EPA-AA-TEB-EF-88-01

Analysis of Impact of Fuel RVP on Exhaust Emissions at 75°F Ambient Temperature

by

Celia Shih

May 12, 1988

Test and Evaluation Branch
Emission Control Technology Division
Office of Mobile Sources
U.S. Environmental Protection Agency

TABLE OF CONTENTS

1.0 BACKGROUND

In the summer of 1985, a study was conducted to evaluate the potential exhaust emission benefits from fuel volatility control. In the Emission Factor (EF) programs, vehicles were tested at three different fuels with Reid Vapor Pressure (RVP) at 9.0, 10.4, and 11.7 psi. Test data from a total of 207 light-duty gasoline-powered vehicles (LDGVs) were examined (Ref. 1). These consisted of all 1981 and newer model year vehicles. It was concluded that vehicles tested with higher RVP fuels had higher exhaust HC and CO emissions. The effect of fuel RVP on NOx emissions, however, was found to be nonsignificant.

The draft Regulatory Impact Analysis (RIA) for volatility control discussed the impact of fuel volatility on exhaust HC emissions based on a total of 322 vehicles from EF three-fuel testing (Ref. 2, pp. 2-110 to 2-120). The relationships between the exhaust HC and CO emissions and fuel RVP were assumed to be linear. Regression coefficients were derived for HC and CO emissions for 1981 and later model year LDGVs.

For pre-1981 LDGVs, the regressions of HC and CO emissions as a function of fuel RVP were developed from a small data base of nineteen 1978-80 model year vehicles tested at Automotive Testing Laboratories (ATL). Sixteen of the vehicles were part of the test program at ATL under a contract with the American Petroleum Institute (Ref. 3). Three vehicles were tested at ATL under an EPA contract (Ref. 4).

In the MOBILE emission prediction model, the basic exhaust emissions are derived from tests with Indolene fuel (the certification fuel with RVP at 9.0 psi). To properly account for the in-use fuels, which are usually higher than 9.0 psi in RVP, correction factors are used to adjust the estimated exhaust HC and CO emissions. The RVP correction factors for LDGVs used in MOBILE3 Version 9 (M3V9) were based on linear regression coefficients (summarized in Table 1). The same RVP correction factors were also used for other gasoline-powered vehicle types in M3V9.

Many more vehicles have been tested in the EF programs since M3V9. It was also suggested that the relationship between the exhaust emissions and fuel RVP might not be linear for certain types of vehicles. Therefore, the impact of fuel volatility on exhaust emissions was analyzed again so that more updated RVP correction factors could be used for MOBILE4.

2.0 LIGHT-DUTY GASOLINE-POWERED VEHICLES (LDGVs)

2.1 Data Base

There were no additional data on fuel RVP versus exhaust emissions from pre-1981 model year vehicles. The correction factors developed for M3V9 for the pre-1981 LDGVs are to be used again for MOBILE4.

Between August 1984 and July 1986, a total of 324 LDGVs were tested in EF programs on three RVP fuels. The three fuels used were: Indolene, a summer-grade commercial fuel, and a fuel blended from the other two fuels, with RVPs about 9.0, 11.7, and 10.4 psi, respectively. Many more vehicles, especially model years 1983+ vehicles, have been tested since July 1986 with two fuels (Indolene and commercial fuels). The current analysis was based on all available model years 1981+ LDGV data, including those used in the previous two studies. Some vehicles tested between October 1983 and July 1984 on three RVP fuels were excluded from this analysis, since they were tested with different test procedure.

