Section 4.12 TOTAL PARTICULATE MATTER EMISSION FACTORS

This section discusses the development of particulate matter (PM) exhaust emission factors from gasoline-powered vehicles for EMFAC2000. It also outlines the methodology for calculating tire-wear and brake-wear emission factors for all vehicles.

4.12.1 Introduction

When MVEI7G was released, there were very little PM exhaust emissions data available from gasoline-fueled vehicles. For this reason, the gasoline PM exhaust emission factors in MVEI7G were taken from U.S. EPA's PART5 model, which is the PM portion of MOBILE5.

PM emissions from gasoline-powered vehicles have become a greater concern as a result of U.S. EPA's decision to regulate PM2.5. It is believed that most of the PM from gasoline-powered vehicles is in the PM2.5 micron diameter range. For this reason, several test projects were conducted to gain more knowledge about the characteristics of PM from these vehicles. Data sources from the following studies were considered when determining PM emission factors for EMFAC2000.

The ARB contracted with the College of Engineering-Center for Environmental Research and Technology (CE-CERT) to characterize PM emissions from gasoline-powered vehicle exhaust. The resulting report is titled, "Characterization of Particulate Emissions from Gasoline-Fueled Vehicles", dated May 1998. In Phase 1 of the project, three passenger vehicles - one without a catalyst, one with an oxidation catalyst, and one with a three-way catalyst, were tested on both the Unified Cycle (UC) and the Federal Test Procedure (FTP). These tests were conducted using California's Phase 1 fuel as well as cleaner burning gasoline. In Phase 2 of the project, 24 passenger vehicles of various technology types were tested on the UC using California's cleaner burning gasoline.

A test program conducted by Southwest Research Institute (SwRI), included PM data from 39 passenger vehicles, 14 light duty trucks and seven visibly smoking vehicles. The test procedures and data analysis are summarized in a report titled, "Measurement of Primary Exhaust Particulate Matter Emissions From Light-Duty Motor Vehicles," dated November 1998. All of the vehicles in this program were tested only on the FTP, and the smoking vehicles were identified as those vehicles that emitted visible smoke in nearly every operating condition.

In the National Cooperative Highway Research Program (NCHRP) study, "Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles," dated December 1998, 67 passenger vehicles and 62 light duty trucks were tested on the FTP. Thirty-nine of the vehicles were deemed high gaseous emitters. A Tier 0 vehicle was defined as a high gaseous emitter if the HC or CO emissions were two times the certification standard, or the NOx emissions were four times the standard. A Tier 1 vehicle was considered a high gaseous emitter if the HC, CO or NOx emissions were one and a half times the certification standard.

The last available study that collected PM emissions data was conducted by the Coordinating Research Council (CRC). Its report is titled, "In-Use Light-Duty Gasoline Vehicle Particulate Matter Emissions on the FTP, REP05, and UC Cycles," dated June 1999. This test project included 24 properly functioning vehicles and 6 high CO emitters. The vehicles were tested at 35°F using the FTP, UC, and REP05 driving cycles. Sixteen of the vehicles were passenger cars and 8 were light duty trucks. A vehicle was considered a high CO emitter if the emission rate was at least 30 g/mi.

4.12.2 Data Analysis

The test fleets for both the SwRI and NCHRP studies were biased towards smoking or high gaseous emitter vehicles. SwRI defined a vehicle as a "smoker" if it was visibly smoking during most operating conditions, and NCHRP defined a high emitter based on the vehicle's gaseous emissions relative to its standards. Neither study, though, provided a clear indication of how to identify high particulate matter emitters. An attempt was made to find a relationship between PM and CO emissions from both of these studies; however, the correlation was insignificant. As more data becomes available in the future, this method of determining PM emissions may become more feasible.

CE-CERT's PM emission database included 20 vehicles tested on the UC and three vehicles tested on both the FTP and UC. While this provides some PM emissions data performed on the UC, FTP data from all of the other projects would not be able to be included if this data set were used. The CRC study was also a source of both FTP and UC data; but it involved only 30 vehicles tested on only the hot start UC, at a temperature of 35°F. Upon review of all available PM emissions data, staff determined that it would be best to use the larger sources of FTP data rather than the smaller source of UC data. As a result, the FTP data from the SwRI and NCHRP studies were used to estimate PM emissions from gasoline vehicles.

A comprehensive statistical analysis was performed on all PM emissions to establish the effects of vehicle class and technology type. The analysis showed that there was a significant difference in PM emissions with respect to vehicles with and without catalysts. However, there was no significant difference between passenger cars, light-duty trucks and medium-duty trucks. For this reason, all vehicles were grouped together to obtain bag specific PM emission rates.

