

Emission Factors for Abrasive Materials

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ABSTRACT

Abrasive blasting materials, such as coal slag garnet and copper slag, are often used for cleaning metal surfaces to remove rust and to prepare a surface before the application of a coating. The pre-blast and post-blast (spent) abrasive materials contain traces of heavy metal constituents such as Cr, Mn, Ni, Pb Fe, and Ba. Hence, the health risk associated with the resultant particulate emissions is a source of concern.

Emission factors are often used to estimate emissions from such industrial operations. Since the development of the emission factors for uncontrolled abrasive blasting operations, prepared for US EPA in 1995, several attempts were made to derive emission factors for particulates. This paper will provide an overview of several relevant studies – where emission factors were proposed/ and or could be used to determine particulate emission factors. The studies reviewed include wind tunnel pilot-scale studies which simulate open air activities such as paint removal of bridges and vessels. The studies also include semi-enclosures (similar to spray booths with open ends). Lastly, the paper will propose new emission factors for several abrasive blasting materials that are based on the analysis of airborne experimental data rather than pre-blast test data.

INTRODUCTION

Abrasive blasting materials such as sand, coal slag, iron grit, steel shot, silica, and garnet are used to remove rust, scale, and coatings (paint) from bridges, vessels, vehicles, and equipment. Several factors are considered before an abrasive material is selected. They include properties such as material hardness and shape and the desired level of cleanliness. Environmental and economic considerations also play a role. While blasting with abrasive materials is often conducted in contained environments, there are situations where state agencies allow unconfined blasting.¹ In both scenarios particulates are released to the environment, and, therefore, there is a need to estimate the potential risk on humans and the environment from the toxic metals in the particulate releases from this unit operation.

At this time the US EPA compilation of emission factors only contains emission factors for sand.² The EPA report includes data for total particulates (TPM), particulates less than 10 μ m aerodynamic diameter (PM10), and particulates less than 2.5 μ m aerodynamic diameter (PM2.5). It also includes data for toxic metals for the 3 particle sizes. The University of New Orleans studied the emissions from a number of abrasives of interest. However, their focus was on total particulate emissions.^{3,4} Aspects of other studies were presented in a previous paper which discussed development of emission factors based on pre-blast (virgin) abrasive composition data.⁵

This paper will present newly developed emission factors for abrasive materials based on airborne data. Two studies were extensively used for particulate matter data and composition data. These are the revised source test report for uncontrolled abrasive blasting operations (only silica sand) published in 1995 (USEPA 1995),⁶ and the National Institute of Occupational Safety and Health (NIOSH) Phase 1 and Phase 2 reports published in 1998 (NIOSH 1998). The NIOSH reports were used to develop metal emission factors for six abrasive materials based on respirable particulates (PMresp.) collected in that study.^{7,8}

BODY

Development of Emission Factors

This section is subdivided into several parts. First, the test conditions, sample collection, and method used to calculate the particle fractions and metal composition are described for the EPA 1995 report.⁶ Experimental procedures and test method in the NIOSH 1998^{7,8} reports are described. The steps that were used in this paper to calculate the emission factors for the PM_{resp.} and Preps. metal emission factors are presented. Lastly, the emission factor for silica derived from the NIOSH sponsored study will be compared to those generated in the US EPA sponsored study.⁶ Emission factors for coal slag, copper slag, garnet, and steel grit derived from the NIOSH1998 reports will also be presented.

1. EPA 1995 Report

The EPA revised source test report published in 1995 (EPA 1995) was aimed at developing uncontrolled fugitive emission factors for abrasive blasting operations. Silica sand (-30/+50 mesh) was selected for the study and only one type of material was used throughout the pilot-scale tests which were performed in a low speed wind tunnel 21 m (66 ft) long with a 2.4-x 2.4-m (8-x 8-ft)-square cross section constructed of durable wood. The particulate and metal emissions resulting from surface cleaning a clean surface, a painted surface, and an oxidized surface were documented in the EPA1995 report.⁶ High capacity fans were used to induce a near steady state air flows through the tunnel at average (centerline) speeds of 2.2 m/s (5mph), 4.5 m/s (10 mph), 6.7 m/s (15 mph). These speeds are representative of actual industrial operating conditions. Twenty sampling ports were installed in the tunnel walls made of marine wood. They were installed upstream of the fan in accordance with EPA reference Method 1). The primary air sampling device in this test plan is an Andersen High Capacity Stack Sampler (HCSS) fitted with a cyclone pre-separator to remove the larger particles. This is a four-stage inertial sizing unit which separates the particles into four fractions (nominally >10, 5 to 10, 1-5, and < 1 μ m). The impactor consists of 2 impactor stages followed by a cyclone and back-up filter.⁶

The particle size distribution for the nine combinations of metal surface and wind speed was obtained in several steps:

- Total particulate matter emissions were determined using EPA Reference Method 5.
- PM₁₀ and PM_{2.5} size distributions were determined using a “modified version of EPA Reference Method 201A, Determination of PM₁₀ Emissions (Constant sampling Rate Procedure).” These size fractions were determined based on the cumulative particle distribution (% less than designated D₅₀ size values), which were graphically drawn for the 4 stages.

