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Project Summary

Size Specific Particulate Emission Factors for Industrial and Rural Roads: Source Category Report

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Over the past few years traffic-generated dust emissions from unpaved and paved industrial roads have become recognized as a significant source of atmospheric particulate emissions, especially within industries involved in the mining and processing of mineral aggregates. Although a considerable amount of field testing of industrial roads has been performed, most studies have focused on total suspended particulate (TSP) emissions, because the current air quality standards for particulate matter are based on TSP. Only recently, in anticipation of an air quality standard for particulate matter based on particle size, has the emphasis shifted to the development of size-specific emission factors.

This study was undertaken to derive size-specific particulate emission factors for industrial paved and unpaved roads and for rural unpaved roads from the existing field testing data base. Regression analysis is used to develop predictive emission factor equations which relate emission quantities to road and traffic parameters. Separate equations are developed for each road type and for the following aerodynamic particle size fractions: ≦ 15, ≦ 10, and ≦ 2.5 μm. Finally, recommendations are made for inclusion of the resulting emission factors in the EPA document, *Compilation of Air Pollutant Emission Factors, AP-42.*

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Over the past few years traffic-generated dust emissions from unpaved and paved industrial roads have become recognized as a significant source of atmospheric particulate emissions, especially within industries involved in the mining and processing of mineral aggregates. Typically, road dust emissions exceed emissions from other open dust sources associated with the transfer and storage of aggregate materials. Therefore, the quantification of industrial road dust emissions is necessary to the development of effective strategies for the attainment and maintenance of the national ambient air quality standards (NAAQS) for particulate matter.

Although a considerable amount of field testing of industrial roads has been performed, most studies have focused on total suspended particulate (TSP) emissions, because the current NAAQS for particulate matter are based on TSP. Those studies have produced emission factors that are poorly defined with regard to particle size. Although the high-volume sampler, which is the reference device for measurement of TSP concentration, has a very broad capture efficiency curve, TSP is generally recognized as consisting of particles smaller than 30 μm in aerodynamic diameter.

Only recently, in anticipation of a NAAQS for particulate matter based on particle size, has the emphasis shifted to the development of size-specific emission factors. The following particle size fractions have been of interest in these recent studies:

IP = Inhalable particulate matter consisting of particles equal to or smaller than 15 μm in aerodynamic diameter,

PM-10 = Particulate matter consisting of particles equal to or smaller than 10 μm in aerodynamic diameter, and

FP = Fine particulate matter consisting of particles equal to or smaller than 2.5 μm in aerodynamic diameter.

In practice, these particle size fractions have been determined in the field using inertial sizing devices characterized by calibrated values of 50% cutoff diameter (D_{50}).

This study was undertaken to derive size-specific particulate emission factors for industrial paved and unpaved roads and for rural unpaved roads from the existing field testing data base. In addition, recommendations are made for inclusion of the resulting emission factors in the EPA document, *Compilation of Air Pollutant Emission Factors, AP-42.*

Data Review

Besides an emissions test report on western surface coal mines released in November 1981, the literature search identified two additional reports directed to size specific emission factors for road dust emissions. The first report (dated August 1982) dealt with paved and unpaved roads in the iron and steel industry, and the second (dated December 1982) presented size specific emission factors for paved and unpaved roads in several industries (asphalt and concrete batching, copper smelting, sand and gravel processing, and stone quarrying and processing) and for rural unpaved roads. The reliability of the particle size data presented in these three reports is judged to be substantially better than the data presented in earlier reports for the following reasons:

1. Measurement of particle size distribution was an essential part of the exposure profiling strategies used to quantify emissions in these studies.
2. Particle size distribution was measured simultaneously at more than one height in the road dust plume.
3. Inertial sizing devices were used to obtain direct measurements of aerodynamic particle size distribution.

Table 1 identifies the AP-42 source categories covered by the three test reports.

Multiple Regression Analysis

In deriving recommended AP-42 particulate emission factors for industrial paved and unpaved roads, the first step is to determine if size-specific emission factors correlated with source parameters and if these correlations crossed industry lines. Such correlations would lead to predictive emission factor equations of greater reliability than single-valued mean emission factors. Stepwise Multiple Linear Regression (MLR) is the basic method used to evaluate source parameters for possible use as correction factors in a predictive emission factor equation for a specific particle size fraction.