In order to accurately estimate PM emissions from gasoline vehicles, it is important to incorporate the contribution of smoking vehicles. The study conducted by SwRI defined vehicles as smokers by those that exhibited visible smoke during nearly every operating mode. By looking at the minimum PM emissions levels of these seven smoking vehicles, the cutpoints between normal PM emitters and smoking (high) PM emitters was determined to be the following: 0.20 g/mile for bag 1 and 0.15 g/mile for bag 2.

These cutpoints were used to distinguish smokers from non-smokers (normals) for all vehicles in the combined SwRI and NCHRP database. Any vehicle having a bag specific PM emission rate higher than the cutpoint for either bag was assumed to be a smoking vehicle. All vehicles are thus split into the following categories for further analyses: non-catalyst smokers, non-catalyst normals, catalyst-equipped smokers, and catalyst-equipped normals.

For all catalyst-equipped non-smoking vehicles, bag specific PM emissions were fit with second-order polynomial functions characterizing emissions as a function of age. The bag specific smoking emission rates for catalyst-equipped vehicles were calculated by taking the simple average of those vehicles. This resulted in catalyst-equipped smoking PM emission rates of 0.58 g/mi for bag 1 and 0.27 g/mi for bag 2. In order to accurately weight the non-smoking and smoking emission rates, the population distribution of smoking vehicles is needed.

In a study performed by CE-CERT titled, "Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles", it was determined that at any given time, 2% of all vehicles in California are smoking vehicles. While this study quantifies the number of smoking vehicles overall, it does not assess how this 2% is distributed throughout the fleet. One would assume that there would be fewer smoking vehicles among the newer model years, and subsequently more smokers within the older vehicles.

Without actual data, the challenge then is to identify a relationship that reflects this concept. Staff determined the most appropriate way of modeling this distribution would be to use the inverse relationship of the registration distribution. The registration distribution from 1997 and its inverse are illustrated in Figure 4.12-1. The distribution of smokers was then normalized and curve fit to obtain the smoking vehicle population distribution in Table 4.12-1. For weighting purposes, the values in Table 4.12-1 were then multiplied by the overall smoking population of 2%.

