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Project Summary

Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources

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The primary purpose of this study was to develop emission factors for significant surface coal mining operations that would be applicable at Western surface coal mines and would be based on widely acceptable, state-of-the-art sampling and data analysis procedures. The approach was to develop emission factors for individual mining operations in the form of equations with correction factors to account for site-specific conditions. Factors were determined for three particle size ranges—less than 2.5 μm (fine particulate), less than 15 μm (inhalable particulate), and total suspended particulate.

A total of 265 tests were run at three mines during 1979 and 1980. The following sources were sampled: Drilling (overburden), blasting (coal and overburden), coal loading, bulldozing (coal and overburden), dragline operations, haul trucks, light- and medium-duty vehicles, scrapers, graders, and wind erosion of exposed areas and coal storage piles. The primary sampling method was exposure profiling; however, upwind-downwind, balloon, wind tunnel, and quasi-stack sampling methods were used on sources unsuitable for exposure profiling.

Several variables that might affect emission rates, such as vehicle speed, were monitored during the tests. Significant correction parameters in the emission factor equations were then determined by multiple linear regression analysis. Confidence intervals were also calculated for each of the factors.

Data for determination of deposition rates were obtained, but scatter in the data prevented the development of an algorithm. Control efficiencies for two unpaved road control measures were estimated.

The full report concludes with a comparison of the generated emission factors with previous factors, a statement regarding their applicability to mining operations, and recommendations for additional research in Western and other mines.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, 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

Operations of surface coal mines vary from mine to mine, and the relative amounts of dust produced by the different operations will vary greatly. A ranking of the sources was performed to determine which significant particulate sources warranted sampling, based on average mine conditions. The most significant dust-producing operations are shown in Table 1.

Sampling Program

The number of mines to be surveyed was set at three—a compromise between sampling over the widest range of mining/meteorological conditions by visiting a large number of mines and obtaining the most tests within the given budget and time limits by sampling at only a few mines. The three mines selected were in diverse geographic areas in the Western coal fields having the largest strippable reserves: Fort Union (North

Dakota), Powder River Basin (Montana-Wyoming), and San Juan River (New Mexico-Arizona). These mines had most of the significant dust-reproducing operations, and most operations could be sampled at more than one location in each mine. While sampling was limited to several weeks at each mine, seasonal variations in emission rates were considered by sampling during three of four seasons.

A total of 265 tests (245 of them on uncontrolled sources) were conducted during four sampling periods. Table 1 summarizes the tests by mine and by source. The total number of samples required for each source to achieve a 25 percent relative error at a 20 percent risk level was determined statistically. The calculated sample size could not be obtained from some sources because of difficulties encountered in the field, such as source inactivity, inability to place the sampling array in the required location due to topographical barriers, unstable wind directions, and low or high windspeeds. A major effort was made to obtain a statistically adequate sample size for haul trucks, the major dust-producing source.

Table 1. *Summary of Tests Performed*

Source	*Sampling technique*	*Mine 1*	*Mine 2*	*Mine 1W[a]*	*Mine 3*	*Total*
Drilling, ovb.[b]	*Quasi-stack*	*11*	*-*	*12*	*7*	*30*
Blasting, coal	*Balloon*	*3*	*6*		*7*	*16*
Blasting, ovb.	*Balloon*	*2*			*3*	*5*
Coal loading (shovel/truck or front-end loader)	*Uw-dw[c]*	*2*	*8*		*15*	*25*
Bulldozing, ovb.	*Uw-dw*	*4*	*7*		*4*	*15*
Bulldozing, coal	*Uw-dw*	*4*	*3*		*5*	*12*
Dragline	*Uw-dw*	*6*	*5*		*8*	*19*
Haul trucks	*Profiling*	*7[d]*	*9*	*10[e]*	*9*	*35*
Light- and medium-duty trucks	*Profiling*	*5*	*5*		*3*	*13*
Scrapers	*Profiling*	*5[d]*	*6*	*2*	*2*	*15*
Graders	*Profiling*		*5*		*2*	*7*
Exposed area, ovb.	*Wind tunnel*	*11*	*14*	*3*	*6*	*34*
Exposed area, coal	*Wind tunnel*	*10*	*7*	*6*	*16*	*39*
Total		*70*	*75*	*33*	*87*	*265*