2.2 Results From Paired t-Test

The statistical tool used to examine the fuel volatility effect on exhaust emissions was the paired t-test. As every vehicle in the sample was tested using both the commercial and Indolene fuels, the emission differences for each pair of tests were calculated. The paired t-test is a test of the hypothesis that the mean of the emission differences is zero. Various technology groups based on vehicle's exhaust emission control technologies (open loop versus closed loop), certified CO emission standards (7.0 g/mi or 3.4 g/mi), model years (1981-82 and 1983+), and fuel metering systems (carbureted, ported fuel-injected, and throttle body fuel-injected) were used as strata when performing the paired t-test. No comparison was made for 1981-82 model year throttle body fuel-injected vehicles that were certified at 3.4 g/mi CO standard because of the small sample size (N = 2). The results of the paired t-test are summarized in Table 2. The values listed in Table 2 are the probabilities that the mean differences are due to random error. Therefore, small numerical values of the probabilities are equivalent to high significance levels of the fuel volatility effect on emission differences. The following observations are noted:

1. The means of the CO emission differences are significantly different from zero for all technology groups.

2. For HC emissions, the fuel volatility effects are significant for most of the technology groups. A few

exceptions are: model year 1981-82 carbureted vehicles (both open and closed loop) certified at 3.4 CO standard, and 1983+ throttle body fuel-injected vehicles.

3. The fuel volatility effects on NOx emissions are significant for all 1983+ vehicles, but are mostly nonsignificant for model years 1981-82 vehicles.

The paired t-statistic was also used to examine the fuel volatility effect on exhaust emissions on a bag-by-bag basis. For the third bag emissions of the FTP (the hot start portion), the same conclusions as for the FTP composite can be made. For the emissions from the other two bags (the cold start and the stabilized portions), no consistent trends were noted.

2.3 Regression Results

The technique of analysis of covariance was used on the emission versus fuel RVP data, with technology groups being the covariate. The analysis of covariance tests whether the slope terms are statistically significant, and also tests whether the different technology groups have equal slopes and intercepts. When the hypothesis of equal slopes was accepted, the intercept values were also examined to see if certain technology groups could be combined.

Basically, two types of regressions were considered: non-linear and linear models. Results from a second degree polynomial model showed both the first and second degree coefficient terms to be nonsignificant for all three pollutants. The choice was between a log-linear and linear model. The predicted HC and CO emissions from a linear model were very close to the arithmetic means at 10.4 RVP fuel, but were always lower than the arithmetic means at the 11.7 RVP fuel. Therefore, a log-linear model was used to describe the relationships between fuel volatility and HC and CO exhaust emissions. For NOx emissions, a linear model was found to be adequate. The results are summarized as follows:

1. Different slopes were to be used for model years 1981-82 and 1983+ vehicles. The slope term for NOx emissions of the 1981-82 vehicles was found to be nonsignificant. This is consistent with the paired t-test results discussed above, which found that there was no fuel volatility effect on model year 1981-82 NOx emissions.

2. For the HC and CO emissions of the 1981-82 model year vehicles, common slopes were to be used for all technology groups.

3. Equal slope and equal intercept terms were to be used among the technology groups for all three pollutants for the 1983+ carbureted and fuel-injected vehicles.

The regression coefficients for each technology group are summarized in Table 3. To obtain the RVP correction factors by model year group from the regression coefficients for MOBILE4, the following procedures were used. For the HC and CO emissions of the model year 1981-82 vehicles, the overall regression coefficients were derived from the coefficients of the technology subgroups weighted by their market shares. The market share values, summarized in Table 4, were based on actual sales from EPA's Corporate Average Fuel Economy (CAFE) files. The coefficients of the 1983+ vehicles were used directly as the overall regression coefficients. The RVP correction factors were then developed by normalizing the overall regression equations at the Indolene fuel RVP level. The resulting RVP correction factors for MOBILE4 are summarized in Table 5. Note that the sales weighted constant terms of the HC and CO RVP correction factors for model years 1981 and 1982 were very similar. The emission control system technologies of these two model years were not different. Based on these reasons, the model years 1981 and 1982 were combined, the average of the two constant terms were used to represent the 1981-82 model year vehicles.

