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Project Summary

Characterization of PM-10 Emissions from Antiskid Materials Applied To Ice and Snow-Covered Roadways

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Several areas of the U.S. in violation of the National Ambient Air Quality Standard for PM-10 (particulate matter with diameters ≤ 10 µm) have conducted studies that have identified the resuspension of antiskid material applied to paved roadways as an important source of PM-10. The application of antiskid materials creates a temporary but substantial increase in the amount of fine particulate on the road surface over and above that which is normally present. Measured emission data are lacking for all types of antiskid materials; therefore, an appropriate field program whose objective was to establish a predictive model for PM-10 emissions was undertaken. A source-oriented emissions sampling procedure was conducted on a section of US 53 just west of Duluth, MN, during March/April of 1992. The measured emission factors varied from 1 to 11 g/VKT (vehicle kilometer traveled) for the three tests conducted. The data were not sufficient, however, to develop any specific correlation between the measured emission factors and source parameters. The only general observation made was PM-10 emissions appear to increase with the amount of antiskid material applied. A comparison of measured emission factors with those predicted by an EPA compilation of air pollutant emission factors (AP-42) indicated that most of the measured factors are higher than those that would be predicted from silt-loading values alone. Due to the marginal test conditions during storms, no definitive assessment of this increase can be made until additional data are obtained.

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

Several areas of the U.S. in violation of the National Ambient Air Quality Standard (NAAQS) for PM-10 (airborne particles ≤10 µm in diameter) have conducted studies to determine the sources of these emissions. One source of PM-10 emissions identified in these studies is the resuspension of antiskid material applied to paved roadways. Antiskid materials may consist of abrasives (e. g., sand, stone, or cinders applied to the road surface to improve traction) or deicers, which restore pavement traction by preventing the formation of ice films, weakening the ice/pavement bond, and/or by melting ice and snow.

The application of antiskid materials creates a temporary but substantial increase in the amount of fine particles on the road surface over and above that which is normally present. Prior research has established a direct relationship between the loading of silt-size fines (particles < 75 µm in physical diameter) and the PM-10 emission generated by vehicular traffic. The empirical relationship between silt loading and PM-10 emissions is reflected in EPArecommended PM-10 emission factors for paved urban roads.

In a recent EPA study, a literature search, an engineering analysis, and a laboratory testing program were performed to provide air pollution control agencies with information on how to identify an appropriate antiskid material that is both durable and effective and produces lower PM-10 emissions. The primary objectives of this study were to provide guidance on methods to determine (a) the physical properties and durability of antiskid materials selected for use on ice- and snow-covered roadways, and (b) criteria for defining the elements of an effective PM-10 emission control strategy associated with use of antiskid materials.

Although the above study provided guidance for the selection of antiskid materials, no direct information was developed regarding the actual PM-10 emissions related to their use, the changes in surface silt loading resulting from such application, or the degree of control actually achieved by compliance with the material selection criteria developed in the study. Measured emissions data are lacking for all types of antiskid material, but deicing chemicals have received the least amount of attention. Therefore, an appropriate field program was needed to establish a suitable method for predicting PM-10 emissions from the use of antiskid materials. This is the primary objective of the work reported here.

Source-oriented emissions sampling was employed in the program using Midwest Research Institute's (MRI's) "exposure profiling" approach. The data obtained by this technique were coupled with the results of road surface sampling and materials application data in an attempt to develop a method for predicting PM-10 emissions.

Site Selection

The original test site was located on northbound US 53 at Mile Post (MP) 13.35 (or approximately Station No. 452+50). This particular location has good orientation with respect to the wind direction anticipated for periods after storms, good exposure to ambient winds (i.e., lack of trees in the upwind direction), and a relatively flat median for installation of the air-sampling equipment. However, due to the mild winter in Duluth, the original test site could not be used. The site was selected on the assumption that the ground would remain frozen throughout the sampling period, allowing equipment to be safely placed on the median. When the ground remained thawed, the sampling site was moved approximately 1/4 mi (0.4 km) northbound (i.e., to the west) to an area near the intersection of US 53 with a county road. This area provided a firm surface for the sampling equipment but had a substantial stand of trees bordering the northern portion of the right-of-way which did not conform to criteria established by MRI for exposure profiling. For this and other related reasons, only one of the three test series was conducted under suitable conditions with respect to wind speed and direction. This noncompliance with established criteria adversely affected data quality as discussed below.