[a] *Winter sampling period.*

[b] *ovb. = overburden.*

[c] *Uw-dw = upwind-downwind.*

[d] *Five of these tests were comparability tests (profiling and upwind-downwind).*

[e] *Six of these tests were done by upwind-downwind.*

Sampling Techniques

A thorough review of possible fugitive dust sampling techniques indicated that no one technique was adequate to sample all sources. Exposure profiling, designated as the preferred technique, was used whenever possible (63 profiling tests were performed). Each of the five different sampling techniques used in the study is described briefly in the following paragraphs.

The exposure profiler consisted of a portable tower (4 to 6 m in height) supporting an array of sampling heads Each sampling head was operated as an isokinetic exposure sampler The air-flow stream passed through a settling chamber that trapped particles larger than about 50 μm, and then flowed upward through a horizontally position, standard 8 x 10 in. glass fiber filter. Sampling intakes were positioned directly into the wind, and sampling velocities were adjusted to match the mean windspeed at each height (as determined immediately prior to the test). Windspeed was monitored by hot-wire anemometers throughout the test, and flow rates were adjusted for major changes in mean windspeed. Operating concurrently with the profiler, dichotomous samplers placed at two heights on the tower determined particle size distribution. Duplicate dustfall buckets located at the profiler and 20 and 50 m downwind of the source provided information on deposition.

The exposure profiler concept was modified for sampling blasting operations. The large horizontal and vertical dimensions of the blast plumes required a suspended array of samplers as well as ground-based samplers in order to sample over the plume cross-section in both dimensions. Five 47-mm polyvinyl chloride (PVC) filter heads and sampling orifices were attached to a line suspended from a tethered balloon. The samplers were located at different heights (2.5, 7.6, 15.2, 22.9, and 30.5m), and each sampler was attached to a wind vane so that the orifices would face directly into the wind. The samplers were connected to a ground-based pump with flexible tubing. The pump maintained an isokinetic flow rate for a windspeed of 5 mph. To avoid equipment damage from blast debris and to obtain a representative sample of the plume, the balloon-suspended samplers were located about 100 m downwind of the blast area. The balloon-supported samplers were supplemented with five hi-vol/dichotomous sampler pairs spaced 20 m apart and located on an arc at the same distance as the balloon from the edge of the blast area.

The upwind-downwind array used for sampling point sources included 15 samplers (10 hi-vol and 5 dichotomous). One of each sampler type was located upwind of any dust from the source. Initially, downwind samplers were placed at nominal distances of 30, 60, 100, and 200 m; however, these distances had to be frequently modified because of physical obstructions (e.g., highwall) or potential interfering sources. Two samplers of each type were placed at a distance of 30 m, three hi-vols and two dichotomous samplers at 60 m, three hi-vols at 100 m, and one hi-vol at 200 m. Both sampler types were mounted on tripod stands at a height of 2.5 m, the highest manageable height for this type of rapid-mount stand. The downwind array was modified slightly for sampling line sources. It consisted of two pairs of hi-vol/dichotomous samplers at 5, 20, and 50 m and two hi-vols at 100 m. The two rows of samplers were separated by 20 m. The upwind-downwind method allowed indirect measurement of deposition through calculation of apparent emission rates at a series of downwind distances.