Figure 4.12-1. Population Distribution of PM Smoking Vehicles

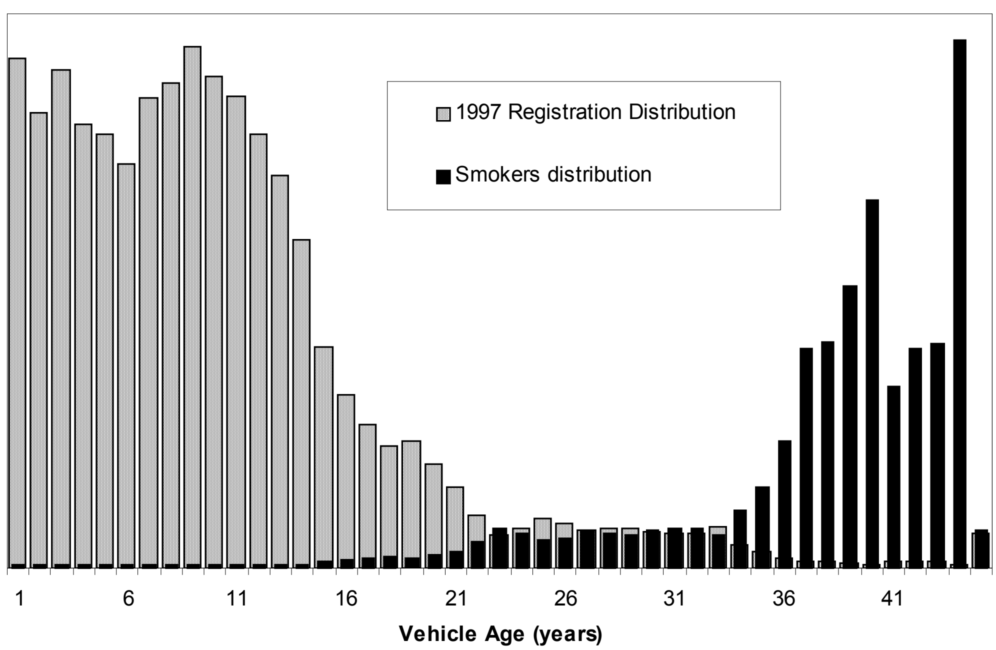
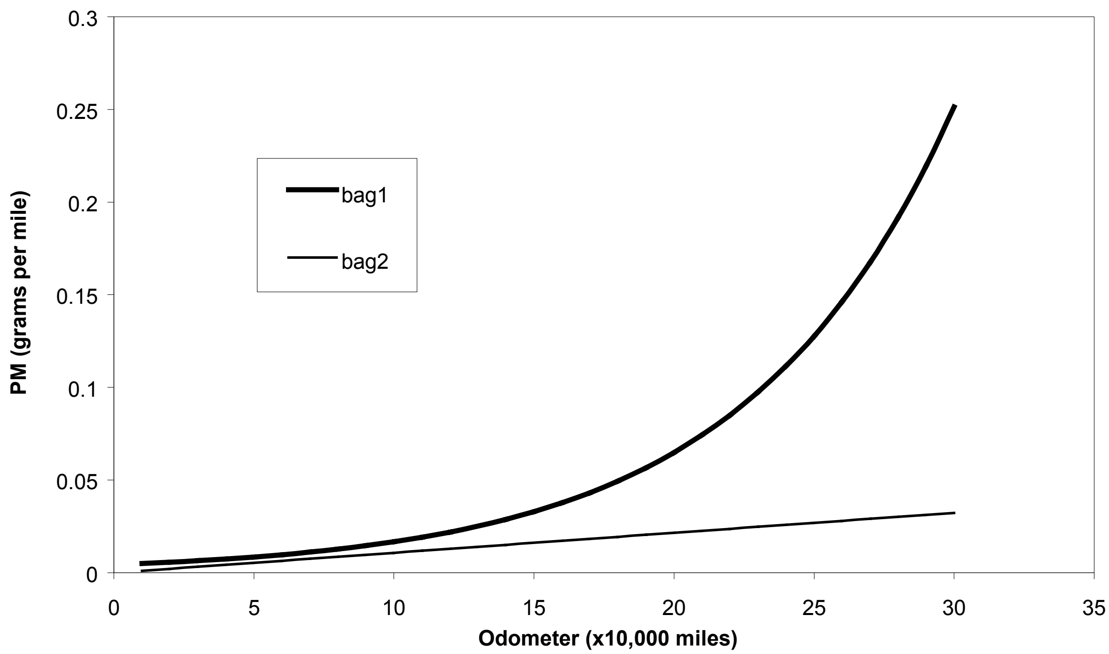


Table 4.12-1. Population Distribution of Smoking Catalyst Vehicles

AGE (yrs)	Distribution of Smokers
1	0.0006
2	0.0007
3	0.0008
4	0.0008
5	0.0010
6	0.0011
7	0.0012
8	0.0014
9	0.0015
10	0.0017
11	0.0020
12	0.0022
13	0.0025
14	0.0028
15	0.0031
16	0.0035
17	0.0040
18	0.0045
19	0.0051
20	0.0057
21	0.0064
22	0.0073
23	0.0082
24	0.0092
25	0.0104
26	0.0117
27	0.0132
28	0.0149
29	0.0167
30	0.0189
31	0.0213
32	0.0239
33	0.0270
34	0.0304
35	0.0343
36	0.0386
37	0.0435
38	0.0490
39	0.0552
40	0.0622
41	0.0701
42	0.0790
43	0.0890
44	0.1003
45	0.1131

To calculate the final particulate emissions by age for catalyst equipped vehicles, the emissions of non-smoking vehicles by age were then weighted together with the emissions of smoking vehicles based on the smoking population distribution. To accommodate the EMFAC2000 model, emissions by age were converted to emissions by cumulative mileage. The resulting curve fit gives bag specific composite catalyst PM emission rates in grams per mile. This is illustrated in Figure 4.12-2.

Figure 4.12-2. Composite Catalyst PM Emission Rates



For the non-catalyst vehicles, there was not enough data to establish any emissions correlation with respect to age. For this reason, the composite PM emission factor was calculated simply by weighting the average smoking emission rate and the average non-smoking emission rate by its assumed population split of 2%:98%. PM emission factors for all gasoline-fueled vehicles are given in Table 4.12-2.

TABLE 4.12-2. PM Emission Factors for Gasoline Vehicles For LDA, LDT, MDT, LHDT, MHDT, and Buses

	CATALYST				NON CAT	
	bag1		bag2		bag1	bag2
zero mile (g/mi)	0.0043204		0		0.06335	0.03582
DR coefficients (per 10,000 mi)	*exponential* y = a*exp(b*x)		*linear* y = m*x		*non cat DR = 0*	
	a	0.0043204	m	0.0010781		
	b	0.1354566				

*Note: If catalyst equipped vehicle emission rates exceed the emission rates of vehicles without catalyst, the non-catalyst emission rate is used.

