened when lower than 9.0 psi fuel is used. Also, the emission increase on CO emissions when 10.5 psi RVP fuel is used in the API/ATL program is ten or more percent, although their associated probabilities are not significant. The API/ATL test results are consistent with the MOBILE4 assumption -- that there is a small fuel volatility effect on exhaust HC/CO emissions when fuel volatilities are higher than the certification level of 9.0 psi and ambient temperatures are 75°F and higher.

3.2 Student-t Test

Since some of the test programs (such as Chevron and API/ATL) used randomized test sequences, the paired-t test procedure may not be appropriate. For this reason, the student-t test procedure was also used for evaluation. The student-t test is a statistical procedure used to compare two sample means and their variances. Therefore, at each temperature level from each test program, the average exhaust emissions from a high volatility fuel can be compared to the average emissions from a low volatility fuel, if the variances of the two samples are statistically equal [10]:

$$T = (E_1 - E_2) / SD$$

where: E_1 = average emissions from a high volatility fuel,
E_2 = average emissions from a low volatility fuel,
SD = standard deviation.

The T statistic is distributed as a t-distribution with (n1+n2-2) degrees of freedom. The hypothesis is that the two sample means are equal (or, $E_1 - E_2 = 0$). This hypothesis is to be rejected if the absolute value of T is greater than a critical value estimated from the t-distribution, based on a significance level of 0.10 and the two sample sizes (n1 and n2).

The two sample emission variances can be compared based on:

$$F = S1^2 / S2^2$$

where:

$S1^2$ = emission variance from a high volatility fuel, and
$S2^2$ = emission variance from a low volatility fuel.

This F statistic is distributed as a f-distribution with (n1-1) and (n2-1) degrees of freedom. The hypothesis is that the ratio of the two variances equals unity. This hypothesis is to be rejected if the numerical value of F is greater than a critical value estimated from the f-distribution, based on a significance level of 0.10 and the two sample sizes (n1 and n2).

For each pollutant, means and standard deviations were calculated and summarized at each temperature level from each test program. Results from pre-1980 vehicles are presented in Table 3, and results from 1980+ vehicles are shown in Table 4.

Also listed in Tables 3 and 4 are three probabilities:

(1) The probability that the two average emissions being different from zero is caused by random error -- denoted as "t-probability."

(2) The probability that the ratio of the two emission variances being different from unity is caused by random error -- denoted as "f-probability."

(3) The probability that the average emissions from a high RVP fuel are lower than the average emissions from a low RVP fuel. Note that this probability has the minimum value of 0.0 and the maximum value of 1.0, and is not calculated when the sample size is less than 5.

In evaluating student-t test results, criteria similar to those used for evaluating the paired-t test are also used. These criteria include: average emissions being significantly different (i.e., the t-probability value needs to be less than or equal to 0.10), and a consistent trend in the occurrences of significance at each temperature level and across the test programs.

An additional criterion is used in evaluating student-t test results. The numerical values associated with the probability that the mean emissions from a high RVP fuel being lower than the mean emissions from a low RVP fuel should be closer to the two extremes, either larger than 0.75 or smaller than 0.25. If this probability value is 0.50, this would imply that there is a 50-50 chance that the average emissions from one RVP level fuel will be lower (or higher) than the average emissions from another RVP level fuel, hence the fuel volatility effect on emissions is not significant. A note of caution is that even if the probability values are close to the two extremes, most of the test programs examined here had relatively small sample sizes (ranging from 4 to 13).

3.2.1 Pre-1980 Vehicles

For pre-1980 vehicles, as can be seen from Table 3, all t- and f-probabilities are greater than 0.10, with the majority of the t-probabilities greater than 0.90. The probabilities that the high RVP fuel emissions being lower than the low RVP fuel emissions are mostly between 0.30 and 0.70 (with only one exception: from Exxon program at 75°F, the probability that the average NOx emissions from 8.8 psi fuel being lower than the emissions from 6.6 psi fuel is 0.27). Therefore, it is concluded that there is no statistically significant fuel RVP effect on exhaust emissions at any temperatures.

3.2.2 1980+ Vehicles

For 1980+ vehicles, as can be seen from Table 4, all t-probabilities at each temperature level are greater than 0.10. The majority of the f-probabilities are also greater than 0.10, with the following exceptions:

Test Program	°F	Fuel RVPs (psi)	Pollutant(s) that showed Significant Differences in Emission Variances
EPA	50	14.6/11.7	HC,CO
EPA	50	11.7/9.0	HC,CO
API/ATL	80	10.5/8.0	CO
API/ATL	80	10.5/6.5	CO
API/ATL	80	9.0/8.0	CO

Note that the significant differences in emission variances are simply an indication that the degrees of dispersion within one sample are different from those in another sample.

The probabilities that the high RVP fuel emissions are lower than the low RVP fuel emissions are also mostly between 0.30 and 0.70, with the following exceptions:

Test Program	°F	Fuel RVPs (psi)	Pollutant	Probability that 1st Mean is < 2nd Mean
EPA	50	14.6/11.7	NOx	0.21
EPA	50	14.6/9.0	NOx	0.10
EPA	50	11.7/9.0	HC	0.29
EPA	50	11.7/9.0	CO	0.26
EPA	50	11.7/9.0	NOx	0.29
API/ATL	80	10.5/8.0	HC	0.23
API/ATL	80	10.5/8.0	CO	0.16
API/ATL	80	10.5/6.5	CO	0.19
API/ATL	80	9.0/8.0	CO	0.29

Note that all the above exceptions lead to the conclusion that the emissions from a high RVP fuel are more likely to be higher than the emissions from a low RVP fuel.

All these results suggest that the average exhaust emissions (HC, CO, and NOx) from a high RVP fuel are <u>not statistically different</u> than the average emissions from a lower RVP fuel.