A portable wind tunnel consisting of an inlet section, a test section, and an outlet diffuser was used to measure dust emissions generated by wind erosion of exposed areas and storage piles. The test section has a 1 by 1 ft cross section so it could be used with rough surfaces. The open-floored test section was placed directly on the 1 by 8 ft surface to be tested, and the tunnel air flow was adjusted to predetermined values that corresponded to the means of NOAA windspeed ranges. Tunnel windspeed was measured by a pitot tube at the downstream end of the test section and related to windspeed at the standard 10 m height by means of a logarithmic profile. An emission-sampling module was located between the tunnel outlet and the fan inlet to measure particulate emissions generated in the test section. The sampling train, which was operated at 15 to 25 ft^3/min, consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, backup filter, and hi-vol motor. Interchangeable probe tips were sized for isokinetic sampling over the desired tunnel windspeed range.

For quasi-stack sampling of overburden drilling, a wooden enclosure with 4 by 6 ft end openings was fabricated in the field. During each test, the enclosure was placed adjacent to, and downwind of the drill platform. The cross section of the enclosure was divided into four rectangles of equal area, and a hot-wire anemometer measured wind velocity at the center of each rectangle. Four exposure profiler samplers with remote flow controllers were used to sample in the four enclosure subareas. Sampler flow rates were adjusted at 2-to 3-minute intervals to near-isokinetic conditions with the windspeed measurements. This sampling technique did not measure particle size distribution of deposition.

Source Characterization

Many independent variables influence particulate emission rates from mining sources. If these variables are to be quantified and included as parameters (correction factors) in the emission factor equations, suspected variables must be measured for each emission test.

Summary of Results

Total suspended particulate (TSP) and inhalable particulate (IP) emission rates are presented in Table 2. For some sources, the number of test values is lower than the number of tests reported in Table 1. This indicated elimination of data after a test was completed. For example, the plume may have missed the sampling array for most of the period or the sampler may have malfunctioned. Most of the tests for which no data are presented in Table 2 (36 out of 44) were run on exposed areas. These tests were unproductive because eroding particles could not be generated on the test surfaces, even at the highest windspeed simulated in the wind tunnel.

The geometric mean values in Table 2 are *not* emission factors; no consideration has been given to correction factors at this point.

The relative standard deviations of emission rates by individual sources ranged from 0.7 to 1.5. Relative standard deviation is a measure of sample variation.

Table 2. *Emission Rates by Source*

Source	*No. of values*	*Units*	*Geometric mean emission rate*		*Range of emission rates from individual tests*	
			TSP	*IP*	*TSP*	*IP*
Drilling, ovb.[a]	*30*	*lb/hole*	*1.16*		*0.04-7.29*	
Blasting, coal	*14*	*lb/blast*	*28.7*	*10.5*	*1.6-514 0*	*0.4-142.8*
Blasting, ovb.	*4*	*lb/blast*	*74.3*	*40.0*	*35.2-270.0*	*16.9-93.9*
Coal loading (shovel/truck or front-end loader)	*25*	*lb/ton*	*0.039*	*0.010*	*007-1.090*	*0.002-0.378*
Bulldozing, ovb.	*15*	*lb/h*	*3.70*	*1.96*	*0.9-20.7*	*0.48-32.60*
Bulldozing, coal	*12*	*lb/h*	*46.0*	*20.5*	*3 0-439.0*	*0.9-236.0*
Dragline	*19*	*lb/yd^3*	*0.050*	*0.013*	*0.004-0.400*	*0.002-0.061*
Haul trucks	*33*	*lb/VMT*	*9.1*	*4.1*	*0.6-73 1*	*0.4-42.1*
Light- and medium-duty trucks	*11*	*lb/VMT*	*2.43*	*1.54*	*0.35-9.0*	*0.34-5.1*
Scrapers	*14*	*lb/VMT*	*24.3*	*11.7*	*3.9-355 0*	*1.4-217.0*
Graders	*7*	*lb/VMT*	*5.8*	*2.8*	*1.8-34.0*	*0.9-15.4*
Exposed area, ovb.	*10*	*lb/acre-s*	*0.0803*	*0.0549*	*0.0107-0.537*	*0.0073-0 336*
Exposed area, coal	*27*	*lb/acre-s*	*0.0980*	*0.0642*	*0.0096-2.27*	*0.0053-1.40*

[a] *ovb. = overburden.*

For most sources with at least 10 data points, emission rates varied more than two orders of magnitude; however, similar variations were noted in independent variables thought to have an effect on emission rates.