[PM₁₀ (or PM_{2.5}) are those particles less than or equal to 10 (or 2.5) micrometers in aerodynamic diameter (equivalent unit density sphere). D₅₀ is the particle diameter associated with 50% collection efficiency for each inertial sizing stage as determined by theoretical calculations or by calibration.]⁶

- The average cumulative percent values for paired HCSS runs were used to calculate the cumulative percent values for the PM₁₀ and PM_{2.5} sizes.
- The average cumulative percent values for PM₁₀ and PM_{2.5} were multiplied by the total particulate concentration from Method 5 to determine the respective size concentrations.

The metals for total HAP and each of the particulate fractions from HCSS impactor stages were analyzed for 11 HAP metals including arsenic (Ar), beryllium (Be), cadmium (Cd), chromium (Cr), manganese (Mn), nickel (Ni), lead (Pb). Results for iron (Fe) were also reported. Metal Emissions were determined using the EPA method in reference 9.

From the data one infers that most of the chromium is in the PM 10 fraction (<10µm). Also, the PM10 size fraction (i.e., percentages of particulate emissions, <10µm) appear to be independent of the surface the abrasive is being applied to. However, that was not the case for the PM2.5 fraction, as the percentage of particulate emissions less than 2.5 µm was close to half that of PM10. The percentage of total Ni that was PM10 (89 % to 99%) also appeared to be independent of the surface being cleaned. That was not the case for Pb. The percentage of PM10 Ni from the clean surfaces was around 99%, whereas for the painted and oxidized surfaces it varied between 37 % and 73 % of total PM Ni. The percentage of PM10 Fe and Mn varied within similar ranges. The PM2.5 metal percentages were always lower than the corresponding PM10 percentages, and the ranges varied from one metal to another.

2. The NIOSH 1998 Reports.

The study^{3,4} was performed in two Phases:

Phase 1 of the study was an enclosed 3.6 m (12ft) long with a 2.4-x 2.4-m (8-x 8-ft) square cross walk-in room, with a Torit-Donaldson 164 m³/min (5800 cfm) particulate (dust) collection system. Blast cleaning air pressures at the nozzle ranged between 621 – 690 kPa (90 - 100 psi) at the blast nozzle and held constant for each abrasive. Eleven generic types of abrasives were studied. They included 10 silica sand abrasives (three with dust suppressant); nine coal slags (two with dust suppressant); 10 copper slags (one with dust suppressant); two nickel slags, 13 garnet abrasives, two staurolite abrasives, four steel grit abrasives, one specular hematite abrasive, one olivine abrasive, one crushed glass abrasive. Each abrasive material was used to clean, to “Near White Metal” blast conditions, a total of 72 square feet (a total of 18 surfaces). Each substrate cleaned was a 0.50 x 61 x 61 cm² (3/16 x 24 x 24 in) section uncoated carbon steel plate containing intact mill scale.

Phase 2 of the abrasive blasting study was performed in a customized containment and ventilation system. Fewer slags were tested than in Phase 1. They included one coal slag, one copper slag, 2 silica sand abrasives, one garnet abrasive, one steel grit abrasive, and one staurolite abrasive. The surface cleaned contained corrosion products and eight areas similar in appearance and condition were selected. The volume of air supply was maintained using a 10.6 m³/min (375 cfm) compressor and the blast cleaning air pressure at the nozzle was held constant between each abrasive at 621 – 690 kPa (90 – 100 psi) as in the Phase 1 report. The target air flow was maintained between 0.25 – 0.36 m/s (50 to 75 fpm). These values are somewhat higher than those used in the Phase 1 study. Several generic types of abrasives were studied. The substrate was made of the side of a steel barge in dry “temporary” dock. (The study generated a third report which discusses the results in the Phase 1 and Phase 2 reports.)

