Appendix

PARTICULATE EMISSION FACTORS FOR MOBILE SOURCES AS CALCULATED IN THE MODEL PART5

1 INTRODUCTION

This appendix describes the methodologies used to calculate particulate emission factors from motor vehicles in the computer model PART5. PART5 is designed to estimate particulate emission factors for a representative vehicle in an average fleet. The model calculates these fleet characteristics, such as the travel fractions, from data that are representative of national averages. The user has the option, in many cases, to input data that represents more closely the characteristics of the region being modeled instead of using the model defaults.

The emission factors calculated by PART5 include the particulate pollutant compounds of lead, sulfate, soluble organic fraction particulate, remaining carbon portion particulate, and total exhausted particulate. The lead and sulfate are formed from the lead and sulfur contained in the fuel. The soluble organic fraction consists primarily of hydrocarbons coming from unburned or partially burned fuel and lubricating oil. The remaining carbon portion consists of soot-like carbon (elemental carbon) and trace amounts of other components from the fuel and lubricating oil. The total exhaust particulate is the sum of these four categories. In addition to these categories of exhaust emissions, idle exhaust emissions[1], brake wear, tire wear, fugitive dust, indirect sulfate, and gaseous sulfur dioxide are also calculated.

The model calculates the emission factors for 12 vehicle classes and a fleet-wide average (estimated by vehicle miles traveled (VMT) weighting of the emission factors for all 12 classes). The vehicle classes include light-duty gasoline vehicles, two classes of light-duty gasoline trucks, heavy-duty gasoline trucks, motorcycles, light-duty diesel vehicles, light-duty diesel trucks, four classes of heavy-duty diesel trucks, and buses. To account for older vehicles on the road, the emission factors reported for each vehicle class are composites of emission factors for vehicles 25+ years old through the calendar year of evaluation (the calendar year of evaluation is provided by the user.) The composite emission factor for each vehicle class is calculated by weighting the emission factor calculated for each model year by the travel fraction for that model year, and then summing the 25 weighted factors. The travel fraction of a model year is the fraction of miles traveled by a vehicle of that model year out of the total number of miles traveled by all model years' vehicles in that vehicle class:

$$EFCOMP_v = \sum_{m=1}^{25} EF_{m,v} * TF_{m,v} \qquad (1)$$

where

$EFCOMP_v$ = the composite emission factor for vehicle class v,
$EF_{m,v}$ = the emission factor for vehicle class v, model-year m,
$TF_{m,v}$ = the travel fraction for vehicle class v, model-year m.

In turn, the overall travel fraction of a vehicle class represents the fraction of the total number of vehicle miles traveled (VMT) of that class out of the total highway VMT (from all 12 classes). The

[1]* Idle emissions are calculated only for heavy-duty diesel vehicles.

VMT fractions for each vehicle class are multiplied by the corresponding composite emission factors ($EFCOMP_v$), then the sum of these adjusted emission factors is reported as the emission factor for all vehicles:

$$EFALL = \sum_{v=1}^{12} EFCOMP_v * TFCLASS_v \quad (2)$$

where

$EFALL$ = the weighted emission factor for all vehicles,
$TFCLASS_v$ = the vehicle miles traveled of vehicle class v.

The emission factor for all vehicles, $EFALL$, represents the average g/mi emissions from the entire fleet, so this emission factor, when multiplied by the total number of vehicle miles traveled in a particular region, provides an estimate of the total grams of particulate emissions contributed by the entire on-road motor vehicle fleet.

The rest of this appendix describes in detail the methodologies used to calculate the emission factors for each pollutant category for gasoline-fueled and diesel-fueled vehicles, as well as the factors for dust, brake wear, and tire wear emissions. The adjustment factors for different vehicle speeds and particle size cutoffs are also described.

2 GASOLINE-FUELED VEHICLES

LEAD EMISSION FACTORS

Lead particulate emission factors are based on the assumption that virtually all the lead in fuel is exhausted. As a result, the emission factors (in units of grams per mile) depend principally on the lead content in the fuel and the fuel economy of the vehicle (in miles per gallon). The lead content of leaded fuel is substantially greater than that of unleaded fuel, so the fraction of vehicles that have had their catalysts removed (and thus are assumed to be using leaded fuel in most cases) can also be an important factor in determining the lead emission factor from a vehicle that is representative of the entire fleet.

