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Technical Report

# Size Specific Total Particulate Emission Factors for Mobile Sources

By

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## 1.0 INTRODUCTION

The following material was developed to predict total particulate emission factors of on-road vehicles, trucks and motorcycles, both gasoline and diesel fueled, at various vehicle speeds for particles in the respirable size range (less than 10 microns). Particulate emissions from these vehicles may also be determined at other size intervals less than 10 microns (e.g., less than 7.5, 5, or 2.5 microns).

User inputs to the equations developed for this emission factor determination include area travel fractions by vehicle class, vehicle miles traveled, vehicle speed, particle size limits of interest and calendar year.

This report is arranged to present total particulate emission factor equations, as the sum of individual masses of lead salt, organic and sulfate components for leaded and unleaded gasoline fueled vehicles and compositely (i.e., total particulate mass) for diesel fueled vehicles and motorcycles, and tire and brake wear particulate. These equations are subsequently accompanied by tabulated emission factors which may be inserted into the appropriate particulate component equations. Fleet sales fractions and travel fractions by model year are included for each vehicle class. The fractions within each vehicle class that are equipped with different emission control systems are also provided. Cumulative distributions of particle size for leaded and unleaded gasoline and diesel fuel are presented both graphically and tabularly. Also, for the benefit of the user, an example calculation of particulate emissions from light-duty vehicles is provided.

The procedure herein can be used to project automotive particulate emissions by those agencies developing State

Implementation Plans for particulate matter or by other interested parties within or outside the EPA concerned with size specific particulate emission factor projections for mobile sources.

This document was prepared by the Office of Mobile Sources in response to a request from the Office of Air Quality Planning and Standards. It has been designed to be consistent with the methodology developed in the April 15, 1983 EPA report, Supplementary Guidelines for Lead Implementation Plans--Updated Projections for Motor Vehicle Lead Emissions, by Penny M. Carey, and uses this methodology for the projection of the lead component of total particulate emissions for vehicles using leaded and unleaded gasoline (1)*. In addition to the lead document, from which the methodology for the projection of area lead emission factors is used, this report uses three other sources of particulate emission factor estimates. Emission factors for organics, sulfates on the Federal Test Procedure (FTP) cycle, and heavy-duty gasoline trucks came from the Draft Study of Particulate Emissions from Motor Vehicles (for Section 214 of the Clean Air Act), by the Environmental Sciences Research Laboratory, Office of Research and Development, U.S. EPA, July 1983 (10). Sulfates on the Sulfate Emission Test (SET) cycle and motorcycle emission factors came from the March 1981 EPA report, Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, EPA-460-3-81-005 (2). Light- and heavy-duty diesel particulate emission factors are referenced from the Draft Diesel Particulate Study, Emission Control Technology Division, Office of Mobile Sources, Office of Air and Radiation, U.S. EPA, October 1983 (4). Emission

* Numbers in parentheses represent references which are given at the end of this report in Section 4.0.

factor estimate updating is an ongoing process and, in many cases, these values are based on testing of only a few vehicles.

Further revisions will be made to this document as needed as new information becomes available. In particular, new information on fleet characteristics and on the incidence of fuel switching has recently been prepared in connection with the preparation of MOBILE3, the latest computer program for calcu-
lation of motor vehicle emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen. This document will be revised to reflect this new information as promptly as possible. In the meantime, the calculations described here will give acceptable results.

This document may also have to be revised in the future to reflect changes in the use of unleaded fuel. EPA is currently considering banning the use of leaded fuel because of the health hazards associated with lead and to discourage the practice of misfueling which deteriorates the efficiency of vehicle emission control systems. Since EPA has not at this time proposed these regulations, this report assumes that use of leaded gasoline will continue with only the lead phasedown in effect restricting the lead level to 1 g/gallon in leaded gasoline.

## 2.0 PROJECTING SIZE SPECIFIC TOTAL PARTICULATE EMISSION FACTORS

The purpose of this report is to provide a methodology with which to project areawide total particulate emissions from mobile sources in a given calendar year. Particulate emissions can consist of lead salts, organics and sulfate emissions. The relative amounts vary for different vehicle types, emission control strategies and vehicle operating modes. Analysis of lead particulate indicates that most of the exhausted lead appears as PbClBr. Therefore estimates of the mass of lead particulate will be considerably larger than those predicted by the lead document. Organic emissions include both soluble organics and elemental carbon and are important contributors to total particulate emissions from all vehicles especially diesels. Sulfate emissions, mostly from unleaded gasoline-fueled vehicles equipped with catalysts, are also important contributors to total vehicular particulate emissions.

Areawide particulate emissions, as is shown in Equation 1.0, are a function of calendar year, average vehicle speed, vehicle class travel fractions, the particle size range of interest and the vehicle class emissions associated with the calendar year and vehicle speed. With the exceptions of the vehicle class emission factors, all of the above parameters are inputs selected by the user on an areawide basis to obtain the desired output of mobile source particulate emissions from the area of interest.

Equation 1.0

$$EF_{pm,n,s} = \sum_{i=1}^{6} t_{i,n} EF_{i,n,s} + EF_{brakes} (M_B) + EF_{tires}$$

where:

$EF_{pm,n,s}$ = size specific all-vehicle class total particulate emission factor on January 1 of calendar year n at vehicle speed s (g/mile);

i = vehicle class designator 1 = light-duty vehicles (LDV), 2 = light-duty trucks I (LDT1), 3 = light-duty trucks II (LDT2), 4 = heavy-duty trucks I (HDT1), 5 = heavy-duty trucks II (HDT2), 6 = motorcycles (MC);

s = vehicle speed; avg. Federal Test Procedure (FTP) = 19.6, avg. Sulfate Emissions Test (SET) = 34.8 (miles/hr); (Note: The FTP and SET are driving cycles used for the determination of emission factors.)

$t_{i,n}$ = area travel fraction of vehicle class i in calendar year n;

$EF_{i,n,s}$ = exhaust particulate emission factor for vehicle class i in calendar year n at vehicle speed s (g/mile).

$EF_{brakes}$ = airborne brake wear particulate emission factor component = 0.0128 grams/mile. This emission factor component is assumed to be the same for all vehicle classes, vehicle speeds and calendar years (all i, s, and n) due to lack of separate information for each i, s, and n;

$EF_{tires}$ = airborne tire wear particulate emission factor component = 0.002 grams/mile. This emission factor component is assumed to be the same for all vehicle classes, vehicle speeds and calendar years (all i, s, and n) due to lack of separate information for each i, s and n;

$M_B$ = fraction of airborne particles less than a user specified size cutoff (0.1-10 um) that are attributable to vehicle brake wear, from Table 19 or Figure 4.

The vehicle classes for which emission factor estimates may be obtained include: 1) light-duty vehicles (passenger cars), 2) light-duty trucks I (0-6000 lbs. GVWR), 3) light-duty trucks II (6001-8500 lbs. GVWR), 4) heavy-duty trucks I (8501-14000 lbs. GVWR), 5) heavy-duty trucks II (greater than 14001 lbs. GVWR), and 6) motorcycles.

The exhaust emission factors for each vehicle class for a given calendar year ($EF_{i,n,s}$) are broken down into component emission factors in Equation 1.1. The components represent the masses of lead salt, organic and sulfate emissions from both leaded and unleaded gasoline fueled vehicles and total particulate mass from diesel vehicles--all of which are multiplied by the fraction of total vehicles of a given model year designed for use on these three fuel types. The sum of these components for each model year is also multiplied by the fraction of the vehicle class travel attributable to that model year ($m_{i,j}$) in the calendar year of interest. For example, the component ($EF_{i,j,k,n,L}$) represents the emissions in grams per mile of lead salts (k=1) from vehicle class i emitted from model year j vehicles that are on the road in calendar year n and are designed for use on leaded fuel. These emission components must be summed up over the twenty model years prior to the calendar year of interest to include all the contributing fractions of emissions from vehicles on the road.

The travel fractions for the six vehicle classes from model years n to n-19 are provided in Tables 5, 10, 13, 15, 16, and 17. These tables are entitled "Travel Weighting Factor Calculation" and there is one for each of the six vehicle classes. (Table 15, however, should be used for all vehicles in the heavy-duty truck I category and all gasoline heavy-duty trucks II. Table 16 should be used for all diesels in the heavy-duty truck II category only. For an explanation of how to compute emissions from heavy-duty trucks II, see Section 2.5.4 on p. 23.) The fraction of vehicles from each class and model year of vehicles designed to use leaded gasoline ($F_{L,i,j}$), unleaded gasoline ($F_{NL,i,j}$), and diesel fuel ($F_{D,i,j}$) are contained in Tables 4, 9, 12, and 14. These tables are entitled "Fleet Sales Fractions". Separate tables are provided for light-duty vehicles and light-duty trucks I and II. Table 14 contains fleet sales fractions of gasoline fueled versus diesel heavy-duty trucks I and II. Gasoline-fueled heavy-duty trucks I are assumed to use leaded gasoline prior to 1987 and unleaded gasoline from 1987 on. Gasoline-fueled heavy-duty truck II and motorcycle fleet sales are assumed to consist entirely of leaded gasoline vehicles for all model years.

Equation 1.1

$$EF_{i,n,s} = \sum_{j=n-19}^{n} [(EF_{i,j,k_1,n,L} + EF_{i,j,k_2,L} + EF_{i,j,k_3,L})(F_{L,i,j})$$

$$+ (EF_{i,j,k_1,n,NL} + EF_{i,j,k_2,NL} + EF_{i,j,k_3,NL})(F_{NL,i,j})$$

$$+ (EF_{i,j,D})(F_{D,i,j})]m_{i,j}$$

where:

| | | |
|---|---|---|
| j | = | model year $j = n-19, n-18, \ldots, n-2, n-1, n$; |
| L | = | vehicles designed for use on leaded fuel; |
| NL | = | vehicles designed for use on unleaded fuel; |
| k | = | component of total particulate emission factor ($k_1$ = lead, $k_2$ = organic, $k_3$ = sulfate) expressed individually for gasoline vehicles and trucks (except motorcycles) and cumulatively for diesel vehicles and trucks and motorcycles; |
| $F_{L,i,j}$ | = | fraction of the vehicle class i fleet designed for use on leaded gasoline in model year j; |
| $F_{NL,i,j}$ | = | fraction of the vehicle class i fleet designed for use on unleaded gasoline in model year j; |
| $F_{D,i,j}$ | = | fraction of the vehicle class i fleet designed for use on diesel fuel in model year j; |
| $m_{i,j}$ | = | travel fraction for vehicle class i in model year j. |

Component emission factors are derived for each vehicle class over different model years at average speeds of 19.6 mph (cyclic driving comparable to average speed of the Federal

Test Procedure) and 34.8 mph (cruising conditions comparable to the average speed of the Sulfate Emissions Test) beginning with Equation 1.1.1 and ending with Equation 1.1.47. Emission factors for speeds between 19.6 and 34.8 should be interpolated linearly.

## 2.1 Lead Emission Factors

Lead emission factors are calculated in the same manner as in the recent report entitled, Supplementary Guidelines for Lead Implementation Plans--Updated Projections for Motor Vehicle Lead Emissions, hereinafter referred to as the "lead document" (1). These lead emission estimates are multiplied by a factor of 1.557 to account for the halogens, typically bromine and chlorine, which combine with lead to form total lead salt particulate emissions. This factor was obtained from a report by the Ethyl Corporation entitled Composition, Size, and Control of Automotive Exhaust Particulates, and is the ratio of PbClBr mass to Pb mass based on FTP results of 16 test vehicles (24).

For $i = 1,2,3$ $j = n-19,\ldots,1974$ $k=1$ $C_s$ = from Table 7 $a_s = 0.75$

Equation 1.1.1

$$EF_{i,j,k_1,n,L} = [Pb_{L,n}(0.929)(M_L) + Pb_{NL,n}(0.071)(M_{NL,NC})] \frac{(a_s)(1.557)}{(E_{c,i,j})(C_s)}$$

where:

$a_s$ = fraction of lead burned that is exhausted; for non-catalyst vehicles use $a_s = 0.75$ (i.e., 75%); for catalyst vehicles use $a_s = 0.30$ (i.e. 30%);

$C_s$ = speed-dependent fuel economy correction factor based on steady cruise or cyclic driving; available from Table 7 (nondimensional);

$Pb_{NL,n}$ = lead content of unleaded gasoline in calendar year n from Table 2 (g/gal);

$Pb_{L,n}$ = average lead content of leaded gasoline in calendar year n from Table 2 (g/gal);

$E_{c,i,j}$ = city/highway combined on-road fuel economy for model year j and vehicle class i from Table 6 (miles/gallon);

$M_L$ = fraction of particles less than a user specified size cutoff (0.1-10 um) that are emitted from vehicles that are fueled with leaded gasoline, from Table 19 or Figure 1;

$M_{NL,C}$ = fraction of particles less than a user specified size cutoff (0.1-10 um) that are emitted from catalyst vehicles that are fueled with unleaded gasoline, from Table 19 or Figure 2;

$M_{NL,NC}$ = fraction of particles less than a user specified size cutoff (0.1-10 um) that are emitted from non-catalyst vehicles that are fueled with unleaded gasoline, from Table 19 or Figure 2.

For $i = 1,2,3$   $j = 1975,\ldots,n$   $k=1$   $C_s$ = from Table 7 $a_s = 0.75$

Equation 1.1.2

$$EF_{i,j,k_1,n,L} = [Pb_{L,n}(0.725)(M_L) + Pb_{NL,n}(0.275)(M_{NL,NC})]\frac{(a_s)(1.557)}{(E_{c,i,j})(C_s)}$$

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For $i = 1,2,3$   $j = 1975,\ldots,n$   $k=1$   $C_s$ = from Table 7 $a_s = 0.30$

Equation 1.1.3

$$EF_{i,j,k_1,n,NL} = [Pb_{NL,n}(1-r_i)(M_{NL,C}) + Pb_{L,n}(r_i)(M_L)]\frac{(a_s)(1.557)}{(E_{c,i,j})(C_s)}$$

where:

$r_i$ = misfueling rate for vehicle class i from Table 18.