Overall Study Design

The source-directed field sampling conducted in this study employed the exposure profiling approach to quantify source emission contributions. The exposure profiling technique for particulate source testing is based on the isokinetic profiling concept used in conventional (stack) testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the effective cross section of the dust source plume. This technique uses a mass flux measurement scheme similar to EPA Method 5 stack testing rather than requiring indirect emission rate calculation through the application of a generalized atmospheric dispersion model.

Air Sampling Equipment

For measurement of particulate emissions from the test road, a vertical network of samplers (Table 1) was positioned 5 m downwind and 10 m upwind from the edge of the pavement. Four downwind vertical sampling arrays (D1 through D4) and two vertical upwind arrays were used. Three of the downwind arrays (D1, D3, and D4) and one upwind array (U2) made use of high-volume (hi-vol) air samplers equipped with constant-flow electronic controllers and cyclone pre-separators. The remaining two arrays (D2 and U1) used hi-vols equipped with Wedding PM-10 inlets and critical orifice flow controllers.

Testing Procedures

Prior to actual sample collection, a number of decisions were made as to the potential for acceptable source-testing conditions. These decisions were based on forecast information obtained either from the local U.S. Weather Service office and/or from the Roadway Weather Information System (RWIS) located at the site. If conditions were considered acceptable, the sampling equipment was prepared for testing. Pretest preparations included calibration of the various air sampling instruments and insertion of filters. All sampling activities followed quality control (QC) procedures approved by EPA prior to testing.

The particulate samples were collected on Type AH grade glass fiber filters. The filters were analyzed gravimetrically at a constant temperature and humidity in a

Table 1. Sampler Deployment[a]

Sampler array ID	No. of instruments	Measurement height(s) (m)	Type of sampler or instrument	Parameter(s) measured
U1	1	3	Hi-vol + Wedding inlet	PM-10, Pb
U2	2	1.5, 3	Hi-vol + Cyclone	PM-10
D1, D3, D4	4	1, 3, 5, 7	Hi-vol + Cyclone	PM-10, Na+, Cl⁻ (Selected arrays only)
D4	2	1,5	Warm wire anemometer	Wind velocity
D4	1	3	Wind vane	Wind direction
D2	1	2.5	Hi-vol + Wedding inlet	PM-10, Pb

[a] Certain downwind sampling equipment could not be used during testing due to persistent generator problems.

special laboratory. Selected filters were also extracted and chemically analyzed by an independent laboratory to determine the concentration of chloride (Cl^-), sodium (Na^+), or lead (Pb) in the particulate sample collected. Appropriate quality assurance/quality control (QA/QC) procedures were used throughout all sample analyses.

Ancillary Sampling and Analysis

The types of ancillary samples and information collected in the program fall into two broad categories: antiskid materials and roadway surface samples, and source activity levels. Each is described below.

In conjunction with the emissions tests, samples were taken of the antiskid material (abrasive/rock salt mix and straight rock salt) applied to the road and the dust remaining on the surface after it dried. These samples were needed not only to evaluate the performance of existing emission models but also to develop improved models for antiskid materials. Antiskid samples were analyzed for silt and moisture content as well as a number of key physical and chemical properties thought to be important in the generation of silt loading (e. g., mass of material < 75 µm in physical diameter) on the road surface. Road surface samples were analyzed for silt content using established MRI procedures.

Source extent and activity data were collected with a variety of tools. For example, in addition to visual observation and note taking, pneumatic traffic counters were used to determine source activity on US 53. A radar gun was used to determine the average speed of vehicles passing the sampler array.