The independent variables evaluated initially as possible correction factors are silt content (%), silt loading (g/m^2), total loading (g/m^2), average vehicle speed (km/hr), average vehicle weight (Mg), and average number of vehicle wheels. Silt denotes that portion of loose surface dust that passes a 200 mesh screen during standard dry sieving.

Unpaved Roads

All three test reports contained data sets for the development of IP and PM-10 emission factor equations for unpaved industrial roads. These data sets are combined for the purpose of developing predictive emission factor equations.

Analysis of the residuals from regression indicates that the equations perform reasonably well for much of the data base, but that they do not adequately account for emissions variability in the surface mining industry. The equations tend to significantly overpredict emissions from mine roads. This is thought to be due to the high degree of compaction of mine roads which are designed to handle heavy mine vehicles. In support of this reasoning, the silt loadings on the test mine roads are much lower than the loadings found in other industries. Based on the above considerations, the decision is made to exclude the surface mining data set from the data base.

The non-mining data base (26 tests) is used to develop several different forms of predictive emission factor equations. A model which includes silt loading and traffic-related parameters is found to account for the highest percentage of emission factor variability. The resulting equations have precision factors of 1.60 and 1.64 for the IP and PM-10 emissions, respectively. The precision factor is defined such that the 68% confidence interval for a predicted value (P) extends from P/f to Pf. The precision factor is determined by exponentiating the standard deviation of the differences (standard error of the estimate) between the natural logarithms of the predicted and actual emission factors. The precision factor is interpreted as a measure of the "average" error in predicting emissions from the regression equation. In addition, a non-parametric analysis of the residuals from the MLR indicates that the equations do not show any systematic predictive bias with respect to industry category.

Alternative equations are developed retaining the same form as the current AP-42 equation but with adjustments to both the coefficient and the exponents of the correction terms based on regression analysis against the study data

Table 1. *Primary Test Reports by AP-42 Section Number*

AP-42 Section No.	*Industrial source category*	*Test report date*
7.3	*Copper smelting*	*12/82*
7.5	*Iron and steel production*	*8/82*
8.1	*Asphaltic concrete plants*	*12/82*
8.10	*Concrete batching*	*12/82*
8.19	*Sand and gravel processing*	*12/82*
8.20	*Stone quarrying and processing*	*12/82*
8.24	*Western surface coal mining*	*11/81*
11.2.1	*Unpaved roads*	*All three*
11.2.6	*Paved roads*	*8/82, 12/82*

base. The alternative equations, which incorporate road surface silt percentage rather than silt loading, are found to have nearly the same predictive reliability (precision factors of 1.81 and 1.76 for IP and PM-10, respectively).

For the IP and PM-10 particle size fractions, the equations incorporating silt percentage are recommended over the equations using silt loading, primarily because of the much greater amount of information available on the expected range of percent silt for industrial roads. To provide a comparable amount of information for the silt loading parameter, it would be necessary to perform a considerable amount of additional road surface characterization work. For the FP size fraction, the recommended model incorporates silt content and is also the most accurate model.

The recommended unpaved road equations for all three particle size fractions follows a single functional form:

$$E = k(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad (1)$$

where:

E = emission factor; i.e., the quantity of particulate emissions from an unpaved road per vehicle kilometer of travel, kg/VKT
s = silt content of road surface material, %
S = mean vehicle speed, km/hr
W = mean vehicle weight, Mg
w = mean number of wheels
p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year

The particle size multiplier (k) in Eq. (1) is found to vary with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier for Eq. (1)

≦15 μm	≦10 μm	≦2.5 μm
0.50	0.36	0.095

Equation (1) is assigned a quality rating of A for application within the ranges of source conditions that were tested in developing the equations, as follows: silt content, 4 to 35%; mean vehicle weight, 2 to 49 Mg; mean vehicle speed, 8 to 64 km/hr; mean number of wheels, 4 to 17. Also, to retain the quality rating of the equation applied to a specific unpaved road, it would be necessary that reliable correction parameter values be determined for the specific road in question.