Multiple Linear Regression Analysis

The method for developing correction factors was based on multiple linear regression (MLR). Briefly, values for all variables being considered as possible correction factors were first tabulated by source along with the corresponding TSP emission rates for each test. The data were then transformed to their natural logarithms (ln) because a preliminary analysis had indicated the emission rates were lognormally rather than normally distributed. The transformed data were applied to the MLR program, specifying the stepwise option and permitting entry of all variables that increased the multiple regression coefficient.

Wind Erosion Sources

The emission rates reported in Table 2 for wind erosion from coal pile surfaces and exposed ground areas were obtained by testing several naturally occurring surfaces at successively increasing windspeeds simulated in the wind tunnel. Analysis of SP (the size fraction less than 30 μm) and IP emission rates indicated that the rates (1) increased with windspeed above a threshold level on newly exposed surfaces and (2) decreased sharply with time after the onset of erosion.

Threshold velocities for detectable movement of surface particles were unexpectedly high. This was attributed to the presence of natural crusts on many of the surfaces tested. The decay in emission rates with time was explained by the limited quantity of particles in any specified particle size range present on the surface (per unit area) that could be removed by wind erosion at a particular windspeed. The available quantity, or erosion potential could be restored by a disturbance of the surface such as the addition or removal of material from a storage pile or the plowing of an exposed ground area.

Particle Size Distribution

Emission factors were developed for three size ranges—fine particulate (FP, <2.5 μm); inhalable particulate (IP, <15 μm); and total suspended particulate (TSP, no well-defined upper cut point, but approximated as 30 μm). Dichotomous samplers generated the FP and IP data and hi-vol samplers generated the TSP data. Suspended particulate (SP) emission rates determined from exposure profiling tests were not actually TSP; rather, these rates were the fraction of total particulates less the 30 μm in aerodynamic diameter. Only a calculated estimate of the suspended fraction could be made because the profiler samplers indiscriminately collect all particle sizes present in the plume.

Independent data analyses were performed on IP and TSP/SP data to derive emission factors for these two size ranges. Data analysis problems associated with the very low concentrations prevented determination of emission factors for the FP size fraction by calculation of emission rates followed by multiple linear regression. Instead, net FP concentrations for all tests were expressed as a fraction of TSP or SP, and the average fraction for each source was applied to the TSP/SP emission factor for that source to calculate an FP emission factor.

Table 3 shows the average ratios of FP and IP to TSP or SP emission rates by source. The IP fractions were reasonably consistent, varying from 0.30 to 0.67. In general, these ratios were lower than the frequently quoted average ratio of 0.65 for urban ambient monitoring. These ratios were based on measurements taken near the sources. As the emissions proceed downwind, greater deposition in the TSP fraction should increase the ratio.

Table 3. Average Particle Size Distributions by Source

Source	*No. of tests*	*Average IP/TSP*	*Std. dev. of IP/TSP*	*Average FP/TSP*	*Std. dev. of FP/TSP*
Blasting	*18*	*0.46*	*0.29*	*0.051*	*0.039*
Coal loading	*24*	*0.30*	*0.15*	*0.030*	*0.035*
Bulldozing, coal	*12*	*0.49*	*0.24*	*0.031*	*0.033*
Bulldozing, ovb.	*14*	*0.54*	*0.50*	*0.196*	*0.218*
Dragline	*19*	*0.32*	*0.22*	*0.032*	*0.040*
Haul trucks[a]	*28*	*0.52*	*0.08*	*0.033*	*0.037*
Light- and medium-duty vehicles[a]	*11*	*0.65*	*0.16*	*0.074*	*0.078*
Scrapers[a]	*14*	*0.49*	*0.07*	*0.026*	*0.021*
Graders[a]	*7*	*0.48*	*0.10*	*0.055*	*0.041*
Coal storage piles[a]	*27*	*0.61*	*0.08*		
Exposed areas[a]	*10*	*0.67*	*0.06*		