4.0 REGRESSION ANALYSIS

Regression analysis is a statistical tool used to determine the relation between a set of independent variables (fuel volatility and ambient temperature) and a dependent variable (exhaust emissions) so that the latter can be estimated from the former. Since the main purpose of this report is to examine the fuel volatility effect on exhaust emissions, the regression analysis here serves as a final step to see if there exists any effect on exhaust emissions under a combination of factors such as fuel volatility, ambient temperature, and the interaction of the two.

The results presented here are in a simplified form. Basically, the regression model has the following form:

$$E = \exp [\ a + b*RVP + c*Temp + d*RVP*Temp + e*RVP^2 + f*Temp^2 + g*(RVP*Temp)^2\ ]$$

where: E = exhaust emissions in g/mi,
RVP = fuel volatility in psi, and,
Temp = ambient temperature in °F.

A backward selection process is used to determine the final equation form. That is, a full set of all independent variables, whenever appropriate, is used in the first step of regression analysis. The resulting coefficients are checked for significance. The most insignificant variable (with the coefficient having the largest numerical value in significance and greater than 0.10) is to be removed before the execution of the next step of regression analysis. This selection process will continue until all the variables remaining have coefficients with significance levels less than or equal to 0.10. Therefore, at the end of the final step, the remaining independent variables are those that would contribute significantly in the prediction of the dependent variable.

4.1 Pre-1980 Vehicles

The 1975 Chevron and the 1979 Exxon programs data were used in the regression analysis. Note that there were two temperature levels (55 and 75°F) and two fuel volatility levels (8.3 and 11.8 psi RVP) in the 1975 Chevron test program. Therefore, only the constant term (a in the above equation) and three first degree independent variables (RVP, Temp, and RVP*Temp) were used in the initial step of the backward selection process. The 1979 Exxon program data were at 75°F only (but with fuel volatilities ranging from 6.6 to 11.8 psi RVP), thus only the constant term and two RVP related variables (RVP, RVP^2) were used in the regression analysis. Results are summarized in the following:

Test Program	Pollutant	Significant Variables
1975 Chevron	HC	Constant
	CO	Temp
	NOx	Constant
1979 Exxon	HC	Constant
	CO	Constant
	NOx	Constant

As can be seen from the above, for pre-1980 vehicles fuel volatility is a non-significant independent variable for all pollutants across both test programs.

4.2 1980+ Vehicles

Data from two test programs were used in the regression analysis: the 1988 Chevron and the 1987 API/ATL programs. Note that there were two temperature levels (43 and 55°F) and two fuel volatility levels (8.1 and 11.4 psi RVP) in the 1988 Chevron test program. Therefore, only the constant term (denoted as "a" in the above equation) and three first-degree independent variables (RVP, Temp, and RVP*Temp) were used in the initial step of the backward selection process. The 1987 API/ATL program had three levels of temperature (42, 55, and 80°F) and four levels of fuel volatility (6.5, 8.0, 9.0, and 10.5 psi RVP), thus the entire seven independent variables (defined previously) were used in the regression analysis. Results are summarized in the following:

Test Program	Pollutant	Significant Variables
1988 Chevron	HC	RVP, RVP*Temp
	CO	Temp
	NOx	Constant
1987 API/ATL	HC	RVP, RVP*Temp
	CO	$Temp^2$
	NOx	$Temp^2$

As can be seen, for 1980+ vehicles fuel volatility is a significant independent variable for HC emissions across both test programs.

5.0 CONCLUSIONS

The effect of fuel volatility on exhaust emissions based on data not included in the MOBILE4 model was examined. Three types of statistical procedure were used to examine the impact of fuel volatility on exhaust emissions: paired-t test, student-t test, and regression analysis. Results are summarized in the following:

Statistical Procedure	Results
	Pre-1980 Vehicles
Paired-t	a) The 1975 Chevron program data at 55°F showed significant fuel volatility effect (11.8 vs. 8.3 psi fuel) on HC/CO emissions, resulting in higher emissions when low RVP fuel was used. b) For all other test programs at 75°F the RVP effects were non-significant.
Student-t	No statistically significant fuel RVP effect on exhaust emissions at any temperatures.
Regression	Fuel volatility is not a significant independent variable for all pollutants.
	1980+ Vehicles
Paired-t	a) At 42/43°F, the fuel RVP effect was non-significant. b) At 50/55°F, both Chevron and API/ATL data showed significant fuel RVP effect (8 vs. 6 psi RVP) resulting higher HC emissions under lower RVP fuel. c) At 75/80°F, API/ATL data showed significant HC/CO reductions with lower RVP fuel.
Student-t	Some showed significant differences in the variances. No significant differences on the average emissions. Overall, the emissions from one level RVP fuel are likely to be the same as the emissions from another level of RVP fuel.
Regression	For Chevron and API/ATL programs, fuel RVP is a significant independent variable for HC emissions.

The algorithm used in MOBILE4 was based on the use of the more powerful paired-t test procedure, since in EPA's EF testing program vehicles were tested with the higher in-use RVP fuel first. Both Chevron and API/ATL program data were based upon randomized test sequence results. The conclusions from the student-t test would be more applicable for those studies. Even if the paired-t test results were examined for Chevron and API/ATL program data, the majority of the data had shown no fuel volatility impact on exhaust emissions, with significant fuel RVP impact only at 50/55°F based on a relatively small sample size.

The pre-1980 vehicles were equipped with oxidation catalysts and the cold start was controlled mostly by a choke. It is reasonable to believe that the cold start portion of the FTP test might result in slightly higher exhaust emissions by using a lower RVP fuel, especially when the ambient temperature is relatively low and when vehicles may not be in a "top-notch" condition.

For 1980+ vehicles, however, higher exhaust HC emissions occurred only when 8.0 and 6.0 psi fuels were compared and the ambient temperature was at 50/55°F. The sample sizes of these two test programs (Chevron and API/ATL) that showed significant fuel RVP impacts were relatively small (with N=13 and 6, respectively). Further, data from recent fuel surveys [11] showed that only very few brands of gasoline with fuel volatility lower than 8.0 psi were commercially available (in cities like Albuquerque, Las Vegas, Los Angeles, and Phoenix, during the summer months). The lowest fuel volatility surveyed was 7.5 psi RVP from Phoenix in the summer of 1988, for an unleaded premium gasoline.