In both the Phase 1 and Phase 2 NIOSH reports, samples were collected on filters in four locations within the containment. The positions include:

- Make-up air side of containment (fixed location)
- Operator area (fixed location)
- Exhaust (ventilation) area of containment (fixed location)
- On the operator, within the breathing zone

The composition of the airborne metals was determined from samples collected at 2 liters per minute on a 37mm, 0.8 micron pore mixed cellulose ester membrane filter media. The element analysis was done using NIOSH Method 7300. However, respirable particulate matter (PM_{resp.}) were collected, in the NIOSH study, using MSA 10 mm nylon cyclones equipped with 37 mm, 0.5 µm pore pre-weighed PVC filter media, at a flow rate of 1.7 L/min. Analysis of respirable PM was conducted in accordance with NIOSH Method 0600. PM_{resp.} is a sub-fraction of thoracic fraction, which is a sub-fraction of the inhalable particulates.

Calculation of Emission Factors for Silica Sand and Other NIOSH 1998 Abrasives

The NIOSH reports did not provide emission factors for PM_{resp.} or emission factors for Preps. metal for the abrasive materials. That was not the objective of that study. The reports provided concentration results in four locations (zones): Fixed station 1, 2, 3, and operator breathing zone. The flow and composition data at the exhaust (Fixed station No. 3) were used to calculate PM_{resp.} and PM_{resp.} metal concentrations and for developing the emission factors. The emission factors for Cr, Mn, Ni, and Pb were calculated using Equation 1.

Equation 1 $EF_i = ER/m = [(V_i * C_i) / 10^3] / m$

where:

- EF_i = emissions factor of metal pollutant i associated with PM_{resp.}, mg/kg-abr.
- ER = emission rate, mg/min
- V_i = air flow rate, m³/min
- C_i = concentration of metal in exhaust PM_{resp.}, µg/m³
- m = mass of abrasive used, kg/min
- 10^3 = converts µg to mg

PM₁₀, PM_{resp.} and Metals EFs for Silica Sand

Figures 1 through 4 provide PM_{resp.} metal emission factors for Cr, Mn, Ni, and Pb for silica sand. These values were derived using Equation 1 above. The figures also list the PM_{resp.} emission factors for the 12 silica abrasives used in the NIOSH 1998 study. Figures 5 through 8 provide similar data from the EPA 1995 report, and Figures 9 through 12 the concentration of the metals in the bulk, PM_{resp.} and PM₁₀. Table 13 list the emission factors derived for six abrasive materials, using the data in NIOSH 1998 reports for Cr, Mn, Ni, and Pb. The values represent 95% upper confidence level (UCL) of the mean. The statistical package ProUCL version 3.4 was used. The software was recently updated and version 4.0 can be downloaded from the USEPA website.

Discussion and Conclusion

The PM_{resp.} metal emission factors in Table 13 are each based on four or more data points: nine coal slags; five copper slags; seven garnet abrasives; twelve silica sand abrasives (three with dust suppressant; and four steel grit abrasives. Table 13 shows that the PM_{resp.} Cr and Mn emission factors

for copper slag and steel grit abrasives are higher than for silica or garnet. The PM_{resp.} Pb emission factor is also higher for copper slag than for the other four abrasives in Table 13, which is not surprising considering the pre-blast composition of such slags. As for the Ni, garnet has the lowest emission factor, and coal slag the highest. The concentration of Cr at the exhaust location in the Phase 2 report was higher than in the phase 1 report, where several non-detect values were reported. For these cases, we used the limit of detection (LOD) value. The LOD values for Cr in silica sand in the NIOSH Phase 1 report varied between 10.2 and 10.7 $\mu\text{g}/\text{m}^3$. These values are highlighted in red in Tables 1 through 4.

In the next several paragraphs, the data for silica sand in the US EPA 1995 report will be compared with the silica data from the NIOSH 1998 reports. Also, the 95 % UCL emission factors in Table 13 will be compared with emission factors obtained using pre-blast (bulk) metal composition.

Tables 1 (NIOSH data) and Table 5 (USEPA data) show that the variation in the concentration of PM_{resp.} and PM₁₀ leaving the exhaust in both studies are comparable. Except for one data point in each study, the PM₁₀ concentration values ranged between 6.44 and 74.0 mg/m^3 for the USEPA data and between 4.0 and 71.0 mg/m^3 for the NIOSH data. The PM_{resp.} and Cr concentration values in both studies are also comparable. One finds this to be the case for the concentrations of Ni (Tables 3 and 7), and Pb (Tables 4 and 8). Tables 2 and 6 when compared show that the Mn level in PM_{resp.} (NIOSH data) to be an order of magnitude higher than in PM₁₀ (USEPA data). This also explains why the concentration of Mn in PM_{resp.} ($\mu\text{g-Cr}/\text{g-PM}_{\text{resp.}}$) is much higher in the NIOSH data. Table 10 (column 5) provides a comparison of the ratio of PM_{resp.-Mn} to PM_{resp.} (column 4) and ratio of PM_{10-Mn} to PM₁₀ (column 5). It also compares similar ratios (concentration values) for virgin (pre-blast) bulk Mn and Virgin (post-blast) bulk Mn. Tables 9, 11, and 12 show that the levels (concentrations) of metal in PM_{resp.} for Cr, Ni, and Pb are comparable in the two studies.