Start Correction Factors

Start Correction Factors (StCF) for HC, CO, and NOx are currently calculated using modal emissions gathered from tests performed on the Unified Cycle. The purpose of the start correction factor is to adjust the bag 1 gram per mile emission rates to a gram per start value for the first 100 seconds of the start event. In the studies evaluated here, however, there were no second-by-second PM emissions data available. Therefore, the start correction factor is represented here by the number of miles within the first 100 seconds of the FTP. This value is given in Table 4.12-3 and applies to both non-catalyst and catalyst-equipped vehicles.

TABLE 4.12-3. PM Start Correction Factor

	StCF
PM	0.506

* Note: StCF applies to all vehicles regardless of catalyst type.

Tire-Wear and Brake-Wear Emissions

The tire-wear emission factors are based on the methodology included in U.S. EPA's PART5 model and are calculated as follows:

$$EFTW = 0.002 * WHLAVG * PSTIRE, \quad (4.12\text{-}1)$$

where EFTW is the tire-wear emission factor in g/mi,
0.002 g/mi/wheel is the emission rate of airborne particulates from tire-wear,
WHLAVG is the average number of wheels a type of vehicle has, and
PSTIRE is the fraction of particles less than or equal to the particle size cutoff. PSTIRE values are obtained from PART5.

In this case, PSTIRE is equal to one since Part5 assumes that all of the airborne particulates from tire-wear are less than 10 microns. Based on the average number of wheels and the equation shown above, tire-wear emission factors by vehicle class are shown in Table 4.12-4.

Table 4.12-4. Tire-wear PM Emission Rates

Vehicle Class (gasoline & diesel)	Average Number of Wheels	Tire-Wear Emission Factors
LDA	4	0.008
LDT	4	0.008
MDT	4	0.008
LHGT, LHDT	6	0.012
MHGT, MHDT	6	0.012
HHDT	18	0.036
UBD	6	0.012
SCHOOL BUS	6	0.012
MOTOR HOME	6	0.012
MCY	2	0.004

PM emission factors from brake-wear were also obtained from U.S. EPA's PART5 model. The PM emission factor for total brake-wear is 0.0128 g/mi for all vehicles.

PM Size Fractions

PART5 included fractions for various particle sizes including 10.0 μm; however, it did not provide the PM 2.5 value for some of the particle components. In these instances, a linear relationship was determined between the particle size and the fraction of particles less than that size. Similar to Part 5, the linear interpolation was performed on the two nearest points to the PM 2.5 fraction. The resulting fraction which correlates with the 2.5 μm size was then determined from this two-point interpolation. The sizes and corresponding fractions are given in Table 4.12-5.

Table 4.12-5. PM Size Fractions

Particulate Component	Percent Less Than 10 µm	2.5 µm
Gasoline vehicles' exhaust w/catalyst, using unleaded fuel	0.97	0.90
Gasoline vehicles' exhaust w/out catalyst, using unleaded fuel	0.90	0.68
Diesel vehicles	1.00	0.92
Brake-wear	0.98	0.42
Tire-wear	1.00	0.25

4.12.3 Conclusion

Table 4.12-6 contains a comparison of the statewide exhaust PM emissions for gasoline-fueled vehicles. The tons per day estimates from MVEI7G contain the PM emission factors based on PART5. The EMFAC2000 emissions are calculated using the emission factors from Table 4.12-2.

Table 4.12-6. Statewide Total PM Exhaust Emissions for Gasoline-Fueled Vehicles in Tons per Day

Vehicle Type	2000 MVEI7G	2000 EMFAC2000	2010 MVEI7G	2010 EMFAC2000
LDA				
Non-Catalyst	0.26	0.73	0.01	0.18
Catalyst	2.45	7.78	2.58	10.01
LDT				
Non-Catalyst	0.02	0.31	0.00	0.09
Catalyst	1.12	5.34	1.20	7.85
MDT				
Non-Catalyst	0.00	0.24	0.00	0.07
Catalyst	0.17	1.47	0.25	2.64
LHDT				
Non-Catalyst	0.15	1.80	0.02	0.84
Catalyst	1.05	0.11	1.37	0.18
MHDT				
Non-Catalyst	0.05	0.79	0.01	0.34
Catalyst	0.13	0.04	0.18	0.05