The lead emission factors for a vehicle of model year m and vehicle class v (with the exception of motorcycles; see discussion in the next section) are computed in PART5 using the following formula (see the following section, "Lead Particulate Derivation," page 50, for the derivation of all variables and further explanations):

$$\begin{aligned} LEAD_{m,v} = {} & PLNOCT_{m,v} * VLNOCT_{m,v} \\ & + PUNOCT_{m,v} * VUNOCT_{m,v} \\ & + PLYSCT_{m,v} * VLYSCT_{m,v} \\ & + PUYSCT_{m,v} * VUYSCT_{m,v} \end{aligned} \quad (3)$$

where

$LEAD_{m,v}$ = the lead particulate emissions for a vehicle of model year m and vehicle class v (g/mi)

$PLNOCT_{m,v}$ = the emissions for a non-catalyst, leaded fuel vehicle of model year m and vehicle class v (g/mi)

$PUNOCT_{m,v}$ = the emissions for a non-catalyst, unleaded fuel vehicle of model year m and vehicle class v (g/mi)

$PLYSCT_{m,v}$ = the emissions for a catalyst, leaded fuel vehicle of model year m and vehicle class v (g/mi)

$PUYSCT_{m,v}$ = the emissions for a catalyst, unleaded fuel vehicle of model year m and vehicle class v (g/mi)

$VLNOCT_{m,v}$ = the fraction of non-catalyst, leaded fuel vehicles of model year m and vehicle class v

$VUNOCT_{m,v}$ = the fraction of non-catalyst, unleaded fuel vehicles of model year m and vehicle class v

$VLYSCT_{m,v}$ = the fraction of catalyst, leaded fuel vehicles of model year m and vehicle class v

$VUYSCT_{m,v}$ = the fraction of catalyst, unleaded fuel vehicles of model year m and vehicle class v

This emission rate is adjusted for speed by the factor FEC so that:

$$CLEAD_{m,v} = FEC * LEAD_{m,v} \quad (4)$$

where

$CLEAD_{m,v}$ = the lead emissions for a vehicle of model year m and vehicle class v, which has been adjusted for the speed effect (g/mi)

$$FEC = 1 / SCF_c \quad (5)$$

SCF_c = the speed correction factor, based on either transient driving cycle (c=1) or steady cruise driving cycle (c=2):

$$SCF_1 = 0.17930 + (0.038561 * SPEED_v) - (0.00041067 * SPEED_v^2) \quad (6)$$

$$SCF_2 = 0.26929 + (0.054607 * SPEED_v) - (0.00069818 * SPEED_v^2) \quad (7)$$

$SPEED_v$ = the average speed for vehicle class v, user input (mph)

Motorcycles

Due to the absence of catalyst emission controls on motorcycles, organic emission factors are not calculated and sulfate emission factors are negligible. The exhaust particulate printed in the output is almost exclusively lead. The lead particulate emission factor for 2-stroke engines is 0.33 g/mi and for 4-stroke engines is 0.046 g/mi. For pre-1978 model years there were 51% 4-stroke engines and 49% 2-stroke engines (see references page 67, EPA 1985a):

$$LEAD_{m,motorcycle} = [(0.49 * 0.33) + (0.51 * 0.046)] * PSL \quad (8)$$

For 1978 and later motorcycles are assumed to consist of 100% 4-stroke engines:

$$LEAD_{m,motorcycle} = 0.046 * PSL \quad (9)$$

where

PSL = the fraction of all particles that are emitted based on user input of the particle size cutoff

Lead Particulate Derivation

The original formulae for lead particulate are found and described in reference EPA 1985a, equation numbers 2-3, 2-4, and 2-5. All of these equations appropriately combine the amount of particulates per vehicle of a given category (i.e., model year group, catalyst or non-catalyst, leaded or unleaded fuel) with the fraction of vehicles in that category. The basic form of the portion of the equation which determines the amount of lead particulate per vehicle is:

$$LEAD_{m,v} = (ABURN * PWR / FE_{m,v}) * PB * PS \quad (10)$$

where

ABURN = the fraction of lead burned that is exhausted (*ABURN* (1) = 0.75 for non-catalyst and catalyst vehicles using leaded fuel, *ABURN* (2) = 0.40 for catalyst vehicles using unleaded fuel in calender years 1975-1980, *ABURN* (3) = 0.44 for catalyst vehicles using unleaded fuel in calender years 1981 and later)

PWR = particle weight ratio (1.557 = PbClBr/Pb)

$FE_{m,v}$ = fuel economy for vehicles of class *v* and model year *m* (mi/gal)

PB = fuel lead content (g/gal) [*PBL* and *PBNL* in formulae below, National Fuel Survey, AAMA 1993]

PS = the fraction of all particles that are emitted (*PSL*, *PSNL* and *PSNLCT* in formulae below), based on user input of the particle size cutoff.

All of the other terms in the equations relate to the fraction of vehicles which exhibit each specific particulate emission rate.