The calculation of area lead particulate emissions necessitates the determination of the percentage of burned lead exhausted ($a_s$). A value for $a_s$ of 0.75 (i.e., 75 percent of the lead burned is exhausted) should be used for non-catalyst equipped, gasoline-powered vehicles. The 0.75 value is based on tests which measured exhaust emissions under cyclic driving conditions and found that 17% of the lead is retained by the engine (in the oil and combustion chamber) and 8% is retained by the muffler and exhaust pipes (33). For gasoline-powered vehicles with catalysts a value of 0.30 for $a_s$ should be used. The 0.30 value accounts for lead retention by the catalyst (approximately 45% based on some tests run by GM (41) on pelleted catalyst-equipped vehicles), the oil, the combustion chamber and the rest of the exhaust system (approximately 25%). The appropriate values for $a_s$ have been included above the appropriate equations for convenience.

Combined city/highway fuel economy ($E_{c,i,j}$) is yet another factor affecting area lead particulate emissions. Fuel economy versus model year is provided for each vehicle class (except motorcycles) in Table 6. Fuel economy of gasoline-fueled heavy-duty trucks was assumed to equal 5.0 mpg in all model years in the lead document since this is the value used in MOBILE2. Values for heavy-duty and future model year fuel economy for other vehicle classes were updated for this report since newer information is now available. The heavy-duty fuel economy values in this report are expected to be changed in a future version to make them consistent with MOBILE3. The values in Table 6 are closer to the MOBILE3 values than was the 5.0 mpg figure used in MOBILE2.

Lead particulate emissions can be determined at any speed by using Equations 1.1.1, 1.1.2 and 1.1.3 (for light-duty vehicles and trucks) and 1.1.18, 1.1.19, and 1.1.20 (for heavy-duty trucks) and the appropriate value of the speed dependent fuel economy correction factor ($C_s$) for the vehicle speed of interest. Values of $C_s$ at various speeds are provided in Table 7. It should be noted that average vehicle speed and $C_s$ can be determined for an area by either of two approaches. One approach is to base $C_s$ on the average vehicle speed for the area of concern. The average area vehicle speed should be a weighted average based on average speeds and VMT data for the various roadway classifications, such as limited access (greater than 5 mph), suburban roads (35 mph) and urban streets (25 mph or less). The other approach, which is considered more accurate, is to determine $C_s$ and area emissions separately for each roadway classification (and average speed).

Area lead particulate emissions are also dependent upon the lead content of gasoline in a given calendar year. Values for the lead content of leaded ($Pb_{L,n}$) and unleaded gasoline ($Pb_{NL,n}$) are contained in Table 2. Values for future years will be updated as new information becomes available.

Emission factors for organic sulfates and diesels have been derived and are listed in Table 1 for speeds of 19.6 and 34.8 mph. However, if emission estimates for these particulate components are desired at other speeds, linear interpolation of emission factors is possible and appropriate. In fact, some of the emission factors in Table 1 (particularly for organic and diesel particulate masses) can be used at "all" vehicle speeds.

## 2.2 Misfueling and Fuel Switching

EPA has observed that misfueling rates (i.e., percentage of vehicles designed for use on unleaded gasoline that use leaded gasoline) are dependent on vehicle mileage and increase with vehicle mileage accumulation. Strictly speaking, this dependence on mileage should be reflected in the calculation of particulate emissions, with each model year receiving its own misfueling rate. However, this further complicates an already complex calculation. To give the user a choice, this report offers both the option of using a single average misfueling rate for all model years of a given vehicle class and exact misfueling rates for each vehicle class by vehicle age. The single average rates are determined for the weighted average mileage accumulated for each vehicle class and are listed in Table 18 for inspection and maintenance (I/M) and non-I/M areas. In other words, in the calculation of emission factors from 1975 on, the misfueling rate ($r_i$) depends only on which vehicle class (i) is being considered and whether the area of interest has an I/M program. As a result, misfueling rates and particulate emissions will be slightly overestimated, with the degree of overestimation declining with later evaluation years and essentially disappearing in 1995. For users who desire more accuracy, Table 18a gives exact misfueling rates for different vehicle ages and classes affected by misfueling.

The use of leaded gasoline on vehicles designed for unleaded fuel results in lead salt emissions. Since most of these vehicles have catalysts, the lead results in poisoning of the catalyst so that organic particulate emissions can be assumed to increase to the levels found with non-catalyst vehicles. Also, catalyst poisoning should result in no sulfur dioxide oxidation to sulfates. Sulfate levels are therefore assumed to be the same as those from non-catalyst vehicles.

Discretionary fuel switching (i.e., percentage of vehicles designed for use on leaded gasoline that use unleaded gasoline) is assumed to equal 7.1% of the leaded fleet prior to 1974 and 27.5% in 1975 and later years and only applies to the lead salt component of light-duty vehicle and light-duty truck I and II emissions. Misfueling and fuel switching rates for all heavy-duty trucks II (over 14000 lbs. GVWR) and motorcycles are assumed to be zero. The misfueling rates employed here were used in the December 1983 EPA report, Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles, EPA-AA-TSS-83-10 (3). The discretionary fuel switching were obtained from Energy and Environmental Analysis, Inc., Assessment of Current and Projected Future Trends in Light-Duty Vehicle Fuel Switching, June 1982 (8).

## 2.3 Particle Size Distribution

Distributions of particle size are different for leaded gasoline, unleaded gasoline and diesel fueled vehicles as well as brake and tire wear particles. They are also different for various conditions of vehicle driving cycle (speed) and load. For the purposes of this report, however, typical or average conditions are presented to facilitate the determination of vehicle particulate emissions versus particle size.

Particle size distributions for leaded, unleaded and diesel fueled vehicles and brake wear particles are contained in Table 19 and also in Figures 1, 2, 3, and 4 (no distributions are available for tire wear particulate). Typically, the average diameter of particles emitted from vehicles fueled with leaded gasoline are the largest, particles emitted from vehicles fueled with unleaded gasoline are somewhat smaller and particles emitted from diesel fueled vehicles are smaller yet. Some of the data for the size distribution of lead particles are conflicting (e.g., Moran et al., 1971 which shows a larger fraction of the lead in smaller size ranges than the other leaded gasoline references.) Thus, these data are less certain than those for unleaded and diesel particles. References for those reports used in the determination of particle size distributions of leaded, unleaded and diesel fueled vehicle emissions and brake wear emissions are listed in Table 19.

Values for $M_L$, $M_{NL,C}$, $M_{NL,NC}$, $M_D$, and $M_B$ should be expressed as dimensionless fractions of total particulate by weight emitted below a given size cutoff. Values may be read directly from Table 19 for the data points listed therein, or may be read off the graphs of continuous cumulative particle size distributions in Figures 1, 2, 3, and 4 for interpolated size cutoffs (e.g., 6.5 um, 2.5 um).

## 2.4 Control System Fractions

Organic and sulfate emissions of gasoline-fueled vehicles depend on the type of vehicle emission control system in addition to the vehicle model year. The fraction of vehicles with different emission control systems to which different emission factors are applied are handled similarly to the fleet sales fractions for leaded, unleaded and diesel vehicles versus model year. The main difference is that these are fractions of the total number of vehicles designed for use of unleaded fuel and not the total number of vehicles in each vehicle class. These fractions are listed in Tables 3, 8, and 11 for light-duty vehicles, light-duty trucks I and II, respectively. These are the vehicle classes that have a relatively wide range of control technology, and as a result, have a wide range of emission factor estimates. It should be noted that since 1975 a small number of non-catalyst equipped vehicles have been certified for use on unleaded gasoline. These vehicles constitute a very small percentage of the total non-catalyst fleet. However, unlike the lead document, these are considered in this report and have been given their own control system fraction category ($F_{i,j,NL,NOCAT}$).

The light-duty vehicle and truck emission control system fractions were obtained from the "sales-weighted" EPA emission factor in-use vehicle test data base. This data base contains gasoline-fueled vehicle mixes approximating the sales mixes for the 1975 through 1982 model years. All vehicles and trucks prior to 1975 models are assumed to be designed for use on leaded fuel (i.e., no diesel or catalyst vehicles). Emission control system fractions for 1983 and later model years are determined from recent projections by Energy and Environmental Analysis, Inc. in a report entitled, Forecasts of Emission Control Technology 1982-1990 (40). For 1987 and later, light-duty trucks I and II which are assumed to convert largely to three-way catalyst technology to meet the proposed 1987 standards.

Air injection fractions were obtained for light-duty vehicles and trucks from the Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles (EPA/AA/83-10) report and include all types of air injection (e.g., pulse-air) in addition to conventional air pump control systems (3).

Data for 1975 through 1978 light-duty truck I technology fractions were obtained by combining EPA fuel economy data base sales figures by engine displacement and model type and Federal Certification Test Results for these years from the Federal Register, Vol. 40, No. 48, March 11, 1975 (11); Vol. 41, No. 46, March 8, 1976 (12); Vol. 42, No. 110, June 8, 1977 (13); and Vol. 43, No. 181, Sept. 18, 1978 (14). The certification data provided emission control systems by model type and engine displacement which were matched with fuel economy sales fractions.

Heavy-duty vehicles are either leaded gasoline or diesel fueled (Table 14) vehicles through 1986. In 1987, more stringent standards have been promulgated. Therefore, it is assumed, for the purposes of this report, that all 1987 and later gasoline fueled trucks in the heavy-duty trucks I category (less than 14,001 lbs.) will be equipped with oxidation catalysts and air injection and will use unleaded gasoline. All 1987 and later gasoline-fueled trucks in the heavy-duty truck II category (greater than 14,000 lbs.) are assumed in this report to still use leaded gasoline. It should be noted that other EPA publications may use different definitions of HDTI and HDTII.

The effect of discretionary fuel switching has not been incorporated in heavy-duty vehicle emission factor equations due to the lack of data on the current fuel purchase behavior of owners of heavy-duty vehicles. Also, as new estimates for heavy-duty fuel economy and new emission standards scenarios become available, these equations will be revised accordingly.

Motorcycle fractions are based on 2-stroke versus 4-stroke emission factor estimates. Before 1978, most on-road motorcycle travel was done by 2-stroke vehicles (53.4%) and slightly less (46.6%) by 4-stroke vehicles according to sales figures in the <u>1983 Motorcycle Statistical Annual</u> published by the Motorcycle Industry Council, Inc (15). In 1978, more stringent control of motorcycle emissions caused nearly all motorcycle manufacturers to build 4-stroke vehicles for on-road usage. Therefore, it is assumed that all motorcycles from 1978 on are 4-stroke vehicles since nearly all 2-stroke mileage is accumulated off-road.

## 2.5 Organic, Sulfate, Diesel, Heavy-Duty Truck and Motorcycle Emission Factors

Emission factors for organics, sulfates and diesel particulates for different model years, control systems, fuel types and vehicle speeds are listed in Table 1. This table also refers the user to the proper equation(s) to which each emission factor should be applied. All emission factors in Table 1 are expressed in grams per mile. The following equations should be used for the calculation of organic, sulfate, diesel, heavy-duty truck and motorcycle emission factor components.

### 2.5.1 Organic Emission Factor Components

For $i = 1,2,3$   $j = n-19,...,1969$   $k=2$

Equation 1.1.4

$$EF_{i,j,k_2,L} = 0.193\ M_L \text{ (g/mile)}$$

For $i = 1,2,3$ $j = 1970,\ldots,1974$ $k=2$

Equation 1.1.5

$$EF_{i,j,k_2,L} = 0.068\ M_L\ \text{(g/mile)}$$

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For $i = 1,2,3$ $j = 1975,\ldots,n$ $k=2$ $r_i$ = from Table 18

Equation 1.1.6

$$EF_{i,j,k_2,L} = 0.030\ M_L\ \text{(g/mile)}$$

Equation 1.1.7

$$EF_{i,j,k_2,NL} = (1-r_i)(F_{i,j,CAT})(0.017)(M_{NL,C})$$

$$+ (r_i)(F_{i,j,CAT})(0.068)(M_L)+(F_{i,j,NL,NOCAT})(0.030)(M_{NL,NC})$$

where:

$F_{i,j,CAT}$ = fraction of the unleaded vehicle class i fleet equipped with a catalyst in model year j;

$F_{i,j,NL,NOCAT}$ = fraction of the unleaded vehicle class i fleet without a catalyst in model year j.

### 2.5.2 Sulfate Emission Factor Components

For $i = 1,2,3$ $j = n-19,\ldots,n$ $k=3$ $s = 19.6$

Equation 1.1.8

$$EF_{i,j,k_3,L} = 0.002\ M_L\ \text{(g/mile)}$$

For $i = 1,2,3$  $j = n-19,...,n$  $k=3$  $s = 34.8$

Equation 1.1.9

$$EF_{i,j,k_3,L} = 0.001\ M_L\ \text{(g/mile)}$$

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For $i = 1,2,3$  $j = 1975,...,n$  $k=3$  $s = 19.6$

Equation 1.1.10

$$EF_{i,j,k_3,NL} = (1-r_i)[(F_{i,j,CAT/NOAIR})(0.005)(M_{NL,C})+(F_{i,j,CAT/AIR})(0.016)(M_{NL,C})+(F_{i,j,NL,NOCAT})(0.002)(M_{NL,NC})]+(r_i)(0.002)(M_L)$$

where:

$F_{i,j,CAT/NOAIR}$ = fraction of the unleaded vehicle class i fleet equipped with a catalyst but no air pump in model year j; this includes oxidation catalyst ($F_{i,j,OXCAT}$) and three-way catalyst ($F_{i,j,3WCAT}$) vehicles with no air pump;

$F_{i,j,CAT/AIR}$ = fraction of the unleaded vehicle class i fleet equipped with a catalyst and an air pump in model year j; this includes oxidation catalyst ($F_{i,j,OXCAT/AIR}$) and three-way plus oxidation catalyst ($F_{i,j,3WCAT/OXCAT}$) vehicles with air pumps.

For $i = 1,2,3$   $j = 1975,\ldots,n$   $k = 3$   $s = 34.8$   $r_i$ = from Table 18

Equation 1.1.11

$$EF_{i,j,k_3,NL} = (1-r_i)[F_{i,j,NL,NOCAT})(0.001)(M_{NL,NC})+(F_{i,j,OXCAT})(0.005)(M_{NL,C})+(F_{i,j,3WCAT})(0.001)(M_{NL,C})+(F_{i,j,OXCAT/AIR})(0.020)(M_{NL,C})+(F_{i,j,3WCAT/OXCAT})(0.025)(M_{NL,C})]+(r_i)(0.001)(M_L)$$

where:

$F_{i,j,OXCAT}$ = fraction of the unleaded vehicle class i equipped with an oxidation catalyst but no air pump in model year j.