Paved Roads

Two data sets were available for the development of paved road IP and PM-10 emission factor equations. These include test data (21 tests) collected for the following industries: iron and steel production, copper smelting, concrete batching, and sand and gravel processing. The independent variables considered initially as possible correction factors are the same as those in the unpaved roads analyses.

Prior to the analysis, it is recognized that the measured correction factors would probably not account for a substantial portion of the variability in IP and PM-10 emissions. One of the major reasons for this is that any direct contribution of particulate from vehicle underbodies, exposed haulage loads (i.e., aggregate materials), or vehicle exhaust is not parameterized by the available correction factors. Similarly, the influence of emissions from unpaved shoulders generated by the wakes of large vehicles is not considered in the correction parameters. Because of the lower magnitude of paved road emissions compared to those from unpaved roads, the influence of these sources would be potentially greater in paved road emission factors. Previously published equations for paved road emissions used augmentation or judgment factors in an attempt to partially account for the influence of these sources.

Based on analysis of the data set, the decision is made to partition the paved road data base into two subsets: Subset 1 includes tests for relatively heavily loaded roads traveled by predominantly light-duty vehicles (i.e., mean vehicle weight <4 Mg); and Subset 2 includes tests for roads with generally moderate surface loadings and vehicle mixes that can be considered more typical of industrial facilities (i.e., mean vehicle weight ~ 16 Mg). The mean emission factors (IP and PM-10) for Subset 1 are less than 50% of those of Subset 2.

The correlation matrix based on Subset 2 shows a reasonably strong relationship between roadway surface loadings and emissions. The emission factor equations predict the data Subset 2 with precision factors of 1.59 and 1.64 for IP and PM-10 emissions, respectively.

An alternative, consisting of the existing AP-42 emission factor equation with adjustments to the original coefficient to approximate IP and PM-10 emission factors, does not acceptably predict the new emission factor data base. The relatively poor performance of the scaled AP-42 equation is attributed largely to two factors: first, the proportionality constants are based on limited particle sizing information; and second (and more important), the range of source conditions that provided the basis for the AP-42 equation is much smaller than that of the new data base.

The recommended paved road equations for all three particle size fractions follows a single functional form:

$$E = k\left(\frac{sL}{12}\right)^{0.3} \quad (2)$$

where

E = emission factor; i.e., the quantity of particulate emissions from a paved road per vehicle-kilometer of travel, kg/VKT
sL = road surface silt loading, g/m^2

The particle size multiplier (k) is found to vary with aerodynamic size range as follows:

Aerodynamic Particle Size Multiplier for Eq. (2)

≦15 μm	≦10 μm	≦2.5 μm
0.28	0.22	0.081

Equation (2) is assigned a quality rating of A for application within the range of source conditions that were tested in developing the equation as follows: silt loading, 2 to 240 g/m^2; and mean vehicle weight, 6 to 42 Mg. Also, to retain the quality ratings of Eq. (2) applied to a specific industrial paved road, it would be necessary that reliable correction parameter values for the specific road in question be determined.

For roads that are traveled by predominantly light-duty traffic, the single-value emission factors represented by the geometric means for Subset 1, should provide reasonable upper limits for IP and PM-10 emissions, as follows:

Emission Factors for Light-Duty Vehicles on Heavily Loaded Roads

≦15 μm	≦10 μm
0.12 kg/VKT	0.093 kg/VKT

These emission factors are assigned a quality rating of B for application within the range of source conditions that were tested in developing the factors, as follows: silt loading, 15 to 400 g/m^2; and mean vehicle weight, <4 Mg (<4 tons).

Proposed AP-42 Sections

This report also contains the proposed revisions to the AP-42 sections for unpaved roads (Section 11.2.1) and for industrial paved roads (Section 11.2.6), respectively. Updates for these sections were recently included in Supplement 14 to AP-42. To the extent possible, the format used in Supplement 14 is retained for the purpose of incorporating the size-specific particulate emission factors developed in this document.

With regard to unpaved road emission factors for western surface coal mining, it is recommended that the new AP-42 Section 8.24 be used without modification. That section already contained predictive emission factor equations for specified particle size fractions.

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***Dale L. Harmon** is the EPA Project Officer (see below).*

The complete report, entitled "Size Specific Particulate Emission Factors for Industrial and Rural Roads: Source Category Report," (Order No. PB 86-122 611/AS; Cost: $11.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

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