For the case of non-catalyst vehicles using leaded fuel, the amount of lead particulates comes from the first term of equations 2-3 and 2-4 of reference EPA 1985a. The speed correction to the fuel economy is handled later in the program by the factor *FEC*, and therefore is not discussed here. We will also drop the discretionary fuel switching term from the equation. This term will be used later to determine the fraction of non-catalyst vehicles using leaded and unleaded fuel. The final form is:

$$PLNOCT_{m,v} = (ABURN(1) * 1.557 / FE_{m,v}) * PBL * PSL \quad (11)$$

For the case of non-catalyst vehicles using unleaded fuel, the amount of lead particulates comes from the second term of equation 2-3 and 2-4 of reference EPA 1985a. Again the discretionary fuel switching and the speed correction to fuel economy terms are dropped from the equation here (they are handled later in the program). The final form is:

$$PUNOCT_{m,v} = (ABURN(1) * 1.557 / FE_{m,v}) * PBNL * PSNL \quad (12)$$

For the case of catalyst equipped vehicles using unleaded fuel, the amount of lead particulates comes from the first term of equation 2-5 of reference EPA 1985a. The speed correction to the fuel economy is handled later in the program by the factor *FEC*, and therefore can be ignored here. The term for misfueling can also be removed, since it will be used later to determine the fraction of catalyst equipped vehicles using leaded and unleaded fuel. The final form as:

$$PUYSCT_{m,v} = (ABURN(2 \text{ or } 3) * 1.557 / FE_{m,v}) * PBNL * PSNLCT \quad (13)$$

Note that catalyst equipped vehicles burning unleaded fuel have a different fraction of lead burned exhausted (*ABURN*) than the other categories and that it depends on the model year of the vehicle.

For the case of catalyst-equipped vehicles using leaded fuel, the amount of lead particulates comes from the remaining terms of equation 2-5 of reference EPA 1985b. The speed correction to the fuel economy is handled later in the program by the factor *FEC*, and therefore can be ignored here. The terms for misfueling and for catalyst removal can also be ignored here, since these will be used later to determine the fraction of vehicles which are catalyst equipped and what fraction of catalyst equipped vehicles use leaded and unleaded fuel. The final form is:

$$PLYSCT_{m,v} = (ABURN(1) * 1.557 / FE_{m,v}) * PBL * PSL \quad (14)$$

There are four different combinations of catalyst and misfueling which will each have a separate estimate of particulate emissions. They are:

Catalyst-equipped vehicles using unleaded fuel
Catalyst-equipped vehicles using leaded fuel
Non-catalyst vehicles using unleaded fuel
Non-catalyst vehicles using leaded fuel

First the number of catalyst equipped vehicles must be determined. $CATFCT_{m,v}$ is the fraction of all vehicles which are originally catalyst equipped and $TAMFRC_{m,v}$ is the fraction of originally catalyst equipped vehicles which have had their catalyst removed for model year m and vehicle class v. Therefore, the remaining catalyst equipped vehicles are:

$$CATS_{m,v} = CATFCT_{m,v} * (1.-TAMFRC_{m,v}) \quad (15)$$

The fraction of non-catalyst vehicles using leaded gasoline, then, would be:

$$VLNOCT_{m,v} = (1.-CATS_{m,v}) * (1.-DFS_{m,v}) \quad (16)$$

Where $DFS_{m,v}$ is discretionary fuel switching (use of unleaded fuel by non-catalyst vehicles) for model year m and vehicle class v. The fraction of non-catalyst vehicles using unleaded gasoline is then:

$$VUNOCT_{m,v} = (1.-CATS_{m,v}) * DFS_{m,v} \quad (17)$$

The fraction of all vehicles equipped with catalysts, but using leaded fuel, would be:

$$VLYSCT_{m,v} = CATFCT_{m,v} * (RMIS_{m,v} - TAMFRC_{m,v}) \quad (18)$$

This assumes that all vehicles with removed catalysts are a subset of $RMIS_{m,v}$, the misfueling rate for model year m and vehicle class v. The catalyst removed vehicles are treated as non-catalyst vehicles in the equations above. The remaining vehicles will all be catalyst-equipped vehicles using unleaded fuel. That fraction is:

$$VUYSCT_{m,v} = (1. - VLNOCT_{m,v} - VUNOCT_{m,v} - VLYSCT_{m,v}) \quad (19)$$

Finally, all of the terms can be combined to give the composite lead particulate emission rate for this vehicle/model year (compare to equation 3):

$$LEAD_{m,v} = PLNOCT_{m,v} * VLNOCT_{m,v} + PUNOCT_{m,v} * VUNOCT_{m,v} + PLYSCT_{m,v} * VLYSCT_{m,v} + PUYSCT_{m,v} * VUYSCT_{m,v} \quad (20)$$

This rate is adjusted for speed by the factor *FEC* so that:

$$CLEAD_{m,v} = FEC * LEAD_{m,v} \quad (21)$$

SULFATE EMISSION FACTORS

The particulate sulfate emission factors consist of direct and indirect sulfate material. The direct sulfate is exhausted as sulfuric acid, and the indirect sulfate is formed later in the atmosphere from exhausted SO_2. The indirect sulfate in the model is calculated based on the assumption that it consists entirely of ammonium sulfate and ammonium bisulfate. The direct sulfate, indirect sulfate, and gaseous sulfur are all computed in the model, and the emission factors are reported as g/mi (EPA 1990).