In conjunction with the program, detailed information was collected independently by the Minnesota Department of Transportation (MNDOT) on the condition of the weather and pavement during the course of the storm, the types and amounts of antiskid materials applied to the test road, and a general indication of the residual deicing chemical on the road surface at various times. These data were used to augment the information obtained on source activity mentioned above. Additional surface sampling was conducted between storms to develop a silt-loading "history" during data analysis.

Calculation Procedure

To calculate emission rates from the measured PM-10 concentrations (mass/volume), a conservation of mass approach was used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) was obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. To be consistent with the NAAQS, all concentrations and flow rates were expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 in. Hg).

Field Sampling Program

Source Description and Activity

The test site used in the experimental program was located on northbound US 53 on the outskirts of metropolitan Duluth, MN. US 53 is an unlimited-access, four-lane, high-speed roadway carrying commuter traffic to and from Duluth at an approximate volume of 5,000 vehicles/day. Data collected during field sampling showed that most traffic was two-axle, light-duty vehicles traveling between 88 and 97 km/h (55 and 60 mph). Normal surface loadings, determined both visually and by sampling, were generally very low, with silt loadings in the range of 0.2 g/m^2.

Exposure profiling was performed after two minor storms that occurred on April 10, and on April 21 and 22, 1992. One test series was conducted on April 11, with additional testing on April 23 and 26.

During the April 10 storm, approximately 4 to 6 in. (10 to 15 cm) of wet snow fell on US 53 in 24 h. Four applications of an abrasive/salt mixture were made to the northbound lanes over a period of approximately 10 h totaling 395 kg/lane-km (1,400 lb/lane-mi). During the second storm, a combination of wet snow and freezing rain fell during approximately a 36-h period. In this case, only one application of 197 kg/lane-km (700 lb/lane-mi) was made to each lane especially for test purposes.

As determined in previous research, the application rates used by MNDOT are far below those of most other transportation agencies. Also, much of the material applied was either cast off by the snow plow during clearing operations or eliminated by melted precipitation. The material that remained on the surface was quickly lost to the atmosphere by the action of passing vehicles. Thus, surface loadings were generally low, with higher loadings observed in the passing (left) lane, compared to the driving (right) lane.

Exposure Profiling Results

The results of the three PM-10 exposure-profiling tests are shown in Table 2. These results were calculated using the outcome of the gravimetric analyses performed to obtain the measured (i.e., blank-corrected) PM-10 concentration at each sampling location. Net (i.e., upwind-corrected) PM-10 concentrations were then determined at each vertical sampling height by subtracting estimates from a straight line fit of the measured upwind concentrations. (Note that net concentrations were calculated only for arrays with adequate information for integration purposes.) Using these net concentrations, the PM-10 exposure was calculated for each measurement location and exposure integration performed using a two-step process. Finally, PM-10 emission factors were calculated from the data.

Results of Chemical Analyses

As mentioned above, selected filters (including blanks) were submitted for chemical analysis for either Pb or Na^+ and Cl^- content. The concentration of particulate Pb was determined both upwind and downwind of the road during Tests AY-4 and AY-5, using samples collected by the two Wedding PM-10 instruments. (Similar analyses could not be performed for Test AY-3 due to a downwind sample invalidated by generator problems.) In the case of Na^+ and Cl^-, filter sets from one downwind profiler array for each of the three tests were submitted for chemical analysis. The purpose of these analyses was to determine the relative contribution of rock salt to the total PM-10 emissions from the roadway.

As shown by the experimental data, the analyte mass found on most of the filters does not exceed the blank values for any of the three species. Of the few filters which show a net increase in analyte mass over the blank value, the quantity determined is generally so slight as to be negligible. Therefore, for the purpose of this study, it was assumed that the contribution of both Pb and NaCl to the total PM-10 emissions from the road was not significant and thus could be ignored. For this reason, no specific emission factors were developed for either Pb or NaCl in the current program.