As suggested by the data, using fuels with volatilities at 6.0 or 6.5 psi RVP could result in a small exhaust HC emission increase at 50/55°F ambient. But the benefit of using a higher psi fuel to offset this small exhaust HC emissions increase for the early morning trip even in the high temperature ozone season is probably cancelled out by the higher evaporative hot soak HC emissions generated in the midday when the majority of daily trips occur and the ambient temperatures can be over 90 degrees Fahrenheit.

To summarize, in analyzing the currently available data, there were inconsistencies in results. Under the unlikely combination of relatively low temperature and less than 8.0 psi RVP fuel volatilities, a small increase in exhaust HC emissions is negligible when compared with the benefit of a relatively larger decrease in evaporative hot soak emissions. For these reasons, the MOBILE4 model assumed no fuel volatility effect on exhaust emissions when the fuel RVP is below the certification level of 9.0 psi.

This assumption is adequate for most of the areas with moderate ambient temperature profiles in high ozone season (with daily minimum of 60 to the maximum of 84°F). The combination of lower (say, 50/55°F) ambient temperature and lower (6.0) psi RVP fuel is expected to be rare. Even in areas with more extreme ambient temperature profiles (say, 70 to 96°F), the suggested fuel volatility required by 1992 is 7.8 psi RVP in EPA's Final Rule for Phase II Fuel Volatility Control.

It is concluded that the assumptions used in MOBILE4 are adequate for all situations likely to be encountered in real world modeling. There may be uncertainties when estimating exhaust emissions in areas with low RVP fuels (less than 9.0 psi) at temperatures greater than 40°F. More data should be collected and analyzed before these uncertainties can be addressed.

Table 1

Paired-t Test Results
Pre-1980 Vehicles

Amb Temp. (°F)	Fuel RVP (psi)	N	Poll	Mean Emission Difference (g/mi)	Standard Deviation	Probabilities that the Differences are from Random Error	Average Percent Emission Change
			Chevron Data (1973-76 Vehicles)				
55	11.8	8	HC	-0.1561	0.16214	0.0296*	-18.87
	vs.	8	CO	-1.6387	2.39650	0.0943*	-12.70
	8.3	7	NOx	-0.0329	0.08321	0.3364	-2.00
			CARB Data (1978 Vehicle)				
75	8.6	1	HC	-0.2220	-	-	-25.00
	vs.	1	CO	-2.9700	-	-	-29.38
	7.2	1	NOx	0.2100	-	-	17.65
			Chevron Data (1973-76 Vehicles)				
75	11.8	8	HC	-0.0359	0.15777	0.5406	-5.60
	vs.	8	CO	-0.7213	2.81200	0.4917	1.15
	8.3	7	NOx	-0.0114	0.09651	0.7647	-0.38
			Exxon Data (1974-77 Vehicles)				
75	11.8	8	HC	-0.0186	0.16978	0.7654	4.95
	vs.	8	CO	-0.3258	1.04230	0.4060	-7.69
	9.4	8	NOx	0.0164	0.27891	0.8728	-0.91
75	11.8	8	HC	0.0185	0.07007	0.4795	1.25
	vs.	8	CO	0.3456	1.23500	0.4546	4.64
	9.1	8	NOx	0.0729	0.28561	0.4939	1.89
75	11.8	8	HC	0.0189	0.18292	0.7789	8.46
	vs.	8	CO	0.5236	2.85160	0.6195	4.09
	8.8	8	NOx	-0.1018	0.26899	0.3202	-7.56
75	11.8	8	HC	-0.0205	0.23953	0.8157	5.98
	vs.	8	CO	0.8361	1.59310	0.1813	10.73
	6.8	8	NOx	0.0195	0.14529	0.7155	-1.62

* Probability value is less than 0.10, an indication that the emission differences are significant.

Table 1 (Continued)

Paired-t Test Results
Pre-1980 Vehicles

Amb Temp. (°F)	Fuel RVP (psi)	N	Poll	Mean Emission Difference (g/mi)	Standard Deviation	Probabilities that the Differences are from Random Error	Average Percent Emission Change
				Exxon Data (Continued)			
75	11.8	8	HC	-0.0488	0.21001	0.5324	-1.02
	vs.	8	CO	0.4936	2.40380	0.5796	10.73
	6.6	8	NOx	0.1274	0.07821	0.0025*	6.95
75	9.4	8	HC	0.0371	0.19777	0.6119	-5.28
	vs.	8	CO	0.6714	1.46260	0.2353	10.14
	9.1	8	NOx	0.0565	0.29223	0.6015	1.57
75	9.4	8	HC	0.0375	0.13328	0.4523	2.90
	vs.	8	CO	0.8494	3.63790	0.5301	8.41
	8.8	8	NOx	-0.1181	0.35424	0.3770	-7.86
75	9.4	8	HC	-0.0019	0.14134	0.9711	0.64
	vs.	8	CO	1.1619	2.25150	0.1878	14.53
	6.8	8	NOx	0.0031	0.30659	0.9778	-2.42
75	9.4	8	HC	-0.0301	0.15198	0.5925	-7.69
	vs.	8	CO	0.8194	3.19480	0.4917	14.25
	6.6	8	NOx	0.1110	0.30274	0.3342	5.90
75	9.1	8	HC	0.0004	0.20357	0.9960	6.14
	vs.	8	CO	0.1780	2.85570	0.8650	-2.57
	8.8	8	NOx	-0.1746	0.37707	0.2316	-11.15
75	9.1	8	HC	-0.0390	0.26185	0.6862	3.35
	vs.	8	CO	0.4905	1.21800	0.2922	5.24
	6.8	8	NOx	-0.0534	0.24638	0.5594	-4.80
75	9.1	8	HC	-0.0673	0.23439	0.4438	-3.66
	vs.	8	CO	0.1480	2.26850	0.8588	6.23
	6.6	8	NOx	0.0545	0.27382	0.5910	3.59
75	8.8	8	HC	-0.0394	0.07394	0.1757	-2.51
	vs.	8	CO	0.3125	1.98830	0.6701	6.66
	6.8	8	NOx	0.1213	0.24735	0.2082	4.42

* Probability value is less than 0.10, an indication that the emission differences are significant.