The direct sulfate from non-catalyst vehicles using leaded fuel (includes catalyst-equipped vehicles which are misfueled, making the catalyst ineffective) is calculated as:

$$DSULFN = .002, \text{ for speeds at or} < 19.6 \text{ mph} \quad (22)$$

$$DSULFN = .001, \text{ for speeds at or} > 34.8 \text{ mph} \quad (23)$$

The direct sulfate from catalyst vehicles is calculated as:

$$DSULFC_{m,v} = [FRAC_{cat/no\ air}(.005) + FRAC_{cat/air}(.016)], \text{ for speeds at or} < 19.6 \text{ mph} \quad (24)$$

$$DSULFC_{m,v} = [FRAC_{ox/noair}(.005) + FRAC_{3w/noair}(.001) + FRAC_{ox/air}(.020) + FRAC_{3w/air}(.025)], \text{ for speeds at or} > 34.8 \text{ mph} \quad (25)$$

For speeds between 19.6 and 34.8 mph, *DSULFN* and *DSULFC* are interpolated between equations 22 and 23, and 24 and 25, respectively (EPA 1985a).

where

$FRAC_{cat/noair}$ = the fraction of vehicles which are catalyst equipped with no air pump, for vehicles of class v and model year m

$FRAC_{cat/air}$ = the fraction of vehicles which are catalyst equipped with air pump, for vehicles of class v and model year m

$FRAC_{ox/noair}$ = the fraction of vehicles which are oxidation catalyst equipped with no air pump, for vehicles of class v and model year m

$FRAC_{3w/noair}$ = the fraction of vehicles which are 3-way catalyst equipped with no air pump, for vehicles of class v and model year m

$FRAC_{ox/air}$ = the fraction of vehicles which are oxidation catalyst equipped with air pump, for vehicles of class v and model year m

$FRAC_{3w/air}$ = the fraction of vehicles which are 3-way catalyst equipped with air pump, for vehicles of class v and model year m

The direct sulfate from all gasoline-fueled vehicles is computed as:

$$DSULF_{m,v} = CTLFRC_{m,v} * DSULFC_{m,v} + (1. - CTLFRC_{m,v}) * DSULFN \quad (26)$$

where

$CTLFRC_{m,v}$ = $CATFCT_{m,v}$ $(1 - RMIS_{m,v})$, the fraction of the vehicle class that has an effective catalyst

The model assumes that all the sulfur in the fuel is exhausted as either sulfate or gaseous sulfur dioxide, so once the direct sulfate emission factor is calculated, the remaining sulfur in the fuel is considered to be exhausted as SO_2. To calculate the amount of sulfur exhausted as SO_2 in g/mi, the amount of sulfur remaining in the fuel after the direct sulfate emission factor has been found must be calculated.

The following equation is used to derive the fraction of sulfur in the fuel that has been directly converted to sulfate ($DSULF_{m,v}$ calculated in equation 26 above). This equation calculates direct sulfate as a function of the fuel sulfur content, $DCNVRT$ (which is the fraction of sulfur in the fuel that is converted to direct sulfate), and the fuel economy.

$$DSULF_{m,v} = 13.6078 * (1. + WATER) * FDNSTY * SWGHT * DCNVRT / FE_{m,v} \quad (27)$$

where

$DSULF_{m,v}$ = the direct sulfate emission factor of a vehicle in class v and of model-year m (g/mi)

$WATER$ = weight ratio of seven water molecules to sulfate, 7.18 / 98 = 1.2857 (this weight ratio comes from the estimate that, at 50% humidity, seven water molecules bond with each sulfuric acid molecule; EPA 1990, p.6-25)

$FDNSTY$ = fuel density in lb/gal (6.09 lb/gal, EPA 1988).

$FE_{m,v}$ = fuel economy for vehicles of class v and model year m (mi/gal)

$SWGHT$ = weight percent of sulfur content in fuel (.034, except reformulated fuel phase II, 2000 and later calendar years .0138, AAMA 1993)

$DCNVRT$ = percent of sulfur in the fuel that is directly converted into sulfate (2%, EPA 1990)

13.6078 = unit conversion factor = (453.592 * 3.)/100., where 453.592 = number of grams in a pound, 3. = weight ratio of SO_4 to sulfur, and the division by 100 is to correct for the weight percent of sulfur, $SWGHT$ (EPA 1990)

Substituting $DSULFC_{m,v}$ and $DSULFN$ (from equations 22 through 25) in equation 27, we can solve for the fractions of sulfur in the fuel that are converted to sulfate separately for catalyst, and noncatalyst vehicles:

$$FCNVRC_{m,v} = DSULFC_{m,v} * FE_{m,v} / (13.6078 * (1.+ WATER) * FDNSTY * SWGHT) \quad (28)$$

$$FCNVRN_{m,v} = DSULFN * FE_{m,v} / (13.6078 * (1.+ WATER) * FDNSTY * SWGHT) \quad (29)$$

where

$FCNVRC_{m,v}$ = the fraction of the percent of fuel that is directly converted into sulfate for catalyst vehicles of class v and model year m

$FCNVRN_{m,v}$ = the fraction of the percent of fuel that is directly converted into sulfate for non-catalyst vehicles of class v and model year m

The gaseous sulfur emission factors, which are dependent on these fractions, are calculated from the equation

$$SO2_{m,v} = 9.072 * FDNSTY * SWGHT * (1. - DCNVRT) / FE_{m,v} \quad (30)$$

where the new terms are

$SO2_{m,v}$ = the gaseous sulfur emission factor of a vehicle in class v of model-year m (g/mi)

9.072 = unit conversion factor = (453.592 * 2.)/100., where 453.592 = number of grams in a pound, 2. = weight ratio of SO_2 to sulfur, and the division by 100 is to correct for the weight percent of sulfur, $SWGHT$.