$F_{i,j,3WCAT}$ = fraction of the unleaded vehicle class i equipped with a three-way catalyst in model year j. (Note: These vehicles are sometimes equipped with air pumps that are usually only used during vehicle start-up. Therefore, the vehicle category as a whole is assumed to emit sulfates at the same rate as non-air pump-equipped vehicles for emission factor consideration.)

$F_{i,j,OXCAT/AIR}$ = fraction of the unleaded vehicle class i equipped with an oxidation catalyst and an air pump in model year j.

$F_{i,j,3WCAT/OXCAT}$ = fraction of the unleaded vehicle class i equipped with both an oxidation and a three-way catalyst in model year j.

2.5.3 Diesel Emission Factors (Light-Duty)

For $i = 1 \quad j = n-19,\ldots,1980$

Equation 1.1.12

$$EF_{i,j,D} = 0.700\ M_D\ \text{(g/mile)}$$

$M_D$ = fraction of particles less than a user specified size cutoff (0.1-10 um) that are emitted from vehicles that are fueled with diesel fuel, from Table 19 or Figure 3;

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For $i = 1 \quad j = 1981,\ldots,1986$

Equation 1.1.13

$$EF_{i,j,D} = 0.320\ M_D\ \text{(g/mile)}$$

---

For $i = 1 \quad j = 1987,\ldots,n$

Equation 1.1.14

$$EF_{i,j,D} = 0.200\ M_D\ \text{(g/mile)}$$

---

For $i = 2,3 \quad j = n-19,\ldots,1980$

Equation 1.1.15

$$EF_{i,j,D} = 0.800\ M_D\ \text{(g/mile)}$$

For i = 2,3   j = 1981,...,1986

Equation 1.1.16

$$EF_{i,j,D} = 0.280\ M_D\ \text{(g/mile)}$$

---

For i = 2,3   j = 1987,...,n

Equation 1.1.17

$$EF_{i,j,D} = 0.260\ M_D\ \text{(g/mile)}$$

2.5.4 Heavy-Duty Truck Emission Factor Components

In this report, heavy-duty trucks are divided into two groups; those less than or equal to 14,000 lbs. GVW are classified as heavy-duty trucks I (i=4) and those greater than 14,000 lbs. GVW are classified as heavy-duty trucks II (i=5). Calculation of heavy-duty truck I emissions is accomplished by the same procedure as light-duty emissions by use of Equation 1.1 (page 7) and the appropriate emission factor component equations discussed on the following pages. Heavy-duty truck II emissions are calculated by a slightly different procedure to distinguish between heavy-duty truck II gasoline and diesel mileage accumulation rates and vehicle age distribution, which together determine travel fraction by vehicle age. Because gasoline and diesel vehicles in the HDT II weight class are characterized by different travel fractions by vehicle age, a single travel fraction $m_{5,j}$ does not exist, and it is necessary to keep the two vehicle types disaggregated.

Gasoline fueled heavy-duty trucks II are assumed to use only leaded fuel for all model years (i.e., $F_{NL,5,j} = 0$ for all j). Therefore, equation 1.1 for heavy-duty trucks II (i=5) is used as modified below.

Equation 1.1 (for i=5)

$$EF_{5,n,s} = \sum_{j=n-19}^{n} [(EF_{5,j,k_1,n,L} + EF_{5,j,k_2,L} + EF_{5,j,k_3,L})$$

$$(F_{L,5,j})(m_{5G,j}) + (EF_{5,j,D})(F_{D,5,j})(m_{5D,j})]$$

where:

$F_{L,5,j}$ = fraction of the heavy-duty truck II fleet designed for use on leaded gasoline in model year j, from Table 14.

$F_{D,5,j}$ = fraction of the heavy-duty truck II fleet designed for use on diesel fuel in model year j, from Table 14.

$m_{5G,j}$ = travel fraction for gasoline fueled heavy-duty trucks II in model year j, from Table 15 (Note: $m_{5G,j} = m_{4,j}$ as explained in Table 15);

$m_{5D,j}$ = travel fraction for diesel fueled heavy-duty trucks II in model year j, from Table 16.

The emission factor component equations for both heavy-duty trucks I and II are listed below in equations 1.1.18 through 1.1.29.

For i = 4,5 j = n-19,...,1986 k = 1 $a_s$ = 0.75

Equation 1.1.18

$$EF_{i,j,k_1,n,L} = \frac{(a_s)(Pb_{L,n})(1.557)}{E_{c,i,j}} (M_L)$$

For $i = 4$ $j = 1987,\ldots,n$ $k = 1$ $a_s = 0.30$ $r_4$ = from Table 18

Equation 1.1.19

$$EF_{4,j,k_1,n,NL} = \frac{(1-r_4)(a_s)(Pb_{NL,n})(1.557)}{E_{c,4,j}}(M_{NL,C}) + \frac{(r_4)(a_s)(Pb_{L,n})(1.557)}{E_{c,4,j}}(M_L)$$

---

For $i = 5$ $j = 1987,\ldots,n$ $k = 1$ $a_s = 0.75$

Equation 1.1.20

$$EF_{5,j,k_1,n,L} = \frac{(a_s)(Pb_{L,n})(1.557)}{E_{c,5,j}}(M_L)$$

---

For $i = 4,5$ $j = n-19,\ldots,1986$ $k = 2$

Equation 1.1.21

$$EF_{i,j,k_2,L} = 0.370\ M_L\ \text{(g/mile)}$$

---

For $i = 4$ $j = 1987,\ldots,n$ $k = 2$ $r_4$ = from Table 18

Equation 1.1.22

$$EF_{4,j,k_2,NL} = (1-r_4)(0.054)(M_{NL,C})+(r_4)(0.370)(M_L)\ \text{(g/mile)}$$

For $i = 5 \quad j = 1987,\ldots,n \quad k = 2$

Equation 1.1.23

$$EF_{5,j,k_2,L} = 0.370\ M_L\ \text{(g/mile)}$$

---

For $i = 4,5 \quad j = n\text{-}19,\ldots,1986 \quad k = 3$

Equation 1.1.24

$$EF_{i,j,k_3,L} = 0.006\ M_L\ \text{(g/mile)}$$

---

For $i = 4 \quad j = 1987,\ldots,n \quad k = 3 \quad r_4$ = from Table 18

Equation 1.1.25

$$EF_{4,j,k_3,NL} = (1-r_4)(0.048)(M_{NL,C})+(r_4)(0.006)(M_L)\ \text{(g/mile)}$$

---

For $i = 5 \quad j = 1987,\ldots,n \quad k = 3$

Equation 1.1.26

$$EF_{5,j,k_3,L} = 0.006\ M_L\ \text{(g/mile)}$$

For i = 4 j = n-19,...,1982

Equation 1.1.27

$$EF_{4,j,D} = 1.423\ M_D\ \text{(g/mile)}$$

---

For i = 4 j = 1983,...,n

Equation 1.1.28

$$EF_{4,j,D} = 1.188\ M_D\ \text{(g/mile)}$$

---

For i = 5 j = n-19,...,n

Equation 1.1.29

$$EF_{5,j,D} = 1.954\ M_D\ \text{(g/mile)}$$

2.5.5 Motorcycle Emission Factors

For i = 6 j = n-19,...,1977

Equation 1.1.30

$$EF_{6,j,L} = [(0.466)(0.046)+(0.534)(0.330)](M_L)$$

$$= 0.198\ M_L\ \text{(g/mile)}$$

For i = 6  j = 1978,...,n

Equation 1.1.31

$$EF_{6,j,L} = 0.046\ M_L\ \text{(g/mile)}$$

## 2.6 Brake and Tire Wear Particulate Emission Factor Components

Additional sources of motor vehicle particulate emissions include brake and tire wear emission components. Limited testing has been performed to estimate the contributions of brake and tire wear emissions to the total light-duty vehicle particulate emission rate. No data exist on the rate at which light-duty trucks, heavy-duty vehicles, or motorcycles emit brake and tire wear emissions. The user should be aware that brake and tire wear particulates are emitted from these vehicle classes at different rates than the light-duty vehicle rate, but since no data exists, the light-duty vehicle rate is used to estimate their contribution to total particulate emission rates.

Brake wear emissions from light-duty vehicles have been measured in a recent study and have been found to consist of significant quantities of particulate in the airborne particle size range. Airborne particulate emission rates for brake wear particles as measured on braking cycles representative of urban driving averaged 0.0128 grams per mile for light-duty gasoline vehicles (42). Particle size distribution for brake wear particulate ($M_B$) is included in this reference and is summarized in Table 19. The rate of 0.0128 g/mile times the appropriate fraction of $M_B$ for the particle size cutoff of interest should be added to any calculation of particulate emissions less than 10 microns for all classes of vehicles. In the example calculation in

Section 3.0 of this report, for example, $M_B$ = 0.98, the brake wear particulate emission rate is therefore 0.0125 g/mile and the total light-duty vehicle particulate emission rate is 0.0731 g/mile. In this particular example, therefore, brake wear emissions account for 17% of the total particulate emission rate.

Tire wear particulate is generally larger in size than brake wear particulate and therefore consists of fewer particles in the airborne size range. Emission rates for airborne tire wear particulate for light-duty vehicles has been estimated at 0.002 g/mile (43,44). This rate should be added to calculations of particulate emissions less than 10 microns for all classes of vehicles. The addition of 0.002 g/mile in the example calculation in Section 3.0 indicates that airborne tire wear particulate accounts for about 3% of the total light-duty particulate emission rate.

No data on airborne particle size distribution are available for analyses of tire wear particulate emission rates at smaller particle size cutoffs (i.e., 2.5 microns or 7 microns). The user should either interpolate between zero and 10 microns to determine the appropriate emission rate for the distribution of tire wear particles below the desired size cutoff (e.g., at 7 microns tire wear emissions = 0.0014 g/mile and at 2.5 microns tire wear emissions = 0.0005 g/mile) or simply neglect tire wear particulate since it is likely to be negligible in these smaller particle size ranges.

Another source of particulate emissions for which emission factors could be developed is reentrained particulate from particles that have been deposited on road surfaces or possibly road material itself. While information is available on these reentrained particulates (46, 47), they are not considered to be directly emitted by mobile sources and therefore are not included in this report.

Table 1

Emission Factors of Motor
Vehicle Engine Total Particulate Emissions

| Applicable Model Year(s) | Particulate Component | Control System | Type of Fuel Used | Vehicle Speed (MPH) | Emission Factor (grams/mile) | Equation Used In | Emission Factor Source Reference No. |
|---|---|---|---|---|---|---|---|
| **Light-Duty Gasoline Vehicles and Trucks:** | | | | | | | |
| Pre-1970 | Organic | NOCAT | Leaded | All | 0.193 | 1.1.4 | 10 |
| 1970-1974 | Organic | NOCAT | Leaded | All | 0.068 | 1.1.5 | 10 |
| 1975+ | Organic | NOCAT | Leaded | All | 0.030 | 1.1.6,7 | 10(a) |
| 1975+ | Organic | CAT | Unleaded | All | 0.017 | 1.1.7 | 10(b) |
| 1975+ | Organic | CAT | Leaded | All | 0.068 | 1.1.7 | 10(c) |
| 1975+ | Organic | NOCAT | Unleaded | All | 0.030 | 1.1.7 | 10(a)(h) |
| All | Sulfate | NOCAT | Leaded | 19.6 | 0.002 | 1.1.8,10 | 10 |
| 1975+ | Sulfate | CAT | Leaded | 19.6 | 0.002 | 1.1.8,10 | 10(d) |
| Pre-1975 | Sulfate | NOCAT | Leaded | 34.8 | 0.001 | 1.1.9 | 2 |
| 1975+ | Sulfate | CAT/NOAIR(f) | Unleaded | 19.6 | 0.005 | 1.1.10 | 10 |
| 1975+ | Sulfate | CAT/AIR(g) | Unleaded | 19.6 | 0.016 | 1.1.10 | 10 |
| 1975+ | Sulfate | NOCAT | Unleaded | 19.6 | 0.002 | 1.1.10 | 10(e) |
| 1975+ | Sulfate | NOCAT | Leaded | 34.8 | 0.001 | 1.1.9 | 2 |
| 1975+ | Sulfate | NOCAT | Unleaded | 34.8 | 0.001 | 1.1.11 | 2 |
| 1975+ | Sulfate | OXCAT/NOAIR | Unleaded | 34.8 | 0.005 | 1.1.11 | 2 |
| 1975+ | Sulfate | 3WCAT | Unleaded | 34.8 | 0.001 | 1.1.11 | 2 |
| 1975+ | Sulfate | OXCAT/AIR | Unleaded | 34.8 | 0.020 | 1.1.11 | 2 |
| 1975+ | Sulfate | 3WCAT/OXCAT | Unleaded | 34.8 | 0.025 | 1.1.11 | 2 |
| 1975+ | Sulfate | CAT | Leaded | 34.8 | 0.001 | 1.1.11 | 2(d) |
| **Light-Duty Diesel Vehicles and Trucks:** | | | | | | | |
| Pre-1981 | All LDDV | - | Diesel | All | 0.700 | 1.1.12 | 4 |
| 1981-1986 | All LDDV | - | Diesel | All | 0.320 | 1.1.13 | 4(i) |
| 1987+ | All LDDV | - | Diesel | All | 0.200 | 1.1.14 | 4 |
| Pre-1981 | All LDDT | - | Diesel | All | 0.800 | 1.1.15 | 4 |
| 1981-1986 | All LDDT | - | Diesel | All | 0.280 | 1.1.16 | 4 |
| 1987+ | All LDDT | - | Diesel | All | 0.260 | 1.1.17 | 4 |
| **Heavy-Duty Gasoline Trucks:** | | | | | | | |
| Pre-1987 | Organic | NOCAT | Leaded | All | 0.370 | 1.1.21,23 | 10 |
| 1987+ | Organic | CAT/AIR | Unleaded | All | 0.054 | 1.1.22 | 10 |

Table 1 (cont'd)

Emission Factors of Motor
Vehicle Engine Total Particulate Emissions

| Applicable Model Year(s) | Particulate Component | Control System | Type of Fuel Used | Vehicle Speed (MPH) | Emission Factor (grams/mile) | Equation Used In | Emission Factor Source Reference No. |
|---|---|---|---|---|---|---|---|
| Pre-1987 | Sulfate | NOCAT | Leaded | All | 0.006 | 1.1.24,26 | 10 |
| 1987+ | Sulfate | CAT/AIR | Unleaded | All | 0.048 | 1.1.25 | 10 |
| Heavy-Duty Diesel Trucks: | | | | | | | |
| Pre-1983 | All HDDT1 | - | Diesel | All | 1.423 | 1.1.27 | 10 |
| 1983+ | All HDDT1 | - | Diesel | All | 1.188 | 1.1.28 | 10 |
| All | All HDDT2 | - | Diesel | All | 1.954 | 1.1.29 | 10 |
| Motorcycles: | | | | | | | |
| All | 4-Stroke | - | Leaded | All | 0.046 | 1.1.30,31 | 2 |
| All | 2-Stroke | - | Leaded | All | 0.330 | 1.1.30 | 2 |

(a) Ratio 1.5/3.4 of 1970-74 organic value.
(b) Combined value of organic from catalyst/no air and catalyst/air vehicles.
(c) Same as 1970-74 no catalyst leaded organic value.
(d) Misfueled vehicles.
(e) Same as no catalyst leaded value.
(f) Includes oxidation catalyst vehicles and three-way catalyst vehicles without air pumps.
(g) Includes oxidation catalyst vehicles and three-way plus oxidation catalyst vehicles with air pumps.
(h) Value should actually be higher for the light-duty truck II class (much like the 1970-74 organic value) but no data exist.
(i) The average LDDV emission factor for 1981 through 1986 is 0.320 g/mile. This emission factor was obtained by averaging the factor of 0.270 g/mile for 1981 through 1984 (appropriate for a 1.5 g/mile NOx standard) and 0.420 g/mile for 1985 and 1986 (appropriate for a 1.0 g/mile NOx standard). Both factors are used in reference 4.