Table 1 (Continued)

Paired-t Test Results
Pre-1980 Vehicles

Amb Temp. (°F)	Fuel RVP (psi)	N	Poll	Mean Emission Difference (g/mi)	Standard Deviation	Probabilities that the Differences are from Random Error	Average Percent Emission Change
				Exxon Data (Continued)			
75	8.8	8	HC	-0.0676	0.06025	0.0156*	-10.62
	vs.	8	CO	-0.0300	1.19070	0.9452	6.87
	6.6	8	NOx	0.2291	0.27782	0.0524*	11.53
75	6.8	8	HC	-0.0283	0.09717	0.4380	-8.83
	vs.	8	CO	-0.3425	1.76110	0.5994	-1.25
	6.6	8	NOx	0.1079	0.10130	0.0196*	7.58

* Probability value is less than 0.10, an indication that the emission differences are significant.

Table 2

Paired-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Fuel RVP (psi)	N	Poll	Mean Emission Difference (g/mi)	Standard Deviation	Probabilities that the Differences are from Random Error	Average Percent Emission Change
			Chevron Data (1981-83 Vehicles)				
43	11.4	11	HC	-0.0245	0.05334	0.1593	-4.29
	vs.	11	CO	-0.2940	0.70524	0.1969	-3.27
	8.1	11	NOx	-0.0154	0.05239	0.3537	-1.10
			API/ATL Data (1983-86 Vehicles)				
42	10.5	6	HC	-0.0158	0.05272	0.4950	-2.32
	vs.	6	CO	-0.1868	1.41350	0.7592	-0.49
	9.0	6	NOx	-0.0242	0.08108	0.4981	-4.20
42	10.5	6	HC	0.0058	0.06246	0.8281	-0.34
	vs.	6	CO	-0.6477	0.85635	0.1231	-7.91
	8.0	6	NOx	-0.0042	0.09735	0.9206	-1.42
42	10.5	6	HC	0.0212	0.13222	0.7111	-3.51
	vs.	6	CO	-0.0910	1.40310	0.8800	-2.40
	6.5	6	NOx	-0.0003	0.09061	0.9932	-0.49
42	9.0	6	HC	0.0217	0.05820	0.4036	1.85
	vs.	6	CO	-0.4608	1.25630	0.4101	-8.53
	8.0	6	NOx	0.0200	0.02258	0.0822*	2.79
42	9.0	6	HC	0.0370	0.13564	0.5336	-1.21
	vs.	6	CO	0.0958	1.32390	0.8662	-3.02
	6.5	6	NOx	0.0238	0.06949	0.4391	3.23
42	8.0	6	HC	0.0153	0.13396	0.7904	-3.15
	vs.	6	CO	0.5567	1.30050	0.3424	4.48
	6.5	6	NOx	0.0038	0.06911	0.8972	0.42

* Probability value is less than 0.10, an indication that the emission differences are significant.

Table 2 (Continued)

Paired-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Fuel RVP (psi)	N	Poll	Mean Emission Difference (g/mi)	Standard Deviation	Probabilities that the Differences are from Random Error	Average Percent Emission Change
				EPA Data (1987 Vehicles)			
50	14.6	10	HC	-0.1197	0.55136	0.5097	-3.02
	vs.	10	CO	-3.2380	10.63600	0.3609	-10.08
	11.7	10	NOx	0.0760	0.10501	0.0479*	7.48
50	14.6	10	HC	0.0901	0.19988	0.1878	5.77
	vs.	10	CO	1.0070	3.79760	0.4234	5.39
	9.0	10	NOx	0.1260	0.13377	0.0155*	13.42
50	11.7	10	HC	0.2098	0.71109	0.3752	1.66
	vs.	10	CO	4.2450	14.12000	0.3666	5.89
	9.0	10	NOx	0.0500	0.11106	0.1883	5.97
				Chevron Data (1981-83 Vehicles)			
55	8.4	11	HC	-0.0453	0.03536	0.0017*	-10.56
	vs.	11	CO	-0.6707	0.90075	0.0331*	-7.91
	6.1	11	NOx	-0.0192	0.03536	0.1022*	-3.61
				API/ATL Data (1983-86 Vehicles)			
55	10.5	6	HC	0.0008	0.04873	0.9682	0.24
	vs.	6	CO	-0.0033	0.95143	0.9935	-2.13
	9.0	6	NOx	0.0100	0.09050	0.7975	1.81
55	10.5	6	HC	0.0200	0.05916	0.4453	2.51
	vs.	6	CO	0.1317	1.04910	0.7709	0.13
	8.0	6	NOx	-0.0250	0.07113	0.4286	-2.59
55	10.5	6	HC	-0.0200	0.08155	0.5742	-4.33
	vs.	6	CO	0.0217	1.32410	0.9696	-3.39
	6.5	6	NOx	-0.0100	0.09077	0.7981	-0.95

* Probability value is less than 0.10, an indication that the emission differences are significant.