Note that the above regression results were derived from fuels with average RVPs between 9.0 and 11.7 psi. Since vehicles are designed for EPA's certification test using 9.0 psi RVP fuel, this should be used as the lower limit. The correction factors for fuels at lower than 9.0 psi RVP are assumed to be 1.0 (that is, no fuel volatility effect on exhaust emissions). Correction factors for fuel RVPs higher than 11.7 psi could be calculated from equations in Table 5. However, the calculated results are extrapolated and may not be reasonable, particularly for fuels with RVP much higher than 11.7 psi and at high temperatures.

2.4 Comparisons

The following table is a comparison of the LDGV RVP correction factors for a commercial fuel at 11.7 psi RVP. The correction factors for M3V9 were calculated from coefficients listed in Table 1, while those for MOBILE4 were calculated from coefficients listed in Table 5.

		Correction Factor for RVP = 11.7 Fuel		
Source	Model Year	HC	CO	NOx
MOBILE4	1971-80	1.050	1.089	1.000
	1981-82	1.176	1.208	1.000
	1983+	1.241	1.310	1.069
M3V9	1972-80	1.050	1.089	1.000
	1981+	1.111	1.232	1.000

As can be seen, for a commercial fuel at 11.7 psi RVP the MOBILE4 correction factors are slightly higher than those from M3V9 for HC emissions, and for the CO and NOx emissions of the 1983+ vehicles. Correction factors at various RVP levels are shown in Figures 1 and 2 for the HC and CO emissions. The differences between the correction factors of M3V9 and MOBILE4 are small. The MOBILE4 correction factors also characterize the exhaust emission differences between the model years 1981-82 and 1983+ vehicles.

Note that the MOBILE4 correction factors for the model years 1971-80 are the same as those from M3V9 for the model years 1972-80. (The model year range of 1972-80 in M3V9 was an error. Since 1971 was the first year that evaporative emission standard applied to all Federal region light duty gasoline powered vehicles, the correction factors should apply to model year 1971 LDGVs also.)

2.5 Temperature and RVP Interactions

The current analysis on the relationship between fuel volatility and exhaust emissions was based on FTP results, i.e., at an ambient temperature range of 68 to 86° F. From limited testing done at Ann Arbor and some vehicles tested at ATL, where a combination of different ambient temperatures and fuel RVP were used, data suggested that the relationship of fuel volatility and exhaust emissions at high RVP fuels and high ambient temperatures may not be linear. At low ambient temperatures (for example, at 20° F), however, there appears to be no fuel volatility effect on exhaust emissions.

At the present time, there are not enough data for a thorough analysis of fuel volatility effect on exhaust emissions outside of the FTP temperature ranges. This is an area for future planning of EF test programs. Ideally, there should be at least forty vehicles tested at three different RVP levels and at five ambient temperatures (20, 50, 75, 85, and 95° F) so that the relationship among the fuel volatility, ambient temperature, and exhaust emissions can be quantified with confidence. This ideal program, of course, would have to be scaled to resource availability. In addition to fuel RVP, other fuel properties (e.g., 90% distillation point) should also be carefully considered in designing this ideal program.

Currently some vehicles are being tested under a contract with ATL at the ambient temperature of 50° F with 9.0 and 11.7 RVP fuels. A preliminary analysis of these data showed that there was a fuel volatility effect on exhaust emissions at 50° F. Based on these available data, an algorithm was developed to account for the impact of temperature and RVP interaction. This algorithm was described in a separate technical note as a part of the MOBILE4 derivation document (Ref. 5).

3.0 OTHER VEHICLE TYPES

In M3V9, the RVP correction factors for LDGVs were also used for other gasoline powered vehicle types, such as light-duty gasoline-powered class 1 and class 2A trucks (LDGT1s and LDGT2s), and heavy-duty gasoline-powered vehicles (HDGVs). The following shows the mapping of LDGV model year groups to other vehicle types, according to their equivalent emission control technologies:

LDGV Model Year	LDGT1 Model Year	LDGT2 Model Year	HDGV Model Year
1972-80	1972-87	1979-87	1985+
1981+	1988+	1988+	-