Table 2

Lead Content of Gasoline

| Year | Leaded Gasoline* (g/gal) | Unleaded Gasoline (g/gal) |
|---|---|---|
| 1974 | 1.79 | - |
| 1975 | 1.82 | 0.014 |
| 1976 | 2.02 | 0.014 |
| 1977 | 2.03 | 0.014 |
| 1978 | 1.94 | 0.014 |
| 1979 | 1.85 | 0.014 |
| 1980 | 1.38 | 0.014 |
| 1981 | 1.15 | 0.014 |
| 1982 | 1.24 | 0.014 |
| 1983 | 1.14 | 0.014 |
| 1984 | 1.1 | 0.014 |
| 1985 | 1.1 | 0.014 |
| 1986 | 1.1 | 0.014 |
| 1987 | 1.1 | 0.014 |
| 1988 | 1.1 | 0.014 |
| 1989 | 1.1 | 0.014 |
| 1990 | 1.1 | 0.014 |

*1974-1982: Lead content based upon data submitted to EPA on historical sales data for leaded gasoline and data indicating the actual pooled average lead content. The value for unleaded gasoline is based on recent MVMA fuel surveys.

1983-1990: Lead content based upon requirements for average lead content of leaded gasoline. During the first half of 1983, small refineries were subject to a pooled average lead standard.

Table 3

Fraction of Light-Duty Vehicle Model Year Sales Equipped with Different Emission Control Systems (Low-Altitude Non-California)

| System | Pre-1975 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $F_{L,1,j}$ | 1.000 | .127 | .132 | .157 | .131 | .090 | .041 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{1,j,NL,NOCAT}$ | 0 | .081 | .020 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{1,j,OXCAT/NOAIR}$ | 0 | .597 | .637 | .650 | .650 | .640 | .421 | .033 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{1,j,OXCAT/AIR}$ | 0 | .322 | .343 | .350 | .350 | .345 | .514 | .099 | .140 | .120 | 0 | 0 | 0 | 0 | 0 |
| $F_{1,j,3WCAT}$ | 0 | 0 | 0 | 0 | 0 | .015 | .053 | .263 | .320 | .220 | .400 | .530 | .550 | .570 | .600 |
| $F_{1,j,3WCAT/OXCAT}$ | 0 | 0 | 0 | 0 | 0 | 0 | .012 | .605 | .540 | .660 | .600 | .470 | .450 | .430 | .400 |
| $F_{D,1,j}$ | 0 | 0 | 0 | 0 | .030 | .040 | .050 | .061 | .047 | .024 | .030 | .054 | .063 | .072 | .082 |
| $F_{1,j,CAT}$ | 0 | .919 | .980 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| $F_{1,j,CAT/NOAIR}$ | 0 | .597 | .637 | .650 | .650 | .655 | .474 | .296 | .140 | .180 | .240 | .370 | .440 | .520 | .530 |
| $F_{1,CAT/AIR}$ | 0 | .322 | .343 | .350 | .350 | .345 | .526 | .704 | .860 | .820 | .760 | .630 | .560 | .480 | .470 |

Sources: U.S. EPA Emission Factor In-Use Test Vehicle Data Base.
EEA Forecasts of Emission Control Technology 1983-1990.
U.S. EPA Fuel Economy Data Base.
Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles.

Note: Model year columns don't add up to 1.000. Only $F_{L,1,j}$ and $F_{D,1,j}$ are fractions of all LDVs. All other systems are fractions of all unleaded LDVs.

Table 4

FLEET SALES FRACTIONS

Light-Duty Vehicles

| Model Years | Unleaded Gasoline Fraction of LDV Fleet, $F_{NL,1,j}$* | Leaded Gasoline Fraction of LDV Fleet, $F_{L,1,j}$* | Diesel Fraction of LDV Fleet, $F_{D,1,j}$* |
|---|---|---|---|
| Pre-1975 | 0.000 | 1.000 | 0.000 |
| 1975 | 0.873 | 0.127 | 0.000 |
| 1976 | 0.868 | 0.132 | 0.000 |
| 1977 | 0.843 | 0.157 | 0.000 |
| 1978 | 0.839 | 0.131 | 0.030 |
| 1979 | 0.870 | 0.090 | 0.040 |
| 1980 | 0.909 | 0.041 | 0.050 |
| 1981 | 0.939 | 0.000 | 0.061 |
| 1982 | 0.953 | 0.000 | 0.047 |
| 1983 | 0.976 | 0.000 | 0.024 |
| 1984 | 0.970 | 0.000 | 0.030 |
| 1985 | 0.946 | 0.000 | 0.054 |
| 1986 | 0.937 | 0.000 | 0.063 |
| 1987 | 0.928 | 0.000 | 0.072 |
| 1988+ | 0.918 | 0.000 | 0.082 |

WHERE:

$F_{NL,1,j}$ = Estimated fraction of the LDV fleet which use unleaded gasoline in model year j;

$F_{L,1,j}$ = Estimated fraction of the LDV fleet which use leaded gasoline in model year j;

$F_{D,1,j}$ = Estimated fraction of the LDV fleet which use diesel fuel in model year j.

*Diesel and gasoline sales projections were made by EPA based on data obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

Percentages of gasoline vehicles requiring leaded and nonleaded fuel obtained from Energy and Environmental Analysis, Inc. "Documentation for the New Highway Fuel Consumption Model", January 1982.

Table 5

TRAVEL WEIGHTING FACTOR CALCULATION*

Light-Duty Vehicles

| Vehicle Age | (a) January 1 Fraction Total Registration** | (b) Annual Mileage Accumulation Rate | (a)(b) | [(a)(b)/(SUM)] Fraction of LDV Travel by Model Year, $m_{1,j}$ |
|---|---|---|---|---|
| 1 | 0.025 | 14400 | 360.0 | 0.031 |
| 2 | 0.106 | 14275 | 1513.2 | 0.131 |
| 3 | 0.096 | 13775 | 1322.4 | 0.115 |
| 4 | 0.074 | 13250 | 980.5 | 0.085 |
| 5 | 0.096 | 12675 | 1216.8 | 0.106 |
| 6 | 0.108 | 12175 | 1314.9 | 0.114 |
| 7 | 0.093 | 11650 | 1083.5 | 0.094 |
| 8 | 0.074 | 11075 | 819.6 | 0.071 |
| 9 | 0.069 | 10575 | 729.7 | 0.063 |
| 10 | 0.062 | 10050 | 623.1 | 0.054 |
| 11 | 0.050 | 9475 | 473.8 | 0.041 |
| 12 | 0.037 | 8975 | 332.1 | 0.028 |
| 13 | 0.031 | 8450 | 262.0 | 0.023 |
| 14 | 0.024 | 7875 | 189.0 | 0.016 |
| 15 | 0.016 | 7375 | 118.0 | 0.010 |
| 16 | 0.010 | 6850 | 68.5 | 0.006 |
| 17 | 0.005 | 6275 | 31.4 | 0.003 |
| 18 | 0.003 | 5775 | 17.3 | 0.002 |
| 19 | 0.002 | 5275 | 10.6 | 0.001 |
| 20+ | 0.016 | 4750 | 76.0 | 0.006 |
| | | SUM: | 11542.4 | |

*Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, March 1981, [EPA-460/3-81-005]. The travel weighting fractions reflect a January 1 evaluation date.

**January 1 fractions of total registration differ from those in the cited source because they have been normalized to add up to 1.000. The cited source performed on equivalent normalization at a later stage in its calculation.

Table 6

City/Highway Combined On-Road Fuel Economy*
(miles/gallon)

| Model Year | Fuel Economy, $E_{c,i,j}$ LDV | LDT1 | LDT2 | HDT1 | HDT2 |
|---|---|---|---|---|---|
| Pre-1970 | 13.9 | 10.6 | 7.9 | 7.6 | 5.5 |
| 1970 | 13.9 | 10.6 | 7.9 | 8.0 | 5.1 |
| 1971 | 13.2 | 10.4 | 7.7 | 8.0 | 5.0 |
| 1972 | 13.1 | 10.2 | 7.4 | 8.0 | 5.0 |
| 1973 | 12.9 | 9.9 | 7.0 | 8.4 | 5.0 |
| 1974 | 12.6 | 9.6 | 6.9 | 8.7 | 5.0 |
| 1975 | 13.9 | 12.0 | 8.8 | 9.1 | 5.0 |
| 1976 | 14.9 | 12.6 | 9.7 | 9.2 | 5.1 |
| 1977 | 15.6 | 13.8 | 9.4 | 9.4 | 5.1 |
| 1978 | 16.7 | 14.3 | 9.6 | 9.2 | 5.2 |
| 1979 | 18.5 | 15.2 | 9.8 | 9.7 | 5.1 |
| 1980 | 19.6 | 16.3 | 11.5 | 10.2 | 5.1 |
| 1981 | 21.8 | 18.1 | 13.3 | 10.7 | 6.0 |
| 1982 | 23.3 | 18.4 | 13.8 | 11.3 | 6.3 |
| 1983 | 24.6 | 18.9 | 14.3 | 11.5 | 6.5 |
| 1984 | 26.0 | 19.5 | 14.9 | 11.8 | 6.7 |
| 1985 | 27.4 | 20.2 | 15.4 | 12.0 | 6.9 |
| 1986 | 28.8 | 21.1 | 16.0 | 12.4 | 7.1 |
| 1987 | 30.2 | 22.0 | 16.6 | 12.7 | 7.3 |
| 1988+ | 31.6 | 22.9 | 17.2 | 13.1 | 7.5 |

*Fuel economies for model years 1980-1988 were obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model - Tenth Quarterly Report" (U.S. DOE Contract Number DE-AC01-80IE-11972, Task No. 8, November 1983). Fuel economies for model years 1970-1979 were obtained from Robert Dulla, EEA.

Table 7

Fuel Economy Correction Factors at Various Speeds, $C_s$
(Normalized to 32.7 miles/hour-cyclic driving)

| | Speed (mph) | $C_s$ Cyclic Driving | $C_s$ Steady Cruise |
|---|---|---|---|
| | 5 | 0.323 | 0.467 |
| | 10 | 0.553 | 0.709 |
| | 15 | 0.692 | 0.997 |
| (~FTP) | 20 | 0.790 | 1.153 |
| | 25 | 0.885 | 1.248 |
| | 30 | 0.963 | 1.294 |
| | 32.7 | 1.000 | 1.303 |
| (~SET) | 35 | 1.022 | 1.303 |
| | 40 | 1.053 | 1.288 |
| | 45 | 1.073 | 1.256 |
| | 50 | 1.078 | 1.210 |
| | 55 | 1.063 | 1.159 |
| | 60 | 1.023 | 1.104 |

Table 8

Fraction of Light-Duty Truck I Model Year Sales Equipped with Different Emission Control Systems (Low-Altitude Non-California)

| System | Pre-1975 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $F_{L,2,j}$ | 1.000 | .188 | .088 | .038 | .027 | .032 | .023 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{2,j,NL,NOCAT}$ | 0 | .123 | .225 | .083 | .069 | .034 | .027 | .011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{2,j,OXCAT/NOAIR}$ | 0 | .570 | .504 | .596 | .605 | .561 | .564 | .574 | .400 | .300 | .150 | .150 | .150 | 0 | 0 |
| $F_{2,j,OXCAT/AIR}$ | 0 | .307 | .271 | .321 | .325 | .405 | .409 | .415 | .500 | .500 | .450 | .450 | .450 | .150 | .150 |
| $F_{2,j,3WCAT}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .100 | .200 | .400 | .400 | .400 | .850 | .850 |
| $F_{2,j,3WCAT/OXCAT}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{D,2,j}$ | 0 | 0 | 0 | 0 | .005 | .011 | .021 | .084 | .067 | .061 | .056 | .050 | .075 | .100 | .125 |
| $F_{2,j,CAT}$ | 0 | .877 | .775 | .917 | .930 | .966 | .973 | .989 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| $F_{2,j,CAT/NOAIR}$ | 0 | .570 | .504 | .596 | .605 | .561 | .564 | .574 | .500 | .500 | .250 | .250 | .250 | .250 | .250 |
| $F_{2,CAT/AIR}$ | 0 | .307 | .271 | .321 | .325 | .405 | .409 | .415 | .500 | .500 | .750 | .750 | .750 | .750 | .750 |

Sources: U.S. EPA Emission Factor In-Use Test Vehicle Data Base.
U.S. EPA Fuel Economy Data Base.
U.S. EPA Federal Register: Federal Certification Test Results 1975-78.
Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles.