Table 2 (Continued)

Paired-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Fuel RVP (psi)	N	Poll	Mean Emission Difference (g/mi)	Standard Deviation	Probabilities that the Differences are from Random Error	Average Percent Emission Change
				API/ATL Data (Continued)			
55	9.0	6	HC	0.0192	0.05181	0.4064	1.97
	vs.	6	CO	0.1350	0.96958	0.7469	1.85
	8.0	6	NOx	-0.0350	0.09165	0.3925	-5.65
55	9.0	6	HC	-0.0208	0.04488	0.3070	-4.30
	vs.	6	CO	0.0250	0.78920	0.9412	-0.76
	6.5	6	NOx	-0.0200	0.06388	0.4777	-3.54
55	8.0	6	HC	-0.0400	0.04940	0.1041*	-6.75
	vs.	6	CO	-0.1100	0.64012	0.6913	-3.77
	6.5	6	NOx	0.0150	0.11962	0.7711	1.15
				CARB Data (1983-88 Vehicles)			
75	8.6	4	HC	-0.0095	0.01555	0.3089	-4.14
	vs.	4	CO	-0.2375	0.43485	0.3546	-2.46
	7.2	4	NOx	0.0025	0.03304	0.8893	-3.03
				API/ATL Data (1983-86 Vehicles)			
80	10.5	6	HC	0.0300	0.03271	0.0746*	7.82
	vs.	6	CO	0.6050	1.10700	0.2383	13.88
	9.0	6	NOx	-0.0167	0.08920	0.6664	-2.92
80	10.5	6	HC	0.0558	0.05748	0.0632*	13.19
	vs.	6	CO	1.1400	1.59360	0.1401	20.55
	8.0	6	NOx	-0.0108	0.10500	0.8105	-2.93
80	10.5	6	HC	0.0208	0.03917	0.2494	7.51
	vs.	6	CO	1.0013	1.59720	0.1852	16.86
	6.5	6	NOx	-0.0258	0.07883	0.4586	-3.78
80	9.0	6	HC	0.0258	0.04364	0.2067	5.61
	vs.	6	CO	0.5350	1.26230	0.3468	5.55
	8.0	6	NOx	0.0058	0.09157	0.8821	-0.35

* Probability value is less than 0.10, an indication that the emission differences are significant.

Table 2 (Continued)

Paired-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Fuel RVP (psi)	N	Poll	Mean Emission Difference (g/mi)	Standard Deviation	Probabilities that the Differences are from Random Error	Average Percent Emission Change
				API/ATL Data (Continued)			
80	9.0	6	HC	-0.0092	0.05572	0.7036	-0.90
	vs.	6	CO	0.3963	1.09570	0.4162	2.69
	6.5	6	NOx	-0.0092	0.05435	0.6966	-1.02
80	8.0	6	HC	-0.0350	0.08283	0.3481	-8.50
	vs.	6	CO	-0.1387	0.86434	0.7105	-7.51
	6.5	6	NOx	-0.0150	0.06964	0.6203	-1.21

Table 3

Student-t Test Results
Pre-1980 Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				Chevron Data (1973-76 Vehicles)				
55	HC	11.8	8	1.07	0.7036	0.5894	0.4108	0.64
		8.3	8	1.23		0.7034		
	CO	11.8	8	16.51	0.7292	81.8400	0.4496	0.63
		8.3	8	18.15		90.3830		
	NOx	11.8	8	1.41	0.9290	0.3878	0.4659	0.53
		8.3	8	1.44		0.4147		
75	HC	11.8	8	0.97	0.9322	0.6657	0.4708	0.53
		8.3	8	1.01		0.7050		
	CO	11.8	8	11.29	0.8763	68.5760	0.3298	0.56
		8.3	8	12.01		96.9190		
	NOx	11.8	8	1.42	0.9766	0.4328	0.4630	0.51
		8.3	8	1.43		0.4654		
				Exxon Data (1974-77 Vehicles)				
75	HC	11.8	8	1.13	0.9734	1.0317	0.3593	0.51
		9.4	8	1.15		1.3688		
	CO	11.8	8	11.42	0.9517	110.7300	0.4899	0.52
		9.4	8	11.74		112.9500		
	NOx	11.8	8	1.79	0.9597	0.4538	0.3777	0.48
		9.4	8	1.77		0.3554		
75	HC	11.8	8	1.13	0.9713	1.0317	0.4864	0.49
		9.1	8	1.11		1.0045		
	CO	11.8	8	11.42	0.9480	110.7300	0.4762	0.48
		9.1	8	11.07		105.6700		
	NOx	11.8	8	1.79	0.8183	0.4538	0.3306	0.41
		9.1	8	1.72		0.3217		
75	HC	11.8	8	1.13	0.9731	1.0317	0.3538	0.49
		8.8	8	1.11		1.3846		
	CO	11.8	8	11.42	0.9181	110.7300	0.3930	0.46
		8.8	8	10.89		89.5090		
	NOx	11.8	8	1.79	0.7723	0.4538	0.4527	0.61
		8.8	8	1.89		0.4981		
75	HC	11.8	8	1.13	0.9716	1.0317	0.3088	0.51
		6.8	8	1.15		1.5271		
	CO	11.8	8	11.42	0.8715	110.7300	0.4246	0.44
		6.8	8	10.58		95.4060		
	NOx	11.8	8	1.79	0.9511	0.4538	0.3389	0.48
		6.8	8	1.77		0.3275		

Table 3 (Continued)

Student-t Test Results
Pre-1980 Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				Exxon Data (Continued)				
75	HC	11.8	8	1.13	0.9311	1.0317	0.3410	0.53
		6.6	8	1.18		1.4230		
	CO	11.8	8	11.42	0.9260	110.7300	0.4851	0.47
		6.6	8	10.92		107.5400		
	NOx	11.8	8	1.79	0.7011	0.4538	0.4258	0.36
		6.6	8	1.66		0.3919		
75	HC	9.4	8	1.15	0.9466	1.3688	0.3467	0.47
		9.1	8	1.11		1.0045		
	CO	9.4	8	11.74	0.8996	112.9500	0.4661	0.45
		9.1	8	11.07		105.6700		
	NOx	9.4	8	1.77	0.8488	0.3554	0.4494	0.43
		9.1	8	1.72		0.3217		
75	HC	9.4	8	1.15	0.9499	1.3688	0.4941	0.48
		8.8	8	1.11		1.3846		
	CO	9.4	8	11.74	0.8683	112.9500	0.3834	0.44
		8.8	8	10.89		89.5090		
	NOx	9.4	8	1.77	0.7230	0.3554	0.3337	0.63
		8.8	8	1.89		0.4981		
75	HC	9.4	8	1.15	0.9976	1.3688	0.4445	0.50
		6.8	8	1.15		1.5271		
	CO	9.4	8	11.74	0.8232	112.9500	0.4148	0.42
		6.8	8	10.58		95.4060		
	NOx	9.4	8	1.77	0.9916	0.3554	0.4584	0.50
		6.8	8	1.77		0.3275		
75	HC	9.4	8	1.15	0.9600	1.3688	0.4802	0.52
		6.6	8	1.18		1.4230		
	CO	9.4	8	11.74	0.8782	112.9500	0.4750	0.44
		6.6	8	10.92		107.5400		
	NOx	9.4	8	1.77	0.7219	0.3554	0.4504	0.37
		6.6	8	1.66		0.3919		
75	HC	9.1	8	1.11	0.9995	1.0045	0.3413	0.50
		8.8	8	1.11		1.3846		
	CO	9.1	8	11.07	0.9718	105.6700	0.4161	0.49
		8.8	8	10.89		89.5090		
	NOx	9.1	8	1.72	0.5940	0.3217	0.2891	0.69
		8.8	8	1.89		0.4981		