Results of Ancillary Sampling and Analysis

Samples of both the abrasive/rock salt mixture and straight rock salt were col-

Table 2. Results of Emission Factor Calculations [a]

Run No.	Array No.	Sampler height (m)	Net PM-10 concentration (μg/std m³) [b]	Wind speed (m/s)	Net PM-10 exposure (μg/cm²)	Integrated exposure (m-μg/cm²) [c]	No. of vehicle passes	PM-10 emission factor (g/VKT)
AY-3	D-1	1	26.9	3.8	109	459	1,175	3.91
		3	14.5	(5.4)	83.2			
		5	-	6.1	(41.6)			
		7	0	(6.7)	0			
	D-4	1	79.8	3.9	338	1,038	983	10.6
		3	28.8	(5.7)	178			
		5	0	6.6	0			
		7	0	(7.3)	0			
AY-4	D-1	1	31.2	0.58	6.84	31.8	220	1.44
		3	19.6	(1.0)	7.41			
		5	1.11	1.2	0.50			
		7	0	(1.4)	0			
AY-5	D-4	1	20.4	1.4	37.7	149	650	2.29
		3	7.8	(1.7)	17.5			
		5	4.5	1.9	11.3			
		7	3.3	(2.1)	9.14			

[a] Parentheses denote inter/extrapolated values.
[b] Net concentration calculated as difference between measured downwind and upwind concentrations. Upwind data inter/extrapolated for different heights.
[c] Integration scheme assumes constant value of exposure from 0 to 1 m height, with Simpson's rule used for integration between 1 m and effective plume height (H). Maximum H assumed ≤ 9 m.

lected from the MNDOT storage piles and/or spreader trucks. These samples were then analyzed for moisture and silt content as well as various key material properties.

Using the data obtained for the abrasive/salt mixture, a comparison was made of properties with EPA material selection criteria. This comparison showed that the abrasive/salt mixture used by MNDOT did not meet three out of the four key parameters thought to be important for high material durability. For this reason, the abrasive/salt mixture analyzed in the current program was classified as being of questionable quality, based on the results of previous testing.

Road surface sampling was also performed throughout the period that field testing was attempted in Duluth, MN. Samples were collected and analyzed to determine silt loading using accepted procedures. Surface samples were collected from both the driving (right) and passing (left) lane on the northbound and southbound sides of the median near the air sampling site with the majority of the sampling performed on the northbound lanes.

Using the silt loading data. PM-10 emission factor estimates were calculated for the various samples using the AP-42 predictive model. Emission factors were predicted for both northbound (abrasive/salt mixture) and southbound (rock salt only) lanes in terms of grams per vehicle kilometer traveled (g/VKT).

As shown in Table 3, predicted emission factors, based on silt-loading data, were generally low, ranging from less than 1 to a maximum of 4 g/VKT. The highest emission factors (resulting from the highest silt loadings) are for samples collected from the northbound lanes (abrasive/salt mixture) after a fairly major storm on February 24, 1992. (Note that this storm occurred *prior* to field testing. After that time, the predicted emissions generally drop to ≤ 1 g/VKT until the next storm in early April. This decrease in loading would be expected due to the effects of traffic, which tends to reestablish a silt-loading "equilibrium" on the road surface after external influences (e.g., the application of antiskid material) have been eliminated. As also found, the estimated emission factors are of the same approximate magnitude as the test results provided in Table 2. This lends some additional credibility to the data obtained by exposure profiling in the current study.

Discussion of Results

As shown by the above test results, the measured emission factors varied from 1 to 11 g/VKT for the three tests conducted. The data were not sufficient, however, to develop any specific correlation between the measured emission factors and source parameters such as quantity of antiskid material applied, time since application, and silt loading. The only general observation that can be made from the data is that the PM-10 emissions appear to increase with the amount of antiskid material applied during the two storms tested (i.e., the emission factors for Test AY-3 are higher than for Tests AY-4 and AY-5). (Also note that Test AY-5 had the most acceptable wind conditions of the three tests conducted and thus represents the most reliable emission factor determined in the study.) Otherwise, the results do not seem to follow a consistent relationship. A major cause for the lack of association was the marginal test conditions discussed above.