[a] *Expressed as fractions of SP (<30 μm) rather than TSP.*

The variation of FP/TSP ratios was much wider, from 0.026 to 0.196. The 0.196 value for bulldozing overburden appeared to be an anomaly, however. Exclusion of this value makes the range 0.026 to 0.074. The fairly consistent ratios of FP and IP to TSP for different sources indicate that the size distribution is similar in all fugitive dust sources at mines.

Three different particle sizing methods were evaluated early in the study—cascade impactors, dichotomous samplers, and microscopy. Side-by-side comparison of these methods showed that the cascade impactors and dichotomous samplers gave approximately the same particle size distributions. In contrast, the microscopy data varied widely. It was concluded that microscopy is a useful tool for semiquantitative estimates of various particle types, but it is inadequate for primary particle sizing of fugitive dust emissions. Despite several unresolved problems involved in the generation of fine particle data for fugitive dust sources, data from the present study are thought to be reasonable based on their consistency and the observed agreement between dichotomous and cascade impactor data.

Deposition

The emission factors in this study were all developed from sampling data obtained very near the source. Emissions are subject to deposition as distance from the source increases

A secondary objective of this study was to develop a deposition function specifically for use with the mining emission factors. Deposition rates were measured by two different methods—dustfall catch and apparent source depletion at successive distances from the source. Although initial side-by-side testing of the two methods indicated that apparent source depletion gave the better results, dustfall measurements were still taken at 5, 20, and 50 m from the source as part of the exposure profiling tests; these dustfall measurements proved to give much more reliable estimates of deposition rates during most of the sampling at the three mines.

The deposition rates by test were correlated with several potential variables such as windspeed and particle distribution. These analyses did not reveal any significant relationships that could form the basis for an empirical deposition function. Because these analyses were nonproductive and the primary method for measuring deposition (apparent source depletion in upwind-downwind sampling) gave unusable results, a deposition function cannot be presented at this time

If additional testing is performed to develop a deposition function, dustfall measurement is recommended as the sampling method. The main shortcoming of dustfall as a measurement of deposition is that it measures total particulate rather than the amount of deposition in the TSP or IP range.

Control Measures

Two mining control measures—application of water and application of a calcium chloride solution—were evaluated by comparing emission rates from treated and untreated areas. Testing was done on the same or adjacent lengths of roadway under similar traffic and meteorological conditions so that the only substantial variable between test pairs was application of the dust control. The number of tests available for determination of control efficiencies was limited and statistically inadequate.

The results of 1-hour test periods immediately after watering (shown in Table 4) indicate that water at a rate of 0.05 gal/yd^2 reduced particulate emissions from haul roads by 60 to 70 percent and those from coal loading by 78 percent. Maintenance of that range of efficiencies would require the reapplication of water at an approximate frequency of once per hour. Results showed that calcium chloride still reduced particulate emission rates from an access road by 95 percent about three months after its application, but no information was obtained on the life expectency of this control. Application rate for the 30 percent solution of calcium chloride was 0.6 gal/yd^2.

Table 4 shows that control efficiencies for IP were essentially the same as those for TSP, whereas those for FP were slightly lower. The 60 to 70 percent control efficiency for watering haul roads was higher than the 50 percent widely reported in the technical literature, possible because testing was done right after the water was applied.

Comparison of Sampling Techniques

The two major sampling techniques, exposure profiling and upwind-downwind sampling, were run simultaneously on a common source for several tests to determine relative performance.