Table 3 (Continued)

Student-t Test Results
Pre-1980 Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				Exxon Data (Continued)				
75	HC	9.1	8	1.11	0.9457	1.0045	0.2971	0.53
		6.8	8	1.15		1.5271		
	CO	9.1	8	11.07	0.9234	105.6700	0.4481	0.46
		6.8	8	10.58		95.4060		
	NOx	9.1	8	1.72	0.8541	0.3217	0.4909	0.57
		6.8	8	1.77		0.3275		
75	HC	9.1	8	1.11	0.9046	1.0045	0.3287	0.54
		6.6	8	1.18		1.4230		
	CO	9.1	8	11.07	0.9775	105.6700	0.4911	0.49
		6.6	8	10.92		107.5400		
	NOx	9.1	8	1.72	0.8578	0.3217	0.4006	0.43
		6.6	8	1.66		0.3919		
75	HC	8.8	8	1.11	0.9489	1.3846	0.4503	0.52
		6.8	8	1.15		1.5271		
	CO	8.8	8	10.89	0.9491	89.5090	0.4675	0.48
		6.8	8	10.58		95.4060		
	NOx	8.8	8	1.89	0.7115	0.4981	0.2969	0.36
		6.8	8	1.77		0.3275		
75	HC	8.8	8	1.11	0.9170	1.3846	0.4861	0.54
		6.6	8	1.18		1.4230		
	CO	8.8	8	10.89	0.9953	89.5090	0.4075	0.50
		6.6	8	10.92		107.5400		
	NOx	8.8	8	1.89	0.5033	0.4981	0.3799	0.27
		6.6	8	1.66		0.3919		
75	HC	6.8	8	1.15	0.9636	1.5271	0.4641	0.52
		6.6	8	1.18		1.4230		
	CO	6.8	8	10.58	0.9467	95.4060	0.4393	0.53
		6.6	8	10.92		107.5400		
	NOx	6.8	8	1.77	0.7244	0.3272	0.4095	0.37
		6.6	8	1.66		0.3919		

Table 4

Student-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				Chevron Data (1981-83 Vehicles)				
43	HC	11.4	13	0.54	0.8817	0.1198	0.4644	0.56
		8.1	13	0.56		0.1263		
	CO	11.4	13	10.22	0.9315	52.1010	0.4688	0.53
		8.1	13	10.47		54.5590		
	NOx	11.4	13	0.55	0.9323	0.1421	0.4379	0.53
		8.1	13	0.56		0.1558		
				API/ATL Data (1983-86 Vehicles)				
42	HC	10.5	6	0.70	0.9424	0.1375	0.4971	0.53
		9.0	6	0.71		0.1366		
	CO	10.5	6	10.47	0.9532	26.8440	0.4395	0.52
		9.0	6	10.65		30.9760		
	NOx	10.5	6	0.76	0.8378	0.0408	0.4770	0.58
		9.0	6	0.79		0.0386		
42	HC	10.5	6	0.70	0.9784	0.1375	0.4699	0.49
		8.0	6	0.69		0.1281		
	CO	10.5	6	10.47	0.8277	26.8440	0.4446	0.58
		8.0	6	11.11		23.5510		
	NOx	10.5	6	0.76	0.9721	0.0408	0.4955	0.51
		8.0	6	0.77		0.0403		
42	HC	10.5	6	0.70	0.9132	0.1375	0.2720	0.46
		6.5	6	0.68		0.0775		
	CO	10.5	6	10.47	0.9753	26.8440	0.4236	0.51
		6.5	6	10.56		22.3920		
	NOx	10.5	6	0.76	0.9978	0.0408	0.4821	0.50
		6.5	6	0.76		0.0425		
42	HC	9.0	6	0.71	0.9199	0.1366	0.4728	0.46
		8.0	6	0.69		0.1281		
	CO	9.0	6	10.65	0.8815	30.9760	0.3855	0.56
		8.0	6	11.11		23.5510		
	NOx	9.0	6	0.79	0.8650	0.0386	0.4815	0.44
		8.0	6	0.77		0.0403		

Table 4 (Continued)

Student-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				API/ATL Data (Continued)				
42	HC	9.0	6	0.71	0.8486	0.1366	0.2744	0.43
		6.5	6	0.68		0.0775		
	CO	9.0	6	10.65	0.9750	30.9760	0.3652	0.49
		6.5	6	10.56		22.3920		
	NOx	9.0	6	0.79	0.8417	0.0386	0.4592	0.43
		6.5	6	0.76		0.0425		
42	HC	8.0	6	0.69	0.9356	0.1281	0.2972	0.47
		6.5	6	0.68		0.0775		
	CO	8.0	6	11.11	0.8446	23.5510	0.4786	0.43
		6.5	6	10.56		22.3920		
	NOx	8.0	6	0.77	0.9746	0.0403	0.4776	0.49
		6.5	6	0.76		0.0425		
				EPA Data (1987 Vehicles)				
50	HC	14.6	10	0.81	0.7459	0.3468	0.0695*	0.62
		11.7	10	0.93		0.9768		
	CO	14.6	10	12.98	0.6204	78.5890	0.0211*	0.68
		11.7	10	16.22		334.3400		
	NOx	14.6	10	0.90	0.4124	0.0469	0.3365	0.21
		11.7	10	0.83		0.0351		
50	HC	14.6	10	0.81	0.7187	0.3468	0.3365	0.37
		9.0	10	0.72		0.2596		
	CO	14.6	10	12.98	0.7876	78.5890	0.3201	0.40
		9.0	10	11.97		57.0110		
	NOx	14.6	10	0.90	0.1837	0.0469	0.3519	0.10
		9.0	10	0.78		0.0361		
50	HC	11.7	10	0.93	0.5582	0.9768	0.0307*	0.29
		9.0	10	0.72		0.2596		
	CO	11.7	10	16.22	0.5060	334.3400	0.0073*	0.26
		9.0	10	11.97		57.0110		
	NOx	11.7	10	0.83	0.5610	0.0351	0.4833	0.29
		9.0	10	0.78		0.0361		