A comparison of the measured emission factors (Table 2) with those predicted by the current AP-42 equation (Table 3) also yields some interesting results. With only a relatively few exceptions, most of the measured factors are higher than those which would be predicted from silt-loading values alone In the case of the test (i.e., northbound) lanes themselves, the measured factors either equal or exceed the lane average emissions predicted by the AP-42 equation, except for the February 26 samples that were collected after a fairly major storm. This suggests that the application of antiskid material results in a short-term increase in PM-10 emissions from the roadway in an amount greater than that which would be predicted by silt

Table 3. Predicted PM-10 Emission Factors for Measured Surface Silt Loadings [a]

Date	Lane sampled	Road surface silt loading (g/m^2)	Predicted PM-10 emission factor (g/VKT)
2/26	NB—Driving	1.04	4.10
	NB—Passing	0.501	2.28
	SB—Driving	0.529	2.38
	SB—Passing	0.271	1.39
2/28	NB—Driving	0.341	1.68
	NB—Passing	0.0262	0.215
	SB—Driving	0.445	2.08
	SB—Passing	0.295	1.50
3/2	NB—Driving	0.0701	0.473
	NB—Passing	0.0661	0.452
	SB—Driving	0.0382	0.291
	SB—Passing	0.122	0.738
3/11	NB—Driving	0.200	1.10
	NB—Passing	0.164	0.935
	SB—Driving	0.208	1.13
	SB—Passing	0.354	1.73
3/19	NB—Driving	0.0431	0.321
4/1	NB—Driving [b]	0.0788	0.520
	NB—Passing [b]	0.156	0.900
4/22	NB—Driving [b]	0.0618	0.428
	NB—Passing [b]	0.544	2.44
4/24	NB—Driving	0.150	0.870
	NB—Passing	0.133	0.790
	SB-Driving and Passing	0.0526	0.376

[a] *PM-10 emission factors predicted using the AP-42 predictive equations and silt-loadings obtained in the program.*
[b] *Loadings measured after application of antiskid material.*

loading alone. Although no definitive assessment of this increase can be made based on available data, the PM-10 emissions could be almost a factor of 3 higher (i.e., 11 vs. 4 g/VKT) than would be predicted from the silt loading. This proportional increase in emissions is considerably higher than the precision factor of approximately 2 for the current AP-42 predictive equation and thus worthy of further study. Therefore, a more explicit evaluation would help determine the extent of the emissions increase due to the application of antiskid material to paved roadways.

Conclusions

The following conclusions were reached as a result of the current study:

1. Because the measurements conducted were performed under difficult environmental conditions that did not meet all of the applicable QC criteria for exposure profiling, data quality was adversely affected.
2. Although the emission factors determined in the program ranged from 1 to 11 g/VKT for the three tests conducted, these values should be used with extreme caution due to the lack of suitable test conditions during sample collection and resulting poor data quality.
3. The contribution of both particulate Pb and NaCl to the total PM-10 emissions from the road did not appear to be significant based on the limited chemical analyses performed during the program.
4. The dry silt loadings determined on US 53 tended to (a) be relatively low and (b) drop off rapidly after a storm, which is typical of high-speed roadways. The amount of silt available for resuspension was also found to be very low due to the minimal application of antiskid material during the experimental program.
5. Emission factors determined in the program were generally higher than those predicted by the current AP-42 equation, based on road surface silt loading. The magnitude of this increase could not be definitively determined from available data, but it may be almost a factor of 3.

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The complete report, entitled "Characterization of PM-10 Emissions from Antiskid Materials Applied To Ice and Snow-Covered Roadways," (Order No. PB93-150209; Cost: $19.50; subject to change) will be available only from
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