Note: Model year columns don't add up to 1.000. Only $F_{L,2,j}$ and $F_{D,2,j}$ are fractions of all LDT1s. All other systems are fractions of all unleaded LDT1s.

Table 9

FLEET SALES FRACTIONS

Light-Duty Trucks I

| Model Years | Unleaded Gasoline Fraction of LDT1 Fleet, $F_{NL,2,j}$* | Leaded Gasoline Fraction of LDT1 Fleet, $F_{L,2,j}$* | Diesel Fraction of LDT1 Fleet, $F_{D,2,j}$* |
|---|---|---|---|
| Pre-1975 | 0.000 | 1.000 | 0.000 |
| 1975 | 0.812 | 0.188 | 0.000 |
| 1976 | 0.912 | 0.088 | 0.000 |
| 1977 | 0.962 | 0.038 | 0.000 |
| 1978 | 0.968 | 0.027 | 0.005 |
| 1979 | 0.957 | 0.032 | 0.011 |
| 1980 | 0.956 | 0.023 | 0.021 |
| 1981 | 0.916 | 0.000 | 0.084 |
| 1982 | 0.933 | 0.000 | 0.067 |
| 1983 | 0.939 | 0.000 | 0.061 |
| 1984 | 0.944 | 0.000 | 0.056 |
| 1985 | 0.950 | 0.000 | 0.050 |
| 1986 | 0.925 | 0.000 | 0.075 |
| 1987 | 0.900 | 0.000 | 0.100 |
| 1988+ | 0.875 | 0.000 | 0.125 |

WHERE:

$F_{NL,2,j}$ = Estimated fraction of the LDT1 fleet which use unleaded gasoline in model year j;

$F_{L,2,j}$ = Estimated fraction of the LDT1 fleet which use leaded gasoline in model year j;

$F_{D,2,j}$ = Estimated fraction of the LDT1 fleet which use diesel fuel in model year j.

*Diesel and gasoline sales projections were made by EPA based on data obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

Percentages of gasoline vehicles requiring leaded and unleaded fuel obtained from Energy and Environmental Analysis, Inc. "Documentation for the New Highway Fuel Consumption Model", January 1982.

Table 10

TRAVEL WEIGHTING FACTOR CALCULATION*

Light-Duty Trucks I**

| Vehicle Age | (a) January 1 Fraction of Total Registration*** | (b) Annual Mileage Accumulation Rate | (a)(b) | [(a)(b)/(SUM)] Fraction of LDT1 Travel by Model Year, $m_{2,j}$ |
|---|---|---|---|---|
| 1 | 0.034 | 15600 | 530.4 | 0.054 |
| 2 | 0.101 | 15200 | 1535.2 | 0.157 |
| 3 | 0.091 | 13625 | 1239.9 | 0.127 |
| 4 | 0.065 | 12175 | 791.4 | 0.081 |
| 5 | 0.098 | 10925 | 1070.7 | 0.110 |
| 6 | 0.106 | 9925 | 1052.1 | 0.108 |
| 7 | 0.081 | 9200 | 745.2 | 0.076 |
| 8 | 0.064 | 8450 | 540.8 | 0.055 |
| 9 | 0.047 | 7875 | 370.1 | 0.038 |
| 10 | 0.051 | 7375 | 376.1 | 0.039 |
| 11 | 0.049 | 6900 | 338.1 | 0.035 |
| 12 | 0.035 | 6500 | 227.5 | 0.023 |
| 13 | 0.038 | 6125 | 232.8 | 0.024 |
| 14 | 0.035 | 5800 | 203.0 | 0.021 |
| 15 | 0.028 | 5425 | 151.9 | 0.016 |
| 16 | 0.023 | 5150 | 118.5 | 0.012 |
| 17 | 0.016 | 4925 | 78.8 | 0.008 |
| 18 | 0.012 | 4625 | 55.5 | 0.006 |
| 19 | 0.011 | 4400 | 48.4 | 0.005 |
| 20+ | 0.014 | 4400 | 61.6 | 0.006 |
| | | SUM: | 9768.0 | |

*Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, March 1981, [EPA-460/3-81-005]. The travel weighting fractions reflect a January 1 evaluation date.

**Light-duty trucks I have a gross vehicle weight (GVW) rating of 6000 pounds or less.

***January 1 fractions of total registration differ from those in the cited source because they have been normalized to add up to 1.000. The cited source performed an equivalent normalization at a later stage in its calculation.

Table 11

<u>Fraction of Model Year Sale of</u>
<u>Light-Duty Trucks II by Emission Control Systems</u>

| System | Pre-1975 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $F_{L,3,j}$ | 1.000 | 1.000 | 1.000 | 1.000 | .988 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{3,j,NL,NOCAT}$ | 0 | 0 | 0 | 0 | 0 | .008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{3,j,OXCAT}$ | 0 | 0 | 0 | 0 | 0 | .496 | .500 | .500 | .500 | .500 | .150 | .150 | .150 | 0 | 0 |
| $F_{3,j,OXCAT/AIR}$ | 0 | 0 | 0 | 0 | 0 | .496 | .500 | .500 | .500 | .500 | .450 | .450 | .450 | 0 | 0 |
| $F_{3,j,3WCAT}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .400 | .400 | .400 | .850 | .850 |
| $F_{3,j,3WCAT/OXCAT}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{D,3,j}$ | 0 | 0 | 0 | 0 | .012 | .025 | .050 | .050 | .080 | .113 | .147 | .180 | .194 | .208 | .222 |
| $F_{3,j,CAT}$ | 0 | 0 | 0 | 0 | 0 | .992 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| $F_{3,j,CAT/NOAIR}$ | 0 | 0 | 0 | 0 | 0 | .496 | .500 | .500 | .500 | .500 | .250 | .250 | .250 | .250 | .250 |
| $F_{3,CAT/AIR}$ | 0 | 0 | 0 | 0 | 0 | .496 | .500 | .500 | .500 | .500 | .750 | .750 | .750 | .750 | .750 |

Source: U.S. EPA Emission Factor In-Use Test Vehicle Data Base.
Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles.

Note: Model year columns don't add up to 1.000. Only $F_{L,3,j}$ and $F_{D,3,j}$ are fractions of <u>all</u> LDT2s. All other systems are fractions of all <u>unleaded</u> LDT2s.

Table 12

FLEET SALES FRACTIONS

Light-Duty Trucks II

| Model Years | Unleaded Gasoline Fraction of LDT2 Fleet, $F_{NL,3,j}$* | Leaded Gasoline Fraction of LDT2 Fleet, $F_{L,3,j}$* | Diesel Fraction of LDT2 Fleet, $F_{D,3,j}$* |
|---|---|---|---|
| Pre-1975 | 0.000 | 1.000 | 0.000 |
| 1975 | 0.000 | 1.000 | 0.000 |
| 1976 | 0.000 | 1.000 | 0.000 |
| 1977 | 0.000 | 1.000 | 0.000 |
| 1978 | 0.000 | 0.988 | 0.012 |
| 1979 | 0.975 | 0.000 | 0.025 |
| 1980 | 0.950 | 0.000 | 0.050 |
| 1981 | 0.950 | 0.000 | 0.050 |
| 1982 | 0.920 | 0.000 | 0.080 |
| 1983 | 0.887 | 0.000 | 0.113 |
| 1984 | 0.853 | 0.000 | 0.147 |
| 1985 | 0.820 | 0.000 | 0.180 |
| 1986 | 0.806 | 0.000 | 0.194 |
| 1987 | 0.792 | 0.000 | 0.208 |
| 1988+ | 0.778 | 0.000 | 0.222 |

WHERE:

$F_{NL,3,j}$ = Estimated fraction of the LDT2 fleet which use unleaded gasoline in model year j;

$F_{L,3,j}$ = Estimated fraction of the LDT2 fleet which use leaded gasoline in model year j;

$F_{D,3,j}$ = Estimated fraction of the LDT2 fleet which use diesel fuel in model year j.

*Diesel and gasoline sales projections were made by EPA based on data obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

Percentages of gasoline vehicles requiring leaded and nonleaded fuel obtained from Energy and Environmental Analysis, Inc., "Documentation for the New Highway Fuel Consumption Model", January 1982.

Table 13

TRAVEL WEIGHTING FACTOR CALCULATION*

Light-Duty Trucks II**

| Vehicle Age | (a) January 1 Fraction of Total Registration*** | (b) Annual Mileage Accumulation Rate | (a)(b) | [(a)(b)/(SUM)] Fraction of LDT2 Travel by Model Year, $m_{3,j}$ |
|---|---|---|---|---|
| 1 | 0.098 | 15800 | 1548.4 | 0.125 |
| 2 | 0.247 | 15400 | 3803.8 | 0.306 |
| 3 | 0.185 | 13800 | 2553.0 | 0.206 |
| 4 | 0.116 | 12300 | 1426.8 | 0.115 |
| 5 | 0.068 | 11125 | 756.5 | 0.061 |
| 6 | 0.067 | 10100 | 676.7 | 0.055 |
| 7 | 0.047 | 9300 | 437.1 | 0.035 |
| 8 | 0.036 | 8550 | 307.8 | 0.025 |
| 9 | 0.027 | 7975 | 215.3 | 0.017 |
| 10 | 0.024 | 7475 | 179.4 | 0.014 |
| 11 | 0.020 | 6975 | 139.5 | 0.011 |
| 12 | 0.013 | 6525 | 84.8 | 0.007 |
| 13 | 0.012 | 6225 | 74.7 | 0.006 |
| 14 | 0.010 | 5875 | 58.8 | 0.005 |
| 15 | 0.006 | 5425 | 32.6 | 0.003 |
| 16 | 0.007 | 5175 | 36.2 | 0.003 |
| 17 | 0.005 | 5000 | 25.0 | 0.002 |
| 18 | 0.004 | 4625 | 18.5 | 0.001 |
| 19 | 0.004 | 4400 | 17.6 | 0.001 |
| 20+ | 0.005 | 4400 | 22.0 | 0.002 |
| | | SUM: | 12414.5 | |

*Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, March 1981, [EPA-460/3-81-005]. The travel weighting fractions reflect a January 1 evaluation date.

**Light-duty trucks II have a gross vehicle weight (GVW) rating of 6001 to 8500 pounds.

***January 1 fractions of total registration differ from those in the cited source because they are normalized to add up to 1.000. The cited source performed an equivalent normalization at a later stage of its calculation.

Table 14

FLEET SALES FRACTIONS

Heavy-Duty Trucks I and II*

| Model Years | Gasoline Fraction of HDT1 Fleet, $F_{L,4,j}$ or $F_{NL,4,j}$** | Diesel Fraction of HDT1 Fleet, $F_{D,4,j}$ | Gasoline Fraction of HDT2 Fleet, $F_{L,5,j}$** | Diesel Fraction of HDT2 Fleet, $F_{D,5,j}$ |
|---|---|---|---|---|
| Pre-1977 | 1.000 (LEADED) | 0.000 | 0.623 (LEADED) | 0.377 |
| 1977 | 1.000 " | 0.000 | 0.468 " | 0.532 |
| 1978 | 1.000 " | 0.000 | 0.440 " | 0.560 |
| 1979 | 1.000 " | 0.000 | 0.412 " | 0.588 |
| 1980 | 1.000 " | 0.000 | 0.472 " | 0.528 |
| 1981 | 1.000 " | 0.000 | 0.330 " | 0.670 |
| 1982 | 0.838 " | 0.162 | 0.360 " | 0.640 |
| 1983 | 0.820 " | 0.180 | 0.344 " | 0.656 |
| 1984 | 0.803 " | 0.197 | 0.327 " | 0.673 |
| 1985 | 0.785 " | 0.215 | 0.311 " | 0.689 |
| 1986 | 0.772 " | 0.228 | 0.303 " | 0.697 |
| 1987 | 0.759 (UNLEADED) | 0.241 | 0.295 " | 0.705 |
| 1988 | 0.746 " | 0.254 | 0.288 " | 0.712 |
| 1989 | 0.733 " | 0.267 | 0.280 " | 0.720 |
| 1990 | 0.720 " | 0.280 | 0.272 " | 0.728 |
| 1991 | 0.716 " | 0.284 | 0.264 " | 0.736 |
| 1992 | 0.712 " | 0.288 | 0.256 " | 0.744 |
| 1993 | 0.708 " | 0.292 | 0.248 " | 0.752 |
| 1994 | 0.704 " | 0.296 | 0.240 " | 0.760 |
| 1995 | 0.700 " | 0.300 | 0.232 " | 0.768 |

*Heavy-duty trucks I are assumed to have a gross vehicle weight (GVW) rating of 8,501 to 14,000 pounds for this report. The reason for the 14,000 pound cutpoint is that it is projected that catalysts will be used in 1987 and beyond on gasoline HDTs with a GVW of 14,000 pounds or under. Heavy-duty trucks II are assumed to have a gross vehicle weight (GVW) rating greater than 14,000 pounds for this report.

**The estimated fractions of the HDT1 and HDT2 model year fleets which are gasoline-powered are based on sales projections by Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983. Gasoline HDT1s use leaded fuel through the 1986 model year and are all unleaded from 1987 on. All gasoline HDT2s use leaded fuel for all model years.