We can conclude from the limited metal data analyzed that the concentration of the metals in the airborne (PM_{resp.} and PM₁₀) fractions is much higher than in the starting (virgin) abrasive materials. Also, the metal concentrations leaving the exhaust for Cr, Ni, and Pb vary within comparable ranges for these particle fractions. Table 2 shows that PM_{resp.} Mn emission concentrations at the exhaust vary between 2.8 and 16.3 $\mu\text{g}/\text{m}^3$, even though one silica sand abrasive was used. These values fall within the range of 4.6 and 947 $\mu\text{g}/\text{m}^3$, for the 12 silica abrasives. Abrasive SS-06 (Table 1) had a level of Mn less than 5 $\mu\text{g}/\text{m}^3$, whereas, Mn concentration for SS-02 was 48 $\mu\text{g}/\text{m}^3$, and for SS-04 947 $\mu\text{g}/\text{m}^3$.

Can we estimate PM₁₀ metal emission factors from data based on PM_{resp.}? A review of Tables 1 through 4 shows that the PM₁₀ Cr, Ni, and Pb emission factors are higher than those for corresponding PM_{resp.} metal emission factors by less than a factor. Whereas, the PM₁₀ Mn emission factors in Table 6 are comparable to those for PM_{resp.} in Table 2. This is the direct result of the higher level of Mn concentration in PM_{resp.} relative to PM₁₀ manganese concentration. The USEPA data did not provide data for PM_{resp.}; however, we calculated PM_{4.0} fraction using Figures 1 through 6, in reference 6, which graphically represent cumulative percent and particle size D₅₀ particle size (microns) for the silica sand abrasive used in that study. Each PM₁₀ concentration (mg/m^3) was divided by the corresponding PM_{4.0} concentration. The arithmetic average value was around 5.0; however, the maximum value of this ratio was 14 and the minimum around two. The concentration of PM_{4.0} in the exhaust is a good indicator of the concentration of PM_{resp.} (even though these two PM size fractions are defined differently). This conclusion was reached after computing these PM₁₀, PM_{4.0}, PM_{2.5}, and PM_{resp.} concentrations simultaneously using a cascade impactor data reductions spreadsheet described in reference 10. However, the log-normal distribution (Probit Method) did not fit well more than half of the the HCSS cascade impactor data⁶ (four data points). The PM concentration values derived using the spreadsheet¹⁰ are not presented in this paper.

The experimental set up and operating conditions are likely to be important in defining the results from an abrasive test. For example a shorter wind tunnel (and computational approach) resulted in more total particulates than documented in the US EPA 1995 report.¹¹ Also, the air flow rate (m³/min) seems to be a relevant factor. There was strong linear negative correlation between PM4.0 concentration (mg/m³) and air flow rate -- after one of the 9 data points (129.6 mg/m³) was removed. This would indicate that less PM4.0 was collected at the higher flow rates. PM10 concentration with gas flow rate also decreased with gas flow rate; however, the correlation was weaker than in the case of PM4.0. However, TPM showed a small positive trend with gas flow rate. All the nine data points for TPM were use. The resultant linear equation predicted well TPM concentration except for one data point.

In the absence of a standard protocol for performing abrasive testing, there is a need to understand how the experimental parameters such as gas flow rate and chamber design affect the PM values and emission factors, so that one can also benefit from data generated under different experimental conditions.

Lastly, The 95 % UCL PM_{resp.} metal emission factors developed here are likely to under estimate the PM10 metal emission factors for the six abrasives. The ratio of PM10 to PM_{resp.} (or the ratio of PM10 to PM4.0) for an abrasive material may provide a simple correction factor.

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KEY WORDS

Abrasive Blasting, Particulate Matter, Emission Factors, PM10, Respirable PM, Toxic Metals, Heavy Metals

ACKNOWLEDGEMENTS

Thanks are due to M.Greskevitch at NIOSH, Morgantown WV for the helpful discussions regarding the NIOSH 1998 reports and to P.T.O. O'Shaughnessy at University of IOWA for providing a modified cascade impactor spreadsheet to the fit the HCSS 4-stage impactor.

DISCLAIMER

This paper may not necessarily reflect official Agency policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for their use.

**Table 1. Emission Factors and PM Respirable Cr in Exhaust
(based on the NIOSH 1998 data, Refs. 7 and 8)**

NIOSH 1998 Reports	Abrasive Media	Abrasive Media (kg/min)	Exhaust Fixed Station #3 Cr Concentration ($\mu