The gaseous sulfur emission factor is calculated in the model as the combination of the sulfur emission factor from both catalyst and noncatalyst vehicles as follows:

$$SO2C_{m,v} = 9.072 * FDNSTY * SWGHT * (1.0 - FCNVRC_{m,v}) / FE_{m,v} \quad (31)$$

$$SO2N_{m,v} = 9.072 * FDNSTY * SWGHT * (1.0 - FCNVRN_{m,v}) / FE_{m,v} \quad (32)$$

and

$$SO2_{m,v} = (CTLFRC_{m,v} * SO2C_{m,v}) + [(1. - CTLFRC_{m,v}) * SO2N_{m,v}] \quad (33)$$

where

$SO2C_{m,v}$ = the SO_2 emission factor from catalyst vehicles in class v of model-year m (g/mi)

$SO2N_{m,v}$ = the SO_2 emission factor from non-catalyst vehicles in class v of model-year m (g/mi)

In addition to the direct sulfate emission factors, the model estimates an indirect sulfate emission factor by assuming that a fraction of the gaseous sulfur dioxide emissions is later converted in the atmosphere to sulfate material. Based on ambient sulfur and sulfate measurements in 11 cities, EPA estimates that 12 percent of all gaseous sulfur is converted to sulfate (EPA 1990, pp. 6-28 to

6-30). Thus, the PART5 model calculates the indirect sulfate emission factors as 12 percent of the gaseous SO_2 motor vehicle emissions.

The model uses the following general formula to derive the emission factors for indirect sulfate, which consists of ammonium sulfate and ammonium bisulfate (EPA 1990, page 6-30):

$$ISULF = ICNVRT * SO2 * (3 / 2) * AMNWGT \quad (34)$$

where

ISULF	=	the estimated indirect sulfate emission factor (g/mi)
SO2	=	the gaseous sulfur emission factor (g/mi)
3 / 2	=	weight ratio of SO_4 to SO_2
AMNWGT	=	the estimated weight ratio of the combination of ammonium bisulfate and ammonium sulfate in the atmosphere to SO_4 (1.6, EPA 1990, p. 6-25)
ICNVRT	=	the fraction of SO_2 converted to sulfate (.12 is the national average, EPA 1990, page 6-29, Table 6-13)

The actual computation is performed in the model for each vehicle type (catalyst and non-catalyst):

$$ISULFC_{m,v} = ICNVRT * SO2C_{m,v} * (3 / 2) * AMNWGT \quad (35)$$

$$ISULFN_{m,v} = ICNVRT * SO2N_{m,v} * (3 / 2) * AMNWGT \quad (36)$$

$$ISULF_{m,v} = (CTLFRC_{m,v} * ISULFC_{m,v}) + [(1.0 - CTLFRC_{m,v}) * ISULFN_{m,v}] \quad (37)$$

where

$ISULFC_{m,v}$	=	the estimated indirect sulfate from catalyst vehicles in class of model-year *m* (g/mi)
$ISULFN_{m,v}$	=	the estimated indirect sulfate from non-catalyst vehicles in class of model-year *m* (g/mi)
$ISULF_{m,v}$	=	the estimated indirect sulfate emission factor of a vehicle in class of model-year *m* (g/mi)

TOTAL EXHAUST PARTICULATE

The total exhaust particulate emission factors for light-duty gasoline vehicles are calculated from the sum of lead, direct sulfate, and a carbon emission factor which includes soluble organics and other remaining carbon. The carbon emission factor has been determined based on reference EPA 1985a and the updated information in EPA 1993a. Table 1 summarizes the carbon emission factors by model year and technology type.

TABLE 1

Carbon Emission Factors for Gasoline Vehicles (g/mi)

Vehicle Type/ Model Year Group	Leaded	Unleaded Catalyst (No-Air)	Unleaded Catalyst (Air)	Unleaded Non-catalyst
Light Duty Gasoline Vehicles:				
pre-1970	.193			.030
1970-1974	.068	.0060	.0250	.030
1975-1980	.030	.0060	.0250	.030
1981+	.017	.0043	.0043	.017
Light Duty Gasoline Trucks I:				
pre-1970	.193			.030
1970-1974	.068	.0060	.0250	.030
1975-1986	.030	.0060	.0250	.030
1987+	.017	.0043	.0043	.017
Light Duty Gasoline Trucks II:				
pre-1979	.370			.054
1979-1986	.068	.0060	.0250	.030
1987+	.030	.0043	.0043	.017
Heavy Duty Gasoline Vehicles:				
pre-1987	.370	.054	.054	.054
1987+	.163	.054	.054	.054

Motorcycles: see page 49 for description of motorcycle emission factors in PART5.