Table 15

TRAVEL WEIGHTING FACTOR CALCULATION*

Heavy-Duty Trucks I**
and Heavy-Duty Gasoline Trucks II

| Vehicle Age | (a) January 1 Fraction of Total Registration*** | (b) Annual Mileage Accumulation Rate | (a)(b) | [(a)(b)/(SUM)] Fraction of HDT1 Travel by Model Year, $m_{4,j}$ and $m_{5G,j}$ |
|---|---|---|---|---|
| 1 | 0.0 | 0 | 0.0 | 0.000 |
| 2 | 0.131 | 21000 | 2741.7 | 0.202 |
| 3 | 0.112 | 18900 | 2110.1 | 0.156 |
| 4 | 0.084 | 17200 | 1449.1 | 0.107 |
| 5 | 0.098 | 15500 | 1524.4 | 0.113 |
| 6 | 0.101 | 14100 | 1425.5 | 0.105 |
| 7 | 0.081 | 12600 | 1018.2 | 0.075 |
| 8 | 0.061 | 11300 | 691.7 | 0.051 |
| 9 | 0.047 | 10300 | 487.6 | 0.036 |
| 10 | 0.050 | 9400 | 473.0 | 0.035 |
| 11 | 0.045 | 8600 | 390.4 | 0.029 |
| 12 | 0.035 | 8000 | 280.6 | 0.021 |
| 13 | 0.034 | 7300 | 250.2 | 0.019 |
| 14 | 0.030 | 6700 | 200.4 | 0.015 |
| 15 | 0.024 | 6300 | 148.8 | 0.011 |
| 16 | 0.020 | 5900 | 119.7 | 0.009 |
| 17 | 0.015 | 5500 | 81.3 | 0.006 |
| 18 | 0.011 | 5200 | 54.8 | 0.004 |
| 19 | 0.009 | 5000 | 47.0 | 0.003 |
| 20+ | 0.011 | 5000 | 55.6 | 0.004 |
| | | SUM: | 13550.2 | |

*Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, March 1981, [EPA-460/3-81-005]. These are MOBILE2 heavy-duty gasoline travel fractions (for gasoline-fueled trucks over 8,501 pounds) which are used in this report for all HDT1s (trucks greater than 8,501 pounds and less than 14,000 pounds) and all HDGT2s (gasoline-fueled trucks over 14,001 pounds). The travel weighting fractions reflect a January 1 evaluation date.

**Heavy-duty trucks I are assumed in this report to have a gross vehicle weight (GVW) rating greater than 8,501 pounds and less than 14,000 pounds.

***January 1 fractions of total registration differ from those in the cited source because they are normalized to add up to 1.000. The cited source performed an equivalent normalization in a later stage of its calculation.

Table 16

TRAVEL WEIGHTING FACTOR CALCULATION*

Heavy-Duty Diesel Trucks II**

| Vehicle Age | (a) January 1 Fraction of Total Registration*** | (b) Annual Mileage Accumulation Rate | (a)(b) | [(a)(b)/(SUM)] Fraction of HDT2 Travel by Model Year, $m_{5D,j}$ |
|---|---|---|---|---|
| 1 | 0.0 | 0 | 0.0 | 0.0 |
| 2 | 0.172 | 70400 | 12135.6 | 0.243 |
| 3 | 0.104 | 66900 | 6937.2 | 0.139 |
| 4 | 0.065 | 60600 | 3948.7 | 0.079 |
| 5 | 0.120 | 54200 | 6483.4 | 0.130 |
| 6 | 0.113 | 47900 | 5432.9 | 0.109 |
| 7 | 0.088 | 43700 | 3824.9 | 0.076 |
| 8 | 0.063 | 39400 | 2466.7 | 0.049 |
| 9 | 0.051 | 36600 | 1873.2 | 0.037 |
| 10 | 0.051 | 34500 | 1748.2 | 0.035 |
| 11 | 0.038 | 33100 | 1243.4 | 0.025 |
| 12 | 0.029 | 32400 | 925.6 | 0.018 |
| 13 | 0.031 | 31700 | 975.0 | 0.019 |
| 14 | 0.023 | 31000 | 727.3 | 0.015 |
| 15 | 0.016 | 29600 | 464.2 | 0.009 |
| 16 | 0.012 | 27500 | 317.6 | 0.006 |
| 17 | 0.009 | 24600 | 209.3 | 0.004 |
| 18 | 0.005 | 20400 | 94.2 | 0.002 |
| 19 | 0.005 | 17600 | 81.3 | 0.002 |
| 20+ | 0.008 | 17600 | 147.6 | 0.003 |
| | | SUM: | 50037.0 | |

*Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, March 1981, [EPA-460/3-81-005]. These are MOBILE2 heavy-duty diesel travel fractions (for diesel-fueled trucks over 8,501 pounds) which are used in this report for all HDDT2s (diesel-fueled trucks over 14,001 pounds). The travel weighting fractions reflect a January 1 evaluation date.

**Heavy-duty trucks II are assumed in this report to have a gross vehicle weight (GVW) rating greater than 14,001 pounds.

***January 1 fractions of total registration differ from those in the cited source because they are normalized to add up to 1.000. The cited source performed an equivalent normalization in a later stage of its calculation.

Table 17

TRAVEL WEIGHTING FACTOR CALCULATION*

Motorcycles

| Vehicle Age | (a) January 1 Fraction of Total Registration** | (b) Annual Mileage Accumulation Rate | (a)(b) | [(a)(b)/(SUM)] Fraction of MC Travel by Model Year, $m_{6,j}$ |
|---|---|---|---|---|
| 1 | 0.0 | 0 | 0.0 | 0.0 |
| 2 | 0.167 | 4100 | 685.7 | 0.356 |
| 3 | 0.159 | 2800 | 445.7 | 0.232 |
| 4 | 0.134 | 2100 | 281.0 | 0.146 |
| 5 | 0.142 | 1600 | 227.0 | 0.118 |
| 6 | 0.131 | 1200 | 157.8 | 0.082 |
| 7 | 0.080 | 800 | 63.7 | 0.033 |
| 8 | 0.051 | 600 | 30.4 | 0.016 |
| 9 | 0.028 | 400 | 11.1 | 0.001 |
| 10 | 0.010 | 200 | 2.1 | 0.010 |
| 11 | 0.098 | 200 | 19.6 | 0.0 |
| 12 | 0.0 | 200 | 0.0 | 0.0 |
| 13 | 0.0 | 0 | 0.0 | 0.0 |
| 14 | 0.0 | 0 | 0.0 | 0.0 |
| 15 | 0.0 | 0 | 0.0 | 0.0 |
| 16 | 0.0 | 0 | 0.0 | 0.0 |
| 17 | 0.0 | 0 | 0.0 | 0.0 |
| 18 | 0.0 | 0 | 0.0 | 0.0 |
| 19 | 0.0 | 0 | 0.0 | 0.0 |
| 20+ | 0.0 | 0 | 0.0 | 0.0 |
| | | SUM: | 1924.0 | |

*Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, March 1981, [EPA-460/3-81-005]. The travel weighting fractions reflect a January 1 evaluation date.

**January 1 fractions of total registration differ from those in the cited source because they are normalized to add up to 1.000. The cited source performed an equivalent normalization in a later stage of its calculation.

Table 18

Rates of Misfueling ($r_i$)
for Different Vehicle Classes*

| | I/M | Non-I/M |
|---|---|---|
| Light-Duty Vehicles (i=1) | 0.08 | 0.17 |
| Light-Duty Trucks I (i=2) | 0.16 | 0.32 |
| Light-Duty Trucks II (i=3) | 0.14 | 0.26 |
| Heavy-Duty Trucks I (i=4)** | 0.17 | 0.35 |
| Heavy-Duty Trucks II (i=5) | 0 | 0 |
| Motorcycles (i=6) | 0 | 0 |

* Values in this table are expressed as fractions of the total number of vehicles in each class. Misfueling rates are determined for the weighted average mileage accumulated for each vehicle class.

**Misfueling rates for Heavy-Duty Trucks I (HDT1) pertain only to gasoline-fueled HDT1s made after model year 1986.

Source: "Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles," EPA-AA-TSS-83-10, Office of Mobile Sources, December 31, 1983.

Table 18a

Rates of Misfueling ($r_i$) for
Different Vehicle Ages and Classes*

| Vehicle Age | Light-Duty Vehicles Non-I/M | Light-Duty Vehicles I/M | Light-Duty Trucks I Non-I/M | Light-Duty Trucks I I/M | Light-Duty Trucks II Non-I/M | Light-Duty Trucks II I/M | Heavy-Duty Gas Vehicles I** Non-I/M | Heavy-Duty Gas Vehicles I** I/M |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.04 | 0.04 | 0.22 | 0.13 | 0.22 | 0.13 | 0.18 | 0.12 |
| 2 | 0.08 | 0.05 | 0.26 | 0.14 | 0.26 | 0.14 | 0.23 | 0.13 |
| 3 | 0.11 | 0.06 | 0.29 | 0.15 | 0.30 | 0.15 | 0.28 | 0.15 |
| 4 | 0.15 | 0.07 | 0.33 | 0.16 | 0.33 | 0.16 | 0.33 | 0.16 |
| 5 | 0.18 | 0.08 | 0.35 | 0.17 | 0.36 | 0.17 | 0.37 | 0.17 |
| 6 | 0.21 | 0.09 | 0.38 | 0.18 | 0.38 | 0.18 | 0.40 | 0.19 |
| 7 | 0.24 | 0.10 | 0.40 | 0.19 | 0.41 | 0.19 | 0.44 | 0.20 |
| 8 | 0.27 | 0.11 | 0.43 | 0.19 | 0.43 | 0.19 | 0.47 | 0.20 |
| 9 | 0.30 | 0.12 | 0.45 | 0.20 | 0.45 | 0.20 | 0.49 | 0.21 |
| 10 | 0.32 | 0.13 | 0.46 | 0.20 | 0.47 | 0.21 | 0.52 | 0.22 |
| 11 | 0.35 | 0.14 | 0.48 | 0.21 | 0.49 | 0.21 | 0.54 | 0.23 |
| 12 | 0.37 | 0.14 | 0.50 | 0.21 | 0.50 | 0.22 | 0.56 | 0.23 |
| 13 | 0.39 | 0.15 | 0.51 | 0.22 | 0.52 | 0.22 | 0.58 | 0.24 |
| 14 | 0.41 | 0.16 | 0.53 | 0.22 | 0.53 | 0.23 | 0.59 | 0.24 |
| 15 | 0.43 | 0.16 | 0.54 | 0.23 | 0.55 | 0.23 | 0.61 | 0.25 |
| 16 | 0.45 | 0.17 | 0.56 | 0.23 | 0.56 | 0.23 | 0.63 | 0.25 |
| 17 | 0.46 | 0.17 | 0.57 | 0.24 | 0.57 | 0.24 | 0.64 | 0.26 |
| 18 | 0.48 | 0.18 | 0.58 | 0.24 | 0.59 | 0.24 | 0.65 | 0.26 |
| 19 | 0.49 | 0.18 | 0.59 | 0.24 | 0.60 | 0.24 | 0.67 | 0.27 |
| 20+ | 0.51 | 0.18 | 0.60 | 0.25 | 0.61 | 0.25 | 0.68 | 0.27 |

*Values in this table are expressed as fractions of the total number of vehicles in each class. Misfueling rates are determined for the average mileage accumulated by each vehicle class of each vehicle age group.

**Misfueling rates for Heavy-Duty Gasoline Vehicles I (HDGV1) are estimates for 1987 and later calendar years. Currently all HDGV1s use leaded fuel. (For example, for the year 1990, use the first three values in either the non-I/M or I/M HDGV1 column. All HDGV1s greater than 3 years old in this case (i.e., pre-1987 vehicles) would have a misfueling rate of zero since they do not require use of unleaded fuel.)

Source: "Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles," EPA-AA-TSS-83-10, Office of Mobile Sources, December 31, 1983.

Table 19

Average Data on Particle Size Distribution

| Leaded Fuel, $M_L$ | Cumulative Fraction of Particulate Mass Smaller Than Diameter 0.2 um | 2 um | 10 um |
|---|---|---|---|
| Median Particle Fractions, $M_L$ | 0.23 | 0.43 | 0.64 |
| Ranges of $M_L$ Values[a] | 0.18-0.28 | 0.28-0.58 | 0.45-0.84 |

[a] 95% confidence intervals on mean of data.

References: (author summary of) Ninomiya et al., 1970; Moran et al., 1971; Gental et al., 1973; Cantwell et al., 1972; Boyer and Laitiner, 1975; Habibi et al., 1970; Hirschler and Gilbert, 1964.

| Unleaded Fuel, $M_{NL}$ | Cumulative Fraction of Particulate Mass Smaller Than Diameter 0.2 um | 2 um | 10 um |
|---|---|---|---|
| $M_{NL,C}$ | 0.87 | 0.89 | 0.97 |
| Ranges of $M_{NL,C}$ Valves[b] | 0.86-0.88 | 0.84-0.94 | 0.84-1.00 |
| $M_{NL,NC}$ | 0.42 | 0.66 | 0.90 |
| Ranges of $M_{NL,C}$ Valves | 0.29-0.55 | 0.52-0.80 | 0.63-1.00 |

[b] 95% confidence intervals by "t" statistics.

References: (author summary of) Foster et al., 1976; Trayser et al., 1976; Foster et al., 1974; Melton et al., 1973; Habibi, 1973; Gental et al, 1973.

| Diesel Fuel, $M_D$ | Cumulative Fraction of Particulate Mass Smaller Than Diameter 0.2 um | 1.0 um | 2.0 um | 2.5 um | 10 um |
|---|---|---|---|---|---|
| $M_D$ | 0.73 | 0.86 | 0.90 | 0.92 | 1.00 |
| Ranges of $M_D$ Values[c] | 0.69-0.75 | 0.76-0.93 | 0.86-0.95 | 0.88-0.95 | 0.97-1.00 |

[c] Intermediate speed, no load, prechamber engine, 2D fuel. (Also, limited data cited below indicate this is appropriate for direct injection engines.)

References: Breslin, et al., 1976; Hare, 1979; Bykowski, 1981; Bykowski, 1983; McCain and Faulkner, 1979; Vuk, et al., 1976; Begeman, 1979; Carpenter and Johnson, 1979; Verrant and Kittelson, 1977.

Table 19 (cont'd)

Average Data on Particle Size Distribution

| Brake Wear Particulate, $M_B$ | Cumulative Fraction of Particulate Mass Smaller Than Diameter 0.43 um | 1.1 um | 4.7 um | 7 um | 10 um |
|---|---|---|---|---|---|
| Median Particle Fractions, $M_B$[d] | 0.09 | 0.16 | 0.82 | 0.90 | 0.98 |
| Ranges of $M_B$ Values | Not available | | | | |

[d]Samples for determining particle size distribution were collected by running about 20 braking cycles weighted to be representative of urban driving conditions.

Reference: Cha et. al., 1983.