Profiling towers and the upwind-downwind samplers (hi-vols and dichotomous samplers) were placed 5, 20, and 50 m downwind of the sources to measure the decrease in particulate flux with distance. This design allowed the indirect determination of deposition rates. Duplicate hi-vols and dichotomous samplers were placed at each of three distances, and two additional hi-vols were located 100 m downwind of the source. Upwind samplers consisted of three hi-vols and a dichotomous sampler,

Table 4. *Control Efficiencies for Watering and Calcium Chloride*

Source	*Control measure*	*Size fraction*	*No. Tests*		*Avg. Emission rate, lb/VMT*[a]		*Mean control eff., %*
			Uncontrolled	*Controlled*	*Uncontrolled*	*Controlled*	
Haul road, Mine 2	*Watering*	*TSP*[b]	*4*	*4*	*5.3*	*2.2*	*59*
		IP	*4*	*4*	*2.8*	*1.1*	*61*
		FP	*4*	*4*	*0.19*	*0.08*	*58*
Haul road, Mine 3	*Watering*	*TSP*[b]	*4*	*5*	*16.3*	*5.0*	*69*
		IP	*4*	*5*	*8.9*	*2.4*	*73*
		FP	*3*	*5*	*0.21*	*0.10*	*54*
Coal ldg., Mine 3	*Watering*	*TSP*	*5*	*9*	*0.188*	*0.042*	*78*
		IP	*4*	*9*	*0.053*	*0.010*	*81*
		FP	*4*	*9*	*0.0028*	*0.0009*	*68*
Access road, Mine 1	*Calcium chloride*	*TSP*[b]	*3*	*2*	*6.8*	*0.35*	*95*
		IP	*3*	*2*	*5.4*	*0.34*	*95*
		FP	*3*	*2*	*0.74*	*0.09*	*88*

[a] *Emission factors for coal loading are expressed in units of lb/ton.*
[b] *Measured as SP, the size fraction less than 30 μm.*

all located 20 m from the upwind edge of the source.

Haul trucks and scrapers were selected for sampling in the comparison study. Because they are ground-level moving point sources (line sources) that emit from relatively fixed boundaries, both sampling methods were applicable and the required extensive sampling array could be located without fear of the sources changing location. Also, haul trucks and scrapers are two of the largest fugitive dust sources at most surface coal mines.

Five tests of each source were run over a 15-day period. All five tests of each source were performed at the same site, so only two sites (one for each source) and one mine were involved in the comparison study.

These data were subjected to Analysis of Variance (ANOVA) to evaluate whether differences in emission rates by sampling method, source, and downwind distance were statistically significant. Sampling method and downwind distance were found to have significant effects ($\sigma = 0.20$) on both TSP and IP emission rates; emission source (haul truck or scraper) was not a significant variable. The emission rates produced by profiling averaged 24 percent higher for TSP and 52 percent higher for IP than corresponding upwind-downwind emission rates, according to the ANOVA results.

Both methods of sampling showed large overall reductions in TSP and IP emission rates with distance. In 6 of 10 tests, however, profiling showed lower emission rates at the closest sampling sites (5 m) than at the middle sites (20 m). These inverted values were attributed to a systematic bias between measurements taken by two contractors, each of whom operated one of these profilers. The reduction of IP emission rates with distance was surprising, because very little deposition of sub-15 μm particles was expected over a 50-m interval.

The reason for the relatively poor comparisons between emission rates obtained by the two sampling/calculation methods was traced primarily to the precision of the samplers. It was not possible to establish from the data which sampling method was more accurate because the paired results were compared with each other rather than a known standard. Error analyses performed, after the side-by-side sampling led to the conclusion that the accuracy of state-of-the-art testing of fugitive emissions is ±25 to 50 percent with either of these two sampling methods.