DIESEL-FUELED VEHICLES

LEAD EMISSION FACTORS

No lead emission factors for diesel-fueled vehicles are calculated in the model. The lead emissions result almost exclusively from the lead content of the fuel; and since the lead content of diesel fuel is negligible, it is assumed that the lead emissions from diesel-fueled vehicles are also negligible.

SULFATE EMISSION FACTORS

The sulfate emission factors are calculated assuming all sulfur in the fuel is exhausted as either sulfuric acid or gaseous sulfur dioxide (EPA 1990).

The direct sulfate emission factor (g/mi) is calculated as follows:

$$DSULF_{m,v} = 13.6078 * (1.0 + WATER) * FDNSTY * SWGHTD * DCNVRT / FE_{m,v} \quad (38)$$

where

$DSULF_{m,v}$ = the direct sulfate emission factor for a vehicle of class v and model year m (g/mi)
$DCNVRT$ = the fraction of sulfur in the fuel that is converted directly to sulfate (2.0 percent, EPA 1990, page 3-4)
$FDNSTY$ = the density of diesel fuel (7.11 lb/gal, EPA 1988b)
$FE_{m,v}$ = the fuel economy for a vehicle of class v and model year m (mi/gal, EPA 1990, Table 6-A-1; note that the same fuel economies are used for both 2BHDDV and LHDDV for all model years)
$SWGHTD$ = the weight percent of sulfur in diesel fuel (0.25 for high sulfur fuel, .05 for low sulfur fuel used for calendar years 1993 and later)
$WATER$ = weight ratio of seven water molecules to sulfate, 7.18 / 98 = 1.2857 (EPA 1990, p. 6-25)
13.6078 = units conversion factor = (453.592 * 3.)/100., where 453.592 = number of grams in a pound, 3 = weight ratio of SO_4 to sulfur, and the division by 100 is to correct for the weight percent of sulfur, $SWGHTD$

The gaseous sulfur emission factor is calculated as follows:

$$SO2_{m,v} = 9.072 * FDNSTY * SWGHTD * (1. - DCNVRT) / FE_{m,v} \quad (39)$$

where the new tems are

$SO2_{m,v}$ = the sulfur emission factor (g/mi) of a vehicle in class v and of model-year m
9.072 = units conversion factor = (453.592 * 2)/100., where 453.592 = number of grams in a pound, 2 = weight ratio of SO_2 to sulfur, and the division by 100 is to correct for the weight percent of sulfur, $SWGHTD$.

The indirect sulfate emission factor, which consists mostly of ammonium sulfate and ammonium bisulfate (EPA 1990, Chapter 6), is calculated as follows:

$$ISULF_{m,v} = ICNVRT * SO2_{m,v} * (3 / 2) * AMNWGT \quad (40)$$

where

$ISULF_{m,v}$ = the indirect sulfate emission factor of a vehicle in class v and of model-year m (g/mi)
$ICNVRT$ = the fraction of SO_2 that is converted to sulfate (either ammonium sulfate or ammonium bisulfate) in the atmosphere (12 percent)
3 / 2 = weight ratio of SO_2 to SO_4,
$AMNWGT$ = the estimated weight ratio of the combination of ammonium bisulfate and ammonium sulfate in the atmosphere to SO_4 (1.6)

TOTAL EXHAUST PARTICULATE

The initial total exhaust particulate emission factors for diesel-fueled vehicle classes ($EFDPM_{m,v}$) are from reference EPA 1990. The emission factors for heavy-duty vehicles are expressed in g/BHP-hr, which are converted to g/mi in PART5. The conversion factors (EPA 1988b and EPA 1992) and emission factors both vary by model year. The emission factors for light-duty diesel vehicles and trucks are in units of g/mi. The total exhaust emission factors given in Table 2 are based on high sulfur fuel. The sulfur content in diesel fuel is being forced down in 1993 by EPA regulatory requirements. When the user requests a calendar year of evaluation of 1993 or later, the program will make the appropriate adjustments to the exhaust emission factors for low sulfur fuel effects.

The only other adjustment that is made to the total exhaust emission factor is the multiplication by the particle size cutoff fraction (see page 65). Particulate emission factors for diesel-powered vehicles are not adjusted for vehicle speed.