## 3.0 EXAMPLE CALCULATION OF AUTOMOBILE PARTICULATE EMISSIONS LESS THAN 10 MICRONS

Problem: For an area characterized by light-duty vehicles driving under cyclic conditions with an average speed of 19.6 miles per hour, calculate the particulate emission rate of particles less than 10 um in diameter for the year 1985. Assume an inspection and maintenance program has been implemented in this area. The simplified misfueling rates from Table 18 will be used.

Solution: Use equations 1.0, 1.1., 1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5, 1.1.6, 1.1.7, 1.1.8, 1.1.10, 1.1.12, and 1.1.13.

Particulate Matter Size Cutoff = 10 um

$n = 1985$ $i = 1 = LDV$ $s = 19.6$ mph $M_B = 0.98$

$t_{1,1985} = 1.0$ $r_i$ (from Table 18) = 0.08

Equation 1.0

$$EF_{PM10,1985,19.6} = (1.0)(EF_{1,1985,19.6})+(0.0128)(0.98)+(0.002)$$

Equation 1.1

$$EF_{1,1985,19.6} = \sum_{j=1966}^{1985} [(EF_{1,j,k_1,1985,L} + EF_{1,j,k_2,L} + EF_{1,j,k_3,L})$$

$$\times (F_{L,1,j}) + (EF_{1,j,k_1,1985,NL} + EF_{1,j,k_2,NL} + EF_{1,j,k_3,NL})$$

$$\times (F_{NL,1,j}) + (EF_{1,j,D})(F_{D,1,j})]m_{1,j}$$

$Pb_{L,1985}$ = 1.1 (g/gal);

$Pb_{NL,1985}$ = 0.014 (g/gal);

$M_{L,10\ um}$ = 0.64;

$M_{NL,C,10\ um}$ = 0.97;

$M_{NL,NC,10\ um}$ = 0.90;

$M_D$ = 1.00;

$a_s$ = 0.75;

$c_s$ = 0.79.

Use the following equations to plug into Equation 1.1 and sum over the appropriate model years:

<u>Equation 1.1.1</u>

$$EF_{1,j,k_1,1985,L} = [(1.1)(0.929)(0.64)+(0.014)(0.071)(0.90)]$$

$$\circ \frac{(0.75)(1.557)}{(E_{c,1,j})(0.79)} = \frac{0.968}{E_{c,1,j}} \qquad \text{for } j = 1966\text{-}74$$

<u>Equation 1.1.2</u>

$$EF_{1,j,k_1,1985,L} = [(1.1)(0.725)(0.64)+(0.014)(0.275)(0.90)]$$

$$\circ \frac{(0.75)(1.557)}{(E_{c,1,j})(0.79)} = \frac{0.760}{E_{c,1,j}} \qquad \text{for } j = 1975\text{-}85$$

<u>Equation 1.1.3</u>

$$EF_{1,j,k_1,1985,L} = [(0.014)(0.92)(0.97)+(1.1)(0.08)(0.64)$$

$$\circ \frac{(0.75)(1.557)}{(E_{c,1,j})(0.79)} = \frac{0.102}{E_{c,1,j}} \qquad \text{for } j = 1975\text{-}85$$

Equation 1.1.4

$$EF_{1,j,k_2,L} = (0.193)(0.64) = 0.124 \text{ (g/mile)}$$

for j = 1966-69

Equation 1.1.5

$$EF_{1,j,k_2,L} = (0.068)(0.64) = 0.044 \text{ (g/mile)}$$

for j = 1970-74

Equation 1.1.6

$$EF_{1,j,k_2,L} = (0.030)(0.64) = 0.019 \text{ (g/mile)}$$

for j = 1975-85

Equation 1.1.7

$$EF_{1,j,k_2,NL} = (0.92)(F_{i,j,CAT})(0.017)(0.97)+$$

$$(0.08)(F_{1,j,CAT})(0.068)(0.64)+$$

$$(F_{1,j,NL,NOCAT})(0.030)(0.90)$$

for j = 1975-85

$$= (0.019)(F_{1,j,CAT}) + (0.027)(F_{1,j,NL,NOCAT})$$

for j = 1975-85

Equation 1.1.8

$$EF_{1,j,k_3,L} = (0.002)(0.64) = 0.001 \text{ (g/mile)}$$

for j = 1966-85

Equation 1.1.10

$$EF_{1,j,k_3,NL} = (0.92)[F_{1,j,CAT/NOAIR})(0.005)(0.97)+$$

$$(F_{1,j,CAT/AIR})(0.016)((0.97)+$$

$$(F_{1,j,NL,NOCAT})(0.002)(0.90)]+(0.08)(0.002)(0.64)$$

$$= [(F_{1,j,CAT/NOAIR})(0.004)+(F_{1,j,CAT/AIR})(0.016)$$

$$+ (F_{1,j,NL,NOCAT})(0.002)]+0.0001$$

for j = 1975-85

Equation 1.1.12

$$EF_{1,j,D} = (0.700)(1.00)$$

$$= 0.700 \text{ (g/mile)} \qquad \text{for } j = 1966\text{-}80$$

Equation 1.1.13

$$EF_{1,j,D} = (0.320)(1.00)$$

$$= 0.320 \text{ (g/mile)} \qquad \text{for } j = 1981\text{-}85$$

After calculating $EF_{1,1985,19.6}$ in Table 20, substitute in Equation 1.0 and obtain the total LDV particulate emission rate:

Equation 1.0

$$EF_{PM10,1985,19.6} = (1.0)(0.0586) + 0.0125 + 0.002$$

$$= \underline{\underline{0.0731}} \text{ (g/mile)}$$

Note: This example is an estimate of particulate emissions from light-duty vehicles only. Therefore, the total emission rate from all vehicle classes for an area in calendar year 1985 can be expected to be considerably higher.

Table 20

EXAMPLE CALCULATIONS

LIGHT-DUTY VEHICLE PARTICULATE EMISSION RATE LESS THAN 10 MICRONS FOR THE YEAR 1985

A. EMISSION FACTOR COMPONENT CALCULATION INPUTS

| Model Year, j | Age | $m_{1,j}$ | $F_{NL,1,j}$ | $F_{L,1,j}$ | $E_{C,1,j}$ | $F_{D,1,j}$ | $F_{1,j,CAT}$ | $F_{1,j,NL,NOCAT}$ | $F_{1,j,CAT/NOAIR}$ | $F_{1,j,CAT/AIR}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 1 | 0.031 | 0.946 | - | 27.4 | 0.054 | 1.000 | - | 0.370 | 0.630 |
| 1984 | 2 | 0.131 | 0.970 | - | 26.0 | 0.030 | 1.000 | - | 0.240 | 0.760 |
| 1983 | 3 | 0.115 | 0.976 | - | 24.6 | 0.024 | 1.000 | - | 0.180 | 0.820 |
| 1982 | 4 | 0.085 | 0.953 | - | 23.3 | 0.047 | 1.000 | - | 0.140 | 0.860 |
| 1981 | 5 | 0.106 | 0.939 | - | 21.8 | 0.061 | 1.000 | - | 0.296 | 0.704 |
| 1980 | 6 | 0.114 | 0.909 | 0.041 | 19.6 | 0.050 | 1.000 | - | 0.474 | 0.526 |
| 1979 | 7 | 0.094 | 0.870 | 0.090 | 18.5 | 0.040 | 1.000 | - | 0.655 | 0.345 |
| 1978 | 8 | 0.071 | 0.839 | 0.131 | 16.7 | 0.030 | 1.000 | - | 0.650 | 0.350 |
| 1977 | 9 | 0.063 | 0.843 | 0.157 | 15.6 | - | 1.000 | - | 0.650 | 0.350 |
| 1976 | 10 | 0.054 | 0.868 | 0.132 | 14.9 | - | 0.980 | 0.020 | 0.637 | 0.343 |
| 1975 | 11 | 0.041 | 0.873 | 0.127 | 13.9 | - | 0.919 | 0.081 | 0.597 | 0.322 |
| 1974 | 12 | 0.028 | - | 1.000 | 12.6 | - | - | - | - | - |
| 1973 | 13 | 0.023 | - | 1.000 | 12.9 | - | - | - | - | - |
| 1972 | 14 | 0.016 | - | 1.000 | 13.1 | | - | - | - | - |
| 1971 | 15 | 0.010 | - | 1.000 | 13.2 | - | - | - | - | - |
| 1970 | 16 | 0.006 | - | 1.000 | 13.9 | - | - | - | - | - |
| 1969 | 17 | 0.003 | - | 1.000 | 13.9 | - | - | - | - | - |
| 1968 | 18 | 0.002 | - | 1.000 | 13.9 | - | - | - | - | - |
| 1967 | 19 | 0.001 | - | 1.000 | 13.9 | - | - | - | - | - |
| 1966- | 20+ | 0.006 | - | 1.000 | 13.9 | - | - | - | - | - |

B. EMISSION FACTOR COMPONENT SUMMATION DESCRIPTIONS

Summation [1] calculates the emission factor component in Equations 1.1.1 and 1.1.2 that are used in Equation 1.1.

Summation [2] calculates the emission factor component in Equation 1.1.3 that is used in Equation 1.1.

Summation [3] calculates the emission factor component in Equations 1.1.4, 1.1.5, and 1.1.6 that are used in Equation 1.1.

Summation [4] calculates the emission factor component in Equation 1.1.7 that is used in Equation 1.1.

Summation [5] calculates the emission factor component in Equation 1.1.8 that is used in Equation 1.1.

Summation [6] calculates the emission factor component in Equation 1.1.10 that is used in Equation 1.1.

Summation [7] calculates the emission factor component in Equations 1.1.12 and 1.1.13 that are used in Equation 1.1.

C. EMISSION FACTOR COMPONENT CALCULATIONS

| Model Year, j | Age | [1] $(EF_{1,j,k_1,1985,L})$ $(F_{L,1,j})(m_{1,j})$ | [2] $(EF_{1,j,k_1,1985,NL})$ $(F_{NL,1,j})(m_{1,j})$ | [3] $(EF_{1,j,k_2,L})$ $(F_{L,1,j})(m_{1,j})$ | [4] $(EF_{1,j,k_2,NL})\cdot$ $(F_{NL,1,j})(m_{1,j})$ | [5] $(EF_{1,j,k_3,L})\cdot$ $(F_{L,1,j})(m_{1,j})$ | [6] $(EF_{1,j,k_3,NL})\cdot$ $(F_{NL,1,j})(m_{1,j})$ | [7] $(EF_{1,j,D})\cdot$ $(F_{D,1,j})(m_{1,j})$ |
|---|---|---|---|---|---|---|---|---|
| 1985 | 1 | - | 0.0001 | - | 0.0006 | - | 0.0003 | 0.0005 |
| 1984 | 2 | - | 0.0005 | - | 0.0024 | - | 0.0017 | 0.0013 |
| 1983 | 3 | - | 0.0005 | - | 0.0021 | - | 0.0016 | 0.0009 |
| 1982 | 4 | - | 0.0004 | - | 0.0015 | - | 0.0012 | 0.0013 |
| 1981 | 5 | - | 0.0005 | - | 0.0019 | - | 0.0012 | 0.0021 |
| 1980 | 6 | - | 0.0005 | - | 0.0020 | - | 0.0011 | 0.0040 |
| 1979 | 7 | 0.0003 | 0.0005 | 0.0002 | 0.0016 | 0.00001 | 0.0007 | 0.0026 |
| 1978 | 8 | 0.0004 | 0.0004 | 0.0002 | 0.0011 | 0.00001 | 0.0005 | 0.0015 |
| 1977 | 9 | 0.0005 | 0.0003 | 0.0002 | 0.0010 | 0.00001 | 0.0004 | - |
| 1976 | 10 | 0.0004 | 0.0003 | 0.0001 | 0.0009 | 0.00001 | 0.0004 | - |
| 1975 | 11 | 0.0003 | 0.0003 | 0.0001 | 0.0007 | 0.00001 | 0.0003 | - |
| 1974 | 12 | 0.0022 | - | 0.0012 | - | 0.00004 | - | - |
| 1973 | 13 | 0.0017 | - | 0.0010 | - | 0.00003 | - | - |
| 1972 | 14 | 0.0012 | - | 0.0007 | - | 0.00002 | - | - |
| 1971 | 15 | 0.0007 | - | 0.0004 | - | 0.00001 | - | - |
| 1970 | 16 | 0.0004 | - | 0.0003 | - | 0.00001 | - | - |
| 1969 | 17 | 0.0002 | - | 0.0004 | - | 0.00000 | - | - |
| 1968 | 18 | 0.0001 | - | 0.0002 | - | 0.00000 | - | - |
| 1967 | 19 | 0.0001 | - | 0.0001 | - | 0.00000 | - | - |
| 1966- | 20+ | 0.0004 | - | 0.0007 | - | 0.00001 | - | - |
| | SUM: | 0.0089 + | 0.0043 + | 0.0058 + | 0.0158 + | 0.00017 + | 0.0094 + | 0.0142 |

0.0142 = 0.0586 = $EF_{1,1985,19.6}$ (g/mile)