Conclusions

Resulting Emission Factors

The emission factors resulting from this study (Table 5) are in the form of equations with correction factors for independent variables that were found to have a significant effect (generally at the 0.05 risk level) on each source's emission rates. The range of independent variable values over which sampling was conducted, and for which the equations are valid, are also shown in the table. Any ambient air quality analysis using these emission factors should have some provision for considering deposition.

The 80 and 95 percent confidence intervals for TSP were presented in the report. The average 80 percent confidence interval was -20 to +24 percent, less than the relative error anticipated in the study design.

The emission factors are for uncontrolled emission rates. Control efficiencies of a few control measures were estimated in limited testing, of the report. These control efficiencies should be applied to the calculated emission factors in cases where such controls have been applied or are anticipated.

A comparison of the emission factors developed in this study with others based on actual testing in surface coal mines indicated ratios of new to existing factors ranging from 0.4 to 2.2.

Limitations to Applications of Factors

Although these emission factors were designed to be widely applicable through the use of correction factors, the following limitations should be considered in their application:

1. The factors should be used only for estimating emissions from Western surface coal mines. There is no basis for assuming they would be appropriate for other types of surface mining operations, or for coal mines located in other geographic areas, without further evaluation.
2. Correction factors used in the equations should be limited to values within the ranges tested (see Table 15-1 of the full report). This is particularly important for correction factors with a large exponent, because of the large change in the resulting emission factor associated with a change in the correction factor.
3. These factors should be combined with a deposition function for use in ambient air quality analyses. After evaluation of the deposition data from this study, no empirical deposition function could be developed. Any function subsequently developed from these data should have provision for further deposition beyond the distance of sampling in this study (100-200m).
4. The factors were obtained by sampling at the point of emission and do not address possible reductions in emissions from dust being contained within the mine pit.
5. As with all emission factors, these mining factors do not assure the calculation of an accurate emission value from an individual operation. The emission estimates are more reliable when applied to a large number of operations, as in the preparation of an emission inventory for an entire mine. The emission

Table 5. *Summary of Western Surface Coal Mining Emission Factors*

Source	TSP/IP	Prediction equation for emission factor	FP fraction of TSP	Units	Range of correction parameters
Drilling	TSP	1.3	None	lb/hole	None
Blasting	TSP	$\frac{961\ A^{0.8}}{D^{1.8}\ M^{1.9}}$	0.030	lb/blast	A = area blasted, ft^2 = 1076 to 103,334 M = moisture, % = 7.2 to 38
	IP	$\frac{2550\ A^{0.6}}{D^{1.5}\ M^{2.3}}$			D = depth of holes, ft = 20 to 135
Coal loading	TSP	$1.16/M^{1.2}$	0.019	lb/ton	M = 6.6 to 38
	IP	$0.119/M^{0.9}$			
Bulldozing, coal	TSP	$78.4\ s^{1.2}/M^{1.3}$	0.022	lb/h	s = silt content, % = 6.0 to 11.3
	IP	$18.6\ s^{1.5}/M^{1.4}$			M = 4.0 to 22.0
Bulldozing, ovb.	TSP	$5.7\ s^{1.2}/M^{1.3}$	0.105	lb/h	s = 3.8 to 15.1
	IP	$1.0\ s^{1.5}/M^{1.4}$			M = 2.2 to 16.8
Dragline	TSP	$0.0021\ d^{1.1}/M^{0.3}$	0.017	lb/yd^3	d = drop distance, ft = 5 to 100
	IP	$0.0021\ d^{0.7}/M^{0.3}$			M = 0.2 to 16.3
Scrapers	TSP	$(2.7 \times 10^{-5})s^{1.3}W^{2.4}$	0.026	lb/VMT	s = 7.2 to 25.2 W = vehicle weight, tons
	IP	$(6.2 \times 10^{-6})s^{1.4}W^{2.5}$			= 36 to 64
Graders	TSP	$0.040\ S^{2.5}$	0.031	lb/VMT	S = vehicle speed, mph = 5.0 to 11.8
	IP	$0.051\ S^{2.0}$			
Light- and medium-duty vehicles	TSP	$5.79/M^{4.0}$	0.040	lb/VMT	M = 0.9 to 1.7
	IP	$322/M^{4.3}$			
Haul trucks	TSP	$0.0067\ w^{3.4}L^{0.2}$	0.017	lb/VMT	w = average number of wheels = 6.1 to 10.0
	IP[a]	$0.0051\ w^{3.5}$			L = silt loading g/m^2 = 3.8 to 254.0