* Probability value is less than 0.10, an indication that the variance differences are significant.

Table 4 (Continued)

Student-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				Chevron Data (1981-83 Vehicles)				
55	HC	8.4	13	0.36	0.6719	0.0465	0.3617	0.66
		6.1	13	0.40		0.0573		
	CO	8.4	13	6.18	0.7344	15.2730	0.3158	0.63
		6.1	13	6.75		20.2720		
	NOx	8.4	13	0.63	0.9278	0.2009	0.4795	0.53
		6.1	13	0.65		0.2071		
				API/ATL Data (1983-86 Vehicles)				
55	HC	10.5	6	0.54	0.9965	0.0996	0.4636	0.50
		9.0	6	0.54		0.1085		
	CO	10.5	6	7.95	0.9990	20.6770	0.4715	0.50
		9.0	6	7.95		19.3310		
	NOx	10.5	6	0.79	0.9386	0.0383	0.3315	0.47
		9.0	6	0.78		0.0578		
55	HC	10.5	6	0.54	0.9125	0.0996	0.4537	0.46
		8.0	6	0.52		0.0892		
	CO	10.5	6	7.95	0.9602	20.6770	0.4652	0.48
		8.0	6	7.82		19.0470		
	NOx	10.5	6	0.79	0.8453	0.0383	0.3494	0.57
		8.0	6	0.80		0.0552		
55	HC	10.5	6	0.54	0.9177	0.0996	0.4420	0.54
		6.5	6	0.56		0.1142		
	CO	10.5	6	7.95	0.9933	20.6770	0.4214	0.50
		6.5	6	7.93		17.1600		
	NOx	10.5	6	0.79	0.9378	0.0383	0.3480	0.53
		6.5	6	0.80		0.0554		
55	HC	9.0	6	0.54	0.9180	0.1085	0.4177	0.46
		8.0	6	0.52		0.0892		
	CO	9.0	6	7.95	0.9585	19.3310	0.4937	0.48
		8.0	6	7.82		19.0470		
	NOx	9.0	6	0.78	0.8039	0.0578	0.4803	0.59
		8.0	6	0.82		0.0552		

Table 4 (Continued)

Student-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				API/ATL Data (Continued)				
55	HC	9.0	6	0.54	0.9160	0.1085	0.4783	0.54
		6.5	6	0.56		0.1142		
	CO	9.0	6	7.95	0.9921	19.3310	0.4496	0.50
		6.5	6	7.93		17.1600		
	NOx	9.0	6	0.78	0.8871	0.0578	0.4819	0.55
		6.5	6	0.80		0.0554		
55	HC	8.0	6	0.52	0.8324	0.0892	0.3967	0.58
		6.5	6	0.56		0.1142		
	CO	8.0	6	7.82	0.9652	19.0470	0.4558	0.52
		6.5	6	7.93		17.1600		
	NOx	8.0	6	0.82	0.9142	0.0552	0.4984	0.46
		6.5	6	0.80		0.0554		
				CARB Data (1983-88 Vehicles)				
75	HC	8.6	4	0.33	0.9595	0.0640	0.4967	-
		7.2	4	0.34		0.0647		
	CO	8.6	4	4.04	0.9282	11.2500	0.4235	-
		7.2	4	4.27		14.3310		
	NOx	8.6	4	0.45	0.9897	0.0733	0.4605	-
		7.2	4	0.45		0.0647		
				API/ATL Data (1983-86 Vehicles)				
80	HC	10.5	6	0.35	0.6989	0.0192	0.3944	0.36
		9.0	6	0.32		0.0149		
	CO	10.5	6	4.35	0.6275	4.9908	0.3831	0.33
		9.0	6	3.75		3.7726		
	NOx	10.5	6	0.89	0.9125	0.0719	0.4193	0.54
		9.0	6	0.90		0.0593		
80	HC	10.5	6	0.35	0.4307	0.0192	0.1989	0.23
		8.0	6	0.30		0.0086		
	CO	10.5	6	4.35	0.2858	4.9908	0.0657*	0.16
		8.0	6	3.21		1.1420		
	NOx	10.5	6	0.89	0.9401	0.0719	0.3237	0.53
		8.0	6	0.90		0.0467		

* Probability value is less than 0.10, an indication that the variance differences are significant.

Table 4 (Continued)

Student-t Test Results
1980+ Vehicles

Amb Temp. (°F)	Poll	Fuel RVP (psi)	N	Average Emissions (g/mi)	t-prob.	Variance	f-prob.	Prob. 1st Mean is < 2nd
				API/ATL Data (Continued)				
80	HC	10.5	6	0.35	0.8137	0.0192	0.3838	0.41
		6.5	6	0.33		0.0253		
	CO	10.5	6	4.35	0.3521	4.9908	0.0859*	0.19
		6.5	6	3.35		1.3246		
	NOx	10.5	6	0.89	0.8680	0.0719	0.4628	0.56
		6.5	6	0.91		0.0658		
80	HC	9.0	6	0.32	0.6883	0.0149	0.2794	0.35
		8.0	6	0.30		0.0086		
	CO	9.0	6	3.75	0.5676	3.7726	0.1078*	0.29
		8.0	6	3.21		1.1420		
	NOx	9.0	6	0.90	0.9659	0.0593	0.3994	0.48
		8.0	6	0.90		0.0467		
80	HC	9.0	6	0.32	0.9131	0.0149	0.2874	0.54
		6.5	6	0.33		0.0253		
	CO	9.0	6	3.75	0.6763	3.7726	0.1377	0.35
		6.5	6	3.35		1.3246		
	NOx	9.0	6	0.90	0.9507	0.0593	0.4560	0.52
		6.5	6	0.91		0.0658		
80	HC	8.0	6	0.30	0.6514	0.0086	0.1299	0.67
		6.5	6	0.33		0.0253		
	CO	8.0	6	3.21	0.8331	1.1420	0.4373	0.58
		6.5	6	3.35		1.3246		
	NOx	8.0	6	0.90	0.9150	0.0467	0.3576	0.54
		6.5	6	0.91		0.0658		

* Probability value is less than 0.10, an indication that the variance differences are significant.

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APPENDIX

Table A1

List of Test Vehicles
1975 Chevron Research Test program
(All California Vehicles)

Veh.#	Model Year	Make/Model	Engine CID	Carb Bbl	Transmission Auto/Mannal
1	1973	Plymouth Fury	360	2	A
2A*	1973	Pontiac Catalina	400	2	A
2B*	1973	Pontiac Catalina	400	2	A
3	1974	Volkswagon Super Beetle	98	1	M-4
4	1975	Chevrolet Impala	350	4	A
5	1975	Ford LTD	400	2	A
6	1975	Ford Pinto	140	2	A
7	1976	Oldsmobile Cutlass	350	4	A

* Vehicles #2A and #2B were the same vehicle, #2A was tested with the original carburetor and #2B was tested with a replacement carburetor.

Table A2

List of Test Vehicles
1979 Exxon Research Test Program
(All Automatic Transmission Vehicles)

Veh.#	Model Year	Make/Model	Engine CID	Carb Bbl	Catalyst Equipped
A	1976	Ford LTD	400	2	yes
B	1975	Olds	455	4	yes
C	1974	Valiant	225	1	no
D	1974	Vega	140	2	no
E	1977	Granada	302	2	yes
F	1976	Buick	350	2	yes
G	1975	Dodge	318	2	yes
H	1974	Grand Prix	400	4	no

* Vehicles B, E, and G were California vehicles. The engines of vehicles B and G had been overhauled previously, at 3,000 and 6,000 miles, respectively, prior to the testing.

Table A3

List of Test Vehicles
1988 CARB Five-Car Evaluation Project
(All California Vehicles)

Veh.#	Model Year	Make/Model	Engine	# of Cyl	Fuel System
1	1987	Olds Delta 88	3.8L	6	PFI
2	1987	Toyota Camry	2.0L	4	PFI
3	1988	Ford Tempo	2.5L	4	TBI
4	1983	Toyota Tercel	1.5L	4	Carb
5*	1978	Chevrolet Caprice	5.0L	8	Carb

* Vehicle was analyzed separately, since this vehicle was built for compliance with a different evaporative emission standard.

Table B1

List of Test Vehicles
1988 Chevron Research Test Program
(All California Vehicles)

Veh.#	Model Year	Make/Model	Phase	Engine	Displ (Liter)	Fuel System	Trans Auto/ Manual
1	1981	Dodge Aries	I,II	L-4	2.6	Carb	A
2*	1982	Chev Cavalier	I,II	L-4	1.8	Carb	A
3	1982	Olds Ciera	I,II	L-4	2.5	TBI	A
4	1983	Honda Accord	I,II	L-4	1.8	Carb	M-5
5	1982	Ford Escort	I,II	L-4	1.6	Carb	A
6	1983	Chev Cavalier	I	L-4	2.0	TBI	A
7	1981	Datsun 210	I,II	L-4	1.2	Carb	M-5
8	1983	Datsun Maxima	I,II	L-6	2.4	PFI	A
9	1983	Olds Cutlass	I,II	V-6	3.8	Carb	A
10	1983	Mazda GLC	I,II	L-4	1.5	Carb	M-4
11	1983	Toyota Corolla	I	L-4	1.6	Carb	M-5
12	1982	Toyota Corolla	II	L-4	1.8	Carb	M-5
13	1983	Lincoln Town Car	II	V-8	5.0	TBI	A
14**	1983	Toyota SR-5 Pickup	I,II	L-4	2.4	Carb	M-5

* Vehicle was tested with the original carburetor on Phase I, and with the replaced carburetor on Phase II.

** Vehicle was excluded from the analysis, since this vehicle was categorized as a truck.

Table B2

List of Test Vehicles
1987 API/ATL Test Program
(All Federal Vehicles with Automatic Transmission)

Veh.#	Model Year	Make/Model	Engine	Fuel System
CD-1	1985	Olds Cutlass	3.8L	Carb 2V
CD-2	1986	Pontiac Grand AM	3.0L	PFI
CD-3	1983	Mercury Cougar	3.8L	Carb 2V
CD-4	1985	Ford T-Bird	5.0L	TBI
CD-5	1985	Plymouth Horizon	2.2L	Carb 2V
CD-6	1985	Chev Cavalier	2.0L	TBI

Table B3

List of Test Vehicles
EPA/E&D Test Program
(All Federal Vehicles)

Veh #	Model Year	Make/Model	CID	Fuel System
1	1987	Pontiac 6000	151	TBI
3	1987	Ford Taurus Wagon	182	PFI
6	1987	Dodge Shadow	135	TBI
7	1987	Ford Taurus Wagon	182	PFI
10	1987	Olds Cutlass	173	PFI
19	1987	Chrysler Lebaron	135	PFI
20	1987	Mercury Cougar	231	TBI
35	1987	Chev Cavalier	121	TBI
43	1987	Pontiac 6000	151	TBI
56	1987	Chev Cavalier	121	TBI