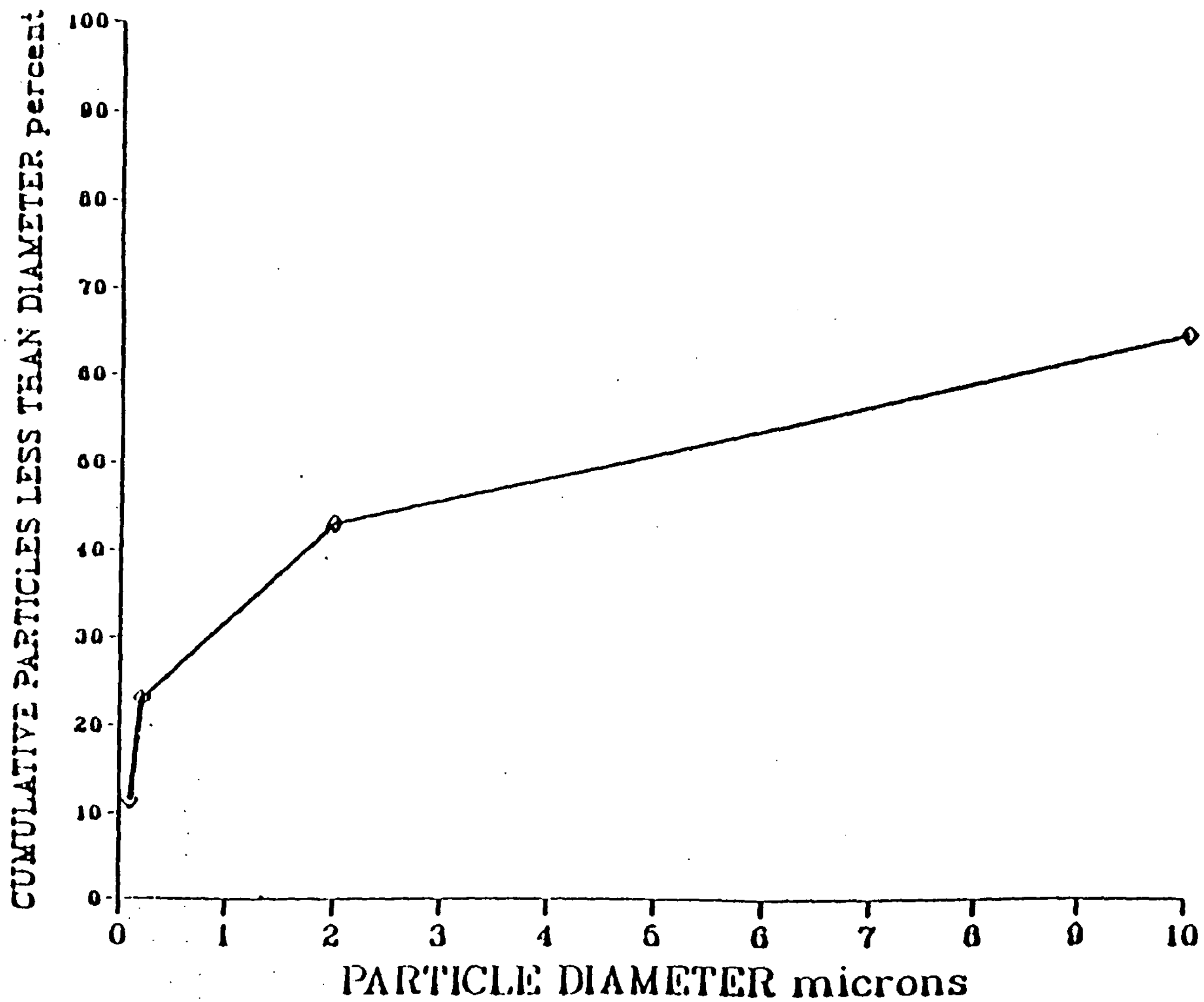



FIGURE 1. LEADED GASOLINE PARTICULATE SIZE DISTRIBUTION

FIGURE 2. UNLEADED GASOLINE PARTICULATE SIZE DISTRIBUTION

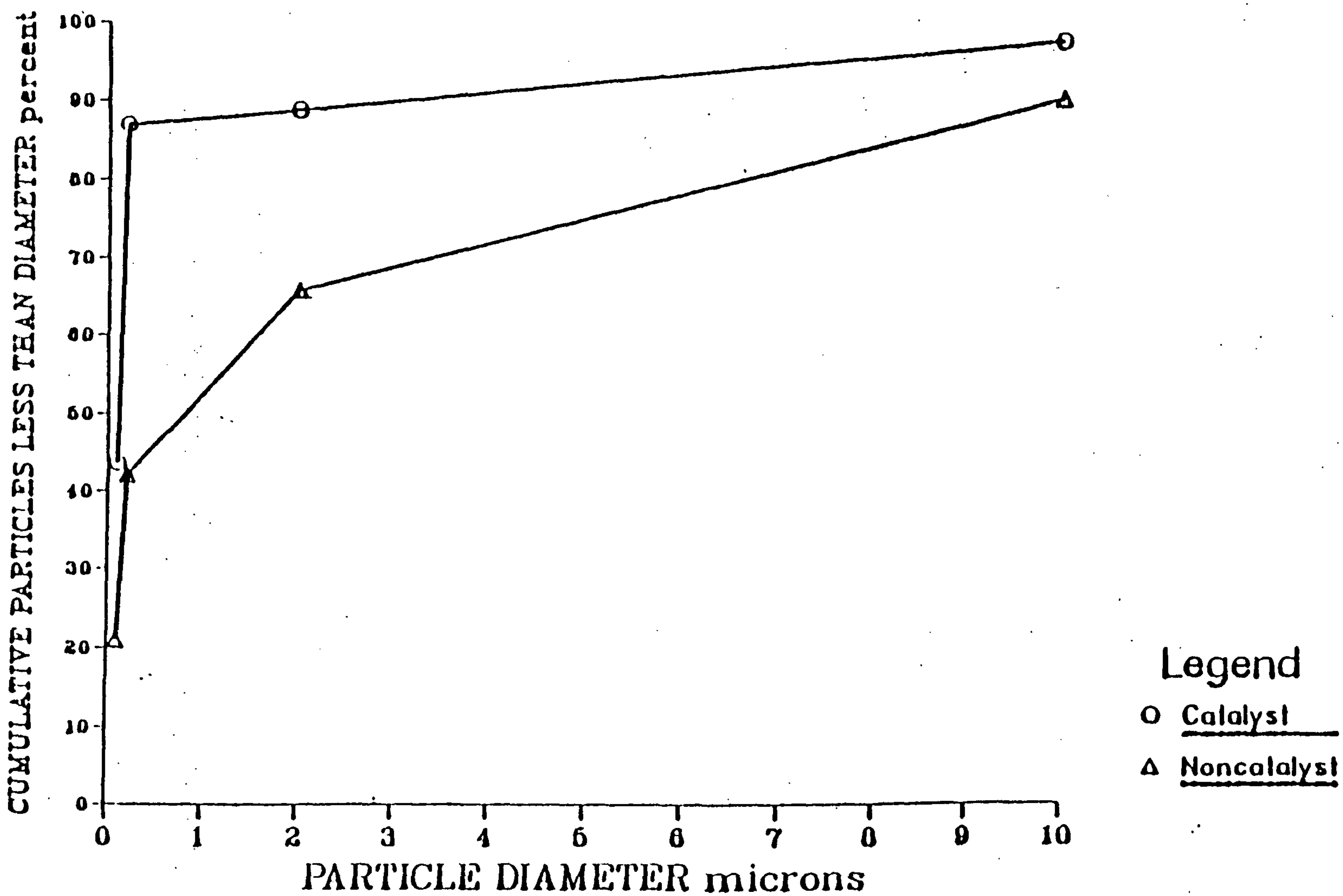


FIGURE 3. DIESEL PARTICULATE SIZE DISTRIBUTION

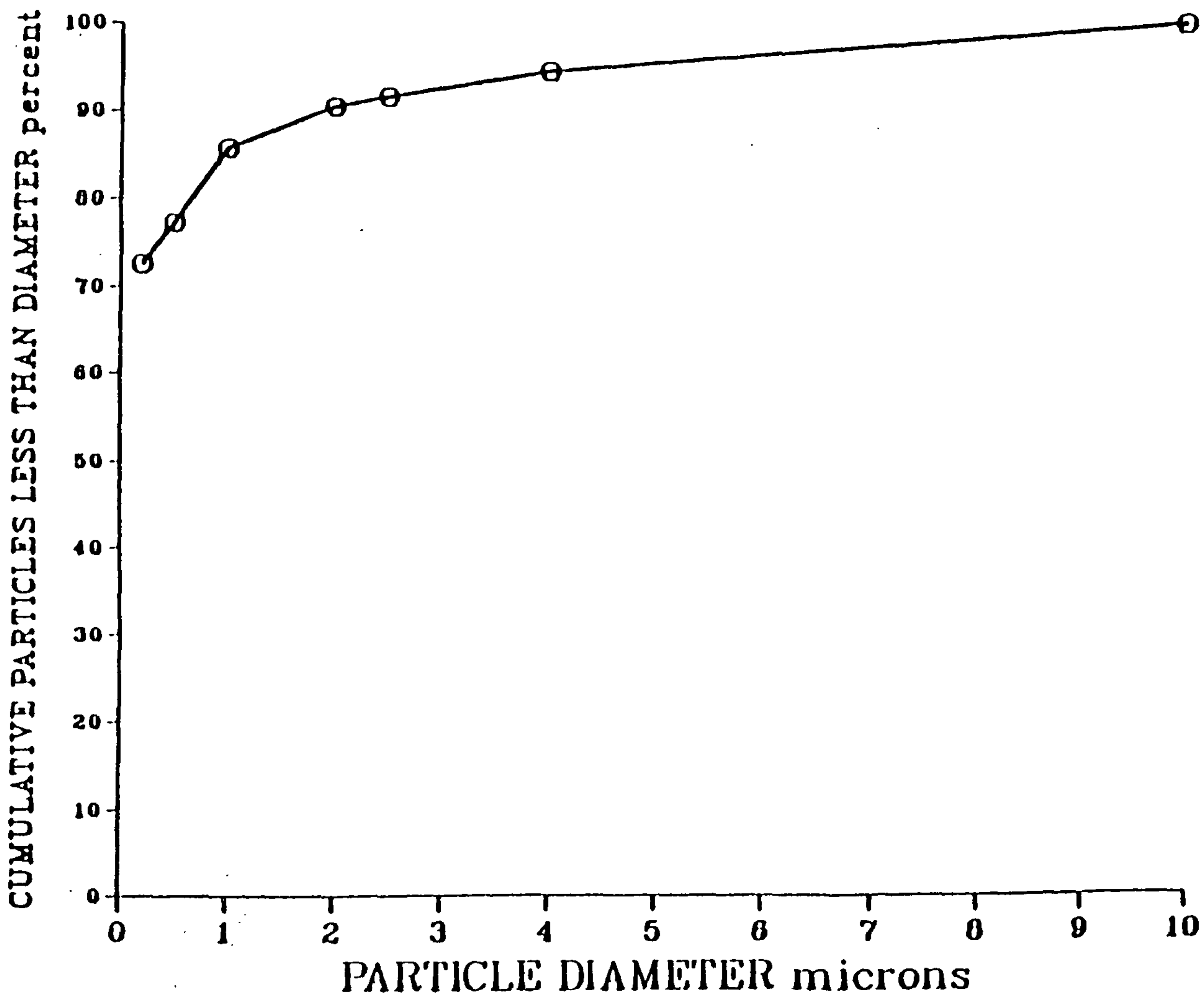
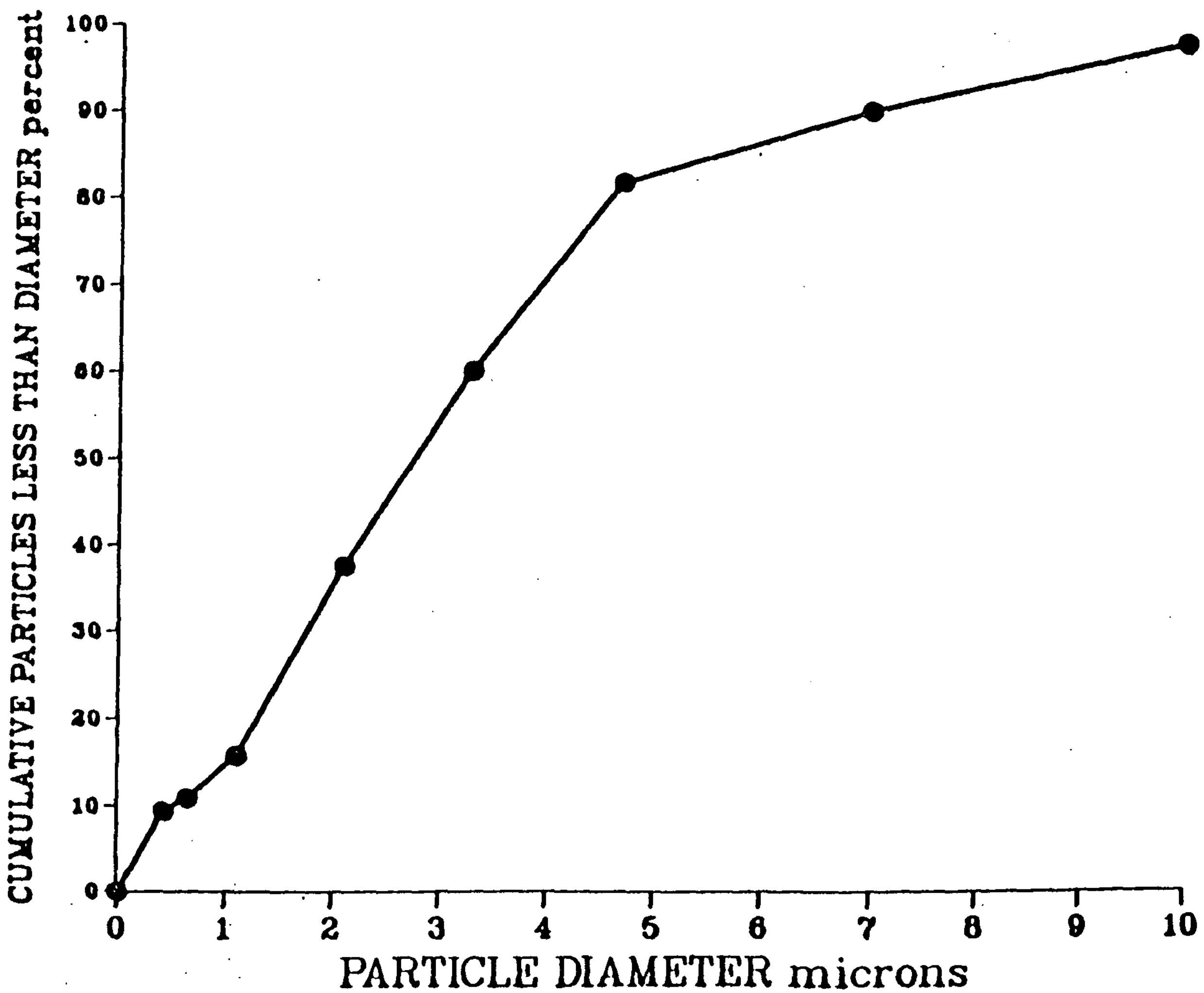


FIGURE 4. BRAKE WEAR PARTICULATE SIZE DISTRIBUTION



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