SOLUBLE ORGANIC FRACTION AND REMAINING CARBON PORTION

The soluble organic fraction (SOF) is calculated as a fraction of the remaining mass:

$$SOF_{m,v} = [\, EF_{m,v} - DSULF_{m,v} \,] * (fraction_{SOF,v}) \quad (41)$$

The remaining carbon portion (RCP) is defined to be everything else:

$$RCP_{m,v} = EF_{m,v} - DSULF_{m,v} - SOF_{m,v} \quad (42)$$

The soluble organic fractions ($fraction_{SOF,v}$) for different vehicle classes are as follows: 0.51 for LHDDVs, 0.44 for MHDDVs, and 0.24 for HHDDVs. The fraction 0.51 is also used for the 2BHDDV vehicle class. The fraction 0.44 is also used for the vehicle class BUSES. The fractions for LDDVs, LDDT1s, and LDDT2s are 0.18, .5, and .48 respectively (EPA 1990, Table 3-9).

where

$SOF_{m,v}$ = the soluble organic fraction of the exhaust particulate emission factor for a vehicle in class v and of model-year m (g/mi)

$RCP_{m,v}$ = the remaining carbon portion (elemental carbon) of the exhaust particulate emission factor for a vehicle in class v and of model-year m (g/mi)

$EF_{m,v}$ = $EFDPM_{m,v}$ * $CF_{m,v}$, exhaust particulate emission factor for a vehicle in class v and of model-year m (g/mi)

$EFDPM_{m,v}$ = exhaust particulate emission factor for a vehicle in class v and of model-year m (g/BHp-hr)

$CF_{m,v}$ = conversion factor from g/BHp-hr to g/mi of a vehicle in class v and of model-year m (BHp-hr/mi)

$fraction_{sof,v}$ = the fraction of the non-sulfate portion (equivalent to the carbon portion) of the diesel exhaust particulate emission factor which is organic carbon, for vehicle in class v (BHp-hr/mi)

TABLE 2

Exhaust Particulate Emission Factors for Diesel Vehicles

Vehicle Type/ Model Year Group	Exhaust Particulate Emission Factor ($EFDPM_{m,v}$)
Light Duty Diesel Vehicles (g/mi):	
pre-1981	.700
1981	.259
1982-1984	.256
1985-1986	.255
1987	.134
1988-1990	.132
1991-1993	.131
1994-1995	.128
1996+	.100
Light Duty Diesel Trucks (g/mi):	
pre-1981	.700
1981	.309
1982-1984	.354
1985-1986	.358
1987	.334
1988-1990	.291
1991-1993	.294
1994-1996	.130
1997+	.109
Class 2B of Heavy Duty Diesel Vehicles (g/BHp-hr):	
pre-1988	.5156
1988-1990	.5140
1991-1993	.2873
1994+	.1011
Light Heavy Duty Diesel Vehicles (g/BHp-hr):	
pre-1988	.5156
1988-1990	.5140
1991-1993	.2873
1994+	.1011

TABLE 2 (cont'd)

Exhaust Particulate Emission Factors for Diesel Vehicles

Vehicle Type/ Model Year Group	Exhaust Particulate Emission Factor ($EFDPM_{m,v}$)
Medium Heavy Duty Diesel Vehicles (g/BHp-hr):	
pre-1987	.6946
1988-1990	.4790
1991-1993	.2747
1994+	.0948
Heavy Heavy Duty Diesel Vehicles (g/BHp-hr):	
pre-1987	.6444
1988-1990	.4360
1991-1993	.2709
1994+	.0836
Buses (g/BHp-hr):	
pre-1987	.6931
1988-1990	.4790
1991	.2772
1992 without traps	.1716
1992 with traps	.0257
1993 without traps	.1457
1993 with traps	.0240
1994+	.0591

4 OTHER EMISSION FACTORS

FUGITIVE DUST

Reentrained road dust emission factors are calculated for both unpaved and paved roads. The fugitive dust emission calculations for unpaved roads are from an empirical formula from the AP-42 Section 11.2.1 (EPA 1988a), and the generic paved road dust calculation formula is from AP-42 Sections 11.2.5 and 11.2.6 (EPA 1993b).

The particulate emission factor for unpaved roads is calculated as

$$UNPVD = PSDUNP * 5.9 * (UNSILT / 12.0) * (SPD / 30.0) * (WEIGHT / 3.0)^{0.7} * (VWHEEL / 4.)^{0.5} * (365 - IPDAYS) / 365 * 453.592 \quad (43)$$

where

UNPVD	=	the fleet average unpaved road dust emission factor (g/mi)
PSDUNP	=	the fraction of particles less than or equal to the particle size cutoff
UNSILT	=	the percent silt content of the surface material (input by the user)
SPD	=	the average vehicle speed (mph, input by the user)
WEIGHT	=	the fleet average vehicle weight (tons, input by the user in lbs)
VWHEEL	=	the fleet average number of wheels (input by the user)
IPDAYS	=	the average number of precipitation days per year with greater than 0.01 inches of rain (input by the user)
453.592	=	the number of grams in a pound

The particulate emissions factor for generic paved roads is calculated as

$$PAVED = PSDPVD * (PVSILT / 2)^{0.65} * (WEIGHT / 3)^{1.5} \quad (44)$$

where

PAVED	=	the fleet average paved road dust emission factor (g/mi)
PSDPVD	=	the base emission factor for the particle size cutoff (input by the user)
PVSILT	=	the road surface silt loading (g/m^2, input by the user)
WEIGHT	=	the fleet average vehicle weight (tons, input by the user in lbs)

BRAKE WEAR

The brake wear emission factor is assumed to be the same for all vehicle classes in the model. It is set equal to

$$BRAKE = 0.0128 * PSBRK, \quad (45)$$

where

PSBRK = the fraction of particles less than or equal to the particle size cutoff.