[a] *Silt loading was not a significant correction parameter for the IP fraction.*

factors are also more reliable when estimating emission over the long term because of short-term source variation.

6. Appropriate adjustments should be made in estimating annual emissions with these factors to account for days with rain, snow cover, temperature below freezing, and intermittent control measures
7. The selection of mines and their small number may have biased final emission factors, but the analysis did not indicate that a bias exists.
8. The confidence intervals cited in Table 13-10 of the full report estimate how well the equations predict the measured emission rates at the geometric mean of each correction factor. For predicting rates under extreme values of the stated range of applicability of the correction factors, confidence intervals would be wider
9. Error analyses for exposure profiling and upwind-downwind sampling indicated potential errors of 30 to 35 percent and 30 to 50 percent, respectively, independent of the statistical errors due to source variation and limited sample size.
10. Geometric means were used to describe average emission rates because the data sets were distributed lognormally rather than normally. This procedure makes comparison with previous emission factors difficult, because previous factors were all arithmetic mean values.
11. Wind erosion emission estimates should be réstricted to calculation of emissions relative to other mining sources; they should not be included in estimates of ambient air impact.

Recommendations

A comprehensive study that has evaluated alternative sampling and analytical techniques is bound to identify areas where additional research would be valuable. Also, some inconsistencies surface during the data analysis phase, when it is too late to repeat any of the field studies. Therefore, a brief list of recommendations for further study is presented here.

1. Sampling at Midwestern and Eastern coal mines is definitely needed so that emission factors applicable to all surface coal mines are available.
2. A resolution of which deposition function is most accurate in describing fallout of mining emissions is still needed. Closely related to this is the need for a good measurement method for deposition for several hundred meters downwind of the source (dustfall if recommended for measurements up to 100 or 200 m). In the present study, both the source depletion and dustfall measurement methods were found to have deficiencies.
3. A method for obtaining a valid size distribution of particles over the range of approximately 1 to 50 μm under near-isokinetic conditions is needed for exposure profiling. The method should utilize a single sample for sizing rather than building a size distribution from fractions collected in different samplers.
4. The emission factors presented herein should be validated by sampling at one or more additional

Western mines and comparing calculated values with the measured ones.

5. Standardized procedures for handling dichotomous filters should be developed. These should address such areas as numbering of the filters rather than their petri dishes, proper exposure for filters used as blanks, transporting exposed filters to the laboratory, equilibrating filters prior to weighing, and evaluation of filter media other than Teflon for studies where only gravimetric data are required.
6. One operation determined in the study design to be a significant dust-producing source, shovel/truck loading of overburden, was not sampled because it was not performed at any of the mines tested. Sampling of this operation at a mine in Wyoming and development of an emission factor would complete the list of emission factors for significant sources at Western coal mines (see Table 2-1 of the full report).
7. Further study of emission rate decay over time from eroding surfaces is needed. In particular, more information should be obtained on the effect of wind gusts in removing the potentially erodible material from the surface during periods when the average windspeed is not high enough to erode the surface
8. More testing of controlled sources should be done so that confidence in the control efficiencies is comparable to that for the uncontrolled emission rates.

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The complete report, entitled "Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources," (Order No. PB 84-170 802; Cost: $23.50, subject to change) will be available only from:

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