Since August 1984, a total of 92 light-duty gasoline-powered trucks (LDGTs) were tested in EF programs on both the Indolene and commercial fuels. The model years of these trucks ranged from 1982 to 1986. The data were divided into four subgroups by their emission standards and fuel metering systems. The sample sizes for each subgroup were small (22 for model year 1982, 26 for model year 1984, 26 for 1985-86 carbureted, and 18 for 1985-86 fuel-injected). The fuel volatility effect on CO emissions was found to be significant. However, the fuel volatility effect on HC and NOx emissions was mixed with no specific trend. Until enough data are available to allow the development of a separate set of LDGT RVP correction factors, the RVP correction factors developed from LDGVs will also be used for trucks.

There were no HDGV data available. The LDGV RVP correction factors will be used also for model years 1985 and later HDGVs. As there were no evaporative emission standards for the pre-1985 HDGVs, no fuel volatility effect on their exhaust emissions is assumed.

The mapping of LDGV model year groups to other vehicle types in MOBILE4 for RVP correction factors is the following:

LDGV Model Year	LDGT1 Model Year	LDGT2 Model Year	HDGV Model Year
1971-80	1971-83	1979-83	1985+
1981	1984	1984	-
1982	1985	1985	-
1983+	1986+	1986+	-

These new mappings of LDGV model year groups to LDGT1s and LDGT2s were based on the similarities in their emission control technologies, such as open loop vs. closed loop, catalyst without vs. with air pump. Also, a high percentage of the 1986+ light duty truck fleet was fuel-injected, similar to the 1983+ light duty vehicle fleet.

4.0 CONCLUSIONS

The effect of fuel volatility on exhaust emissions was examined. The data base consisted of all model years 1981 and newer LDGVs tested at different RVP fuels. The results from the paired t test showed that the effects of fuel volatility on CO and HC emissions are significant. The fuel volatility effects on NOx emissions are significant for all 1983+ vehicles. The RVP correction factors were developed from the data for MOBILE4. These RVP correction factors were also to be used for other gasoline-powered vehicle types.

The impact of temperature and fuel RVP interaction on exhaust emissions appears to be an area for further analysis, pending the availability of additional test data.

Table 1

RVP Correction Factors* for LDGVs
MOBILE3 Version 9

Model Year Group	Pollutant	Coefficient A	Coefficient B	Coefficient DN**
1972-80***	HC	0.56222	0.012512	0.67483
	CO	7.16560	0.334130	10.17277
1981+	HC	0.59295	0.038720	0.94143
	CO	2.54790	0.959900	11.18700

* Correction Factor = (A + B*RVP)/DN where DN = (A + B*RVP) at RVP = 9.0.

** In M3V9, DN was erroneously defined at RVP = 11.5.

*** Regression coefficients were derived from data on model years 1978-80 vehicles.

Table 2

Paired t-Test Results
Comparison of LDGV Exhaust Emissions Between
Commercial and Indolene Fuels

Technology Group	N	Probabilities that Differences Are from Random Error		
		HC	CO	NOx
All Vehicles	544	0.0000	0.0000	0.0000
Carbureted	296	0.0000	0.0000	0.0000
Open Loop	47	0.0108	0.0019	0.2798
(81,82) 3.4 CO Std	16	0.3150	0.0279	0.6264
(81,82) 7.0 CO Std	19	0.0680	0.0471	0.1873
1983+	12	0.0412	0.0101	0.0521
Closed Loop	249	0.0000	0.0000	0.0017
(81,82) 3.4 CO Std	60	0.2431	0.0018	0.6409
(81,82) 7.0 CO Std	80	0.0000	0.0000	0.0584
1983+	109	0.0002	0.0000	0.0002
Fuel Injected	248	0.0525	0.0001	0.0000
Ported	109	0.0000	0.0000	0.0000
(81,82) 3.4 CO Std	13	0.0005	0.0115	0.3381
1983+	96	0.0000	0.0000	0.0000
Throttle Body	139	0.4286	0.0074	0.0049
(81,82) 3.4 CO Std	2			
(81,82) 7.0 CO Std	21	0.0468	0.1467	0.5554
1983+	116	0.6560	0.0206	0.0000

Table 3

LDGV Regression Results

Technology Group	Regression Coefficients**					
	HC		CO		NOx	
	A	B	A	B	A	B
Model Years 1981-82 Vehicles						
Carbureted Open Loop						
3.4 CO std	-0.94	0.06	1.14	0.07	1.14	0.01*
7.0 CO std	-0.56	0.06	1.96	0.07	0.66	0.01*
Carbureted Closed Loop						
3.4 CO std	-0.91	0.06	1.59	0.07	0.92	0.01*
7.0 CO std	-0.79	0.06	1.78	0.07	1.06	0.01*
Fuel-injected						
Ported	-1.27	0.06	1.10	0.07	1.22	0.01*
Throttle Body	-1.25	0.06	1.22	0.07	1.18	0.01*
Model Years 1983+ Vehicles						
All	-1.88	0.08	0.36	0.10	0.60	0.02

* Coefficient is nonsignificant at 80 percent significance level.

** Regression models are:
HC or CO emissions = EXP(A + B*RVP),
NOx emissions = A + B*RVP

Table 4

Market Shares of the Model Year
1981-82 LDGVs

Fuel System	Catalyst Tech.	CO Standard	Market Share* 1981	1982
Carbureted	Open Loop	3.4	0.174	0.125
		7.0	0.107	0.205
Carbureted	Closed Loop	3.4	0.173	0.072
		7.0	0.462	0.427
PFI	Closed Loop	0.057	0.062	
TBI	Closed Loop	0.027	0.109	

*Source: Actual sales from EPA's CAFE files.

Table 5

RVP Correction Factors* for LDGVs
MOBILE4

Model Year Group	Pollutant	Coefficient A	Coefficient B	Coefficient DN
1971-80**	HC	0.56222	0.012512	0.67483
	CO	7.16560	0.334130	10.17277
1981	HC	-0.8520	0.06	0.7320
	CO	1.6012	0.07	9.3110
1982	HC	-0.8501	0.06	0.7334
	CO	1.6200	0.07	9.4877
1981-82***	HC	-0.8511	0.06	0.7326
	CO	1.6106	0.07	9.3990
1983+	HC	-1.88	0.08	0.3135
	CO	0.36	0.10	3.5254
	NOx	0.60	0.02	0.78

* Correction Factor = EXP(A + B*RVP)/DN
where DN = EXP(A + B*RVP) at RVP = 9.0
for 1981+ HC and CO emissions and,
Correction Factor = (A + B*RVP)/DN
where DN = (A + B*RVP) at RVP = 9.0
for pre-1981 HC and CO, and 1983+ NOx emissions.

** The same correction factors used in M3V9.

*** Average of the separate 1981 and 1982 constant terms were to be used for the 1981-82 model years.

References

1. "Relationship between Exhaust Emissions and Fuel Volatility," EPA memorandum from Thomas L. Darlington to Charles L. Gray, Jr., June 24, 1985.

2. Draft Regulatory Impact Analysis: Control of Gasoline Volatility and Evaporative Hydrocarbon Emissions from New Motor Vehicles, US EPA, July 1987.

3. "A Study of Factors Influencing the Evaporative Emissions from In-Use Automobiles," Health and Environmental Sciences Department, API Publication No. 4406, April 1985.

4. Under an EPA contract, the Automotive Testing Laboratory at East Liberty, Ohio tested a total of 56 light-duty gasoline powered vehicles at three RVP fuels (9.0, 10.4, and 11.7 psi) and three different ambient temperatures to quantify the effects of fuel RVP and temperature on evaporative emissions. The exhaust emission results from the three 1980 model year vehicles were used in M3V9 to derive the RVP correction factors on exhaust emissions.

5. MOBILE4 Derivation Notes, Appendix 8-A, April 1988.

Figure 1

Effect of Fuel Volatility on LDGV HC Emissions

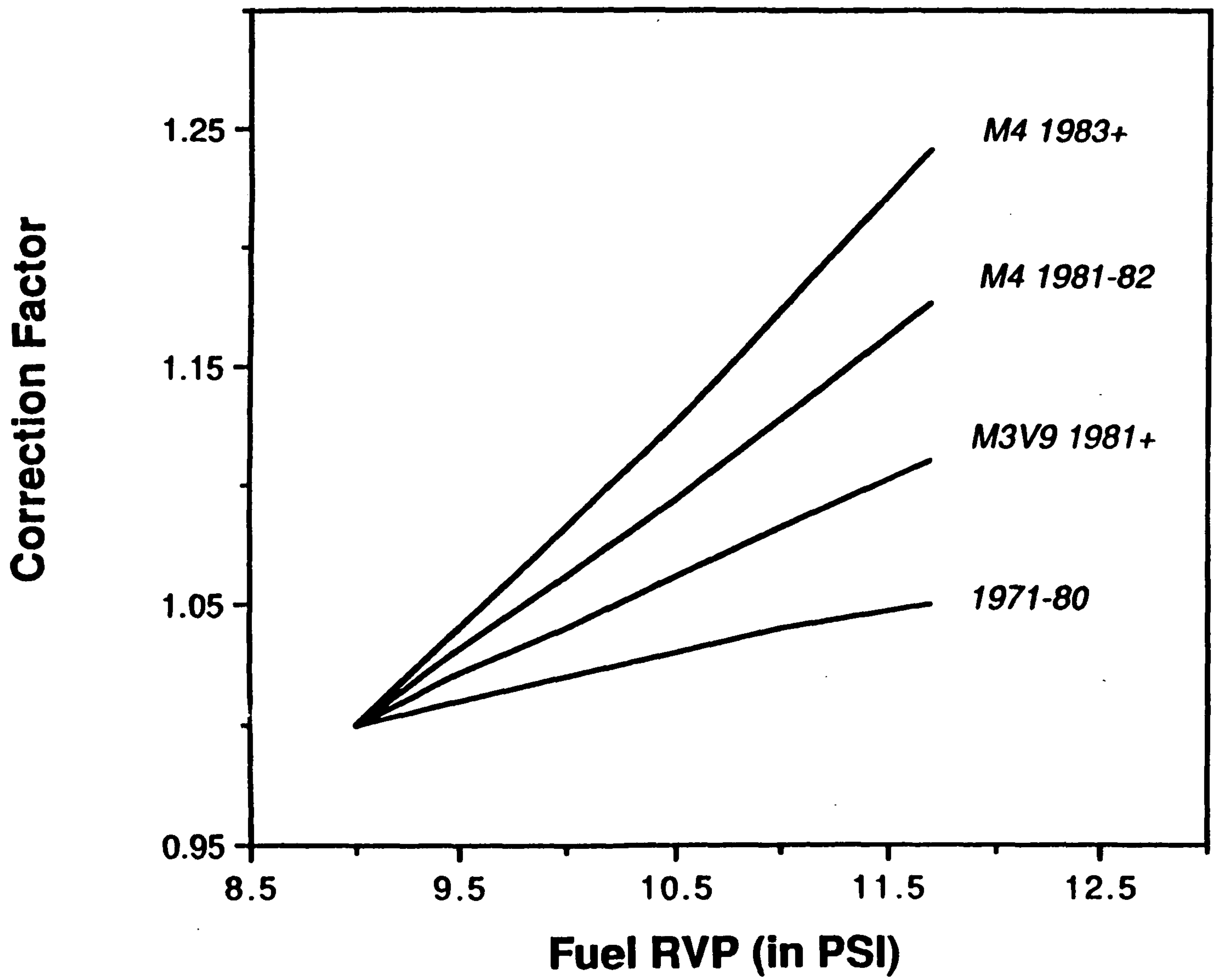

Figure 2

Effect of Fuel Volatility on LDGV CO Emissions