The emission factor 0.0128 g/mi was measured by Cha, Carter, and Bradow (EPA 1985a).

TIRE WEAR

The tire wear emission factor is calculated as

$$EFTIRE_v = 0.002 * PSTIRE * IVEHWL_v \quad (46)$$

where

$EFTIRE_v$ = tire wear emission factor for a vehicle in class v (g/mi)
0.002 = emission rate of airborne particulates from tire wear for light duty-vehicles (EPA 1985b)
PSTIRE = the fraction of particles less than or equal to the particle size cutoff
$IVEHWL_v$ = the average number of wheels on a vehicle of class v: LDGV = 4, LDGT1, 2 = 4, HDGV = 6, MC = 2, LDDV = 4, LDDT = 4, 2BHDDV = 4, LHDDV = 6, MHDDV = 6, HHDDV = 18, BUSES = 4

IDLE EMISSIONS

The idle emission factor data in grams per hour was collected from manufacturers. The factors are reported only for the heavy-duty diesel vehicle classes, and as such, are not factored into the overall vehicle ("All veh.") emissions category. The vehicle class emission factors are calculated by averaging together model-year-specific emissions data, where the model-year-specific emissions data are weighted by the estimated travel fraction of that model year within the vehicle class.

Currently the idle emission rates are model-year-specific but the model year emission rates do not vary by vehicle class. Hence, the same model year emission factors are used for all the heavy duty diesel classes, and the differences between the idle emission factors between classes is a reflection only of the differing travel fractions from model year to model year within that class (where the travel fractions are the $TF_{m,v}$'s in equation (1)). As a result, the emission factors reported for the smaller of the heavy duty diesel vehicle classes, such as 2BHDDV and LHDDV, may be over-predicted.

The base idle emission factors in PART5 for all heavy-duty diesel vehicles are shown in Table 3.

TABLE 3

Model Years	Emission Factor (g/hr)
pre-1988	5.370
1988-1990	3.174
1991-1993	1.860
1994	1.004

5 ADJUSTMENTS AND CORRECTION FACTORS

All the emission factors-exhaust PM, direct and indirect sulfate, lead, SOF, RCP, brake-wear, tire wear, and fugitive dust-are adjusted for the particle size cutoff (PSC).

PARTICLE SIZE CUTOFF

The user of the PART5 model must enter a particle size cutoff. This cutoff is defined to be the maximum aerodynamic diameter (between 1.0 and 10.0 μm) of the particles in the emission factors. Each emission factor is then multiplied by the fraction of particles less than or equal to the PSC.

The fraction of particles less than or equal to the PSC is determined from the fractions in Table 4 (EPA 1985a). When a user inputs a PSC, the program linearly interpolates the appropriate fraction of mass less than or equal to that cutoff based on the data in Table 4 (but not less than the lowest cutoff listed). PART5 has a lower limit of 1.0 for the PSC.

As can be seen in Table 4, the lowest PSC is 2.5 μm for fugitive dust. The program will print a note for the user to be aware that the fugitive dust emission factors are based on 2.5 μm when the user inputs values between 1.0 and 2.4 μm as a PSC.

TABLE 4

Fraction of Particles Less than or Equal to the Particle Size Cutoff

Vehicle Type/ Particulate Component	Particle Size Cutoff (PSC)	Fraction of Particles less than or equal to the Particle Size Cutoff
Gasoline vehicles using leaded fuel/ Lead, Carbon	10.0	0.64
	2.0	0.43
	0.2	0.23
Gasoline vehicles with catalyst, using unleaded fuel/ Lead, Carbon	10.0	0.97
	2.0	0.89
	0.2	0.87
Gasoline vehicles without a catalyst, using unleaded fuel/ Lead, Carbon	10.0	0.90
	2.0	0.66
	0.2	0.42
Diesel vehicles/ Exhaust PM	10.0	1.00
	2.5	0.92
	2.0	0.90
	1.0	0.86
All vehicles/ Brake-wear	10.0	0.98
	7.0	0.90
	4.7	0.82
	1.1	0.16
	0.43	0.09
All vehicles/ Tire-wear	10.0	1.00
	0.10	0.01
All vehicles/ Unpaved Road Dust	10.0	0.36
	5.0	0.20
	2.5	.095
All vehicles/ Paved Road Dust	10.0	7.3*
	2.5	3.3*

*Note: Paved Road Dust values are actual emission factors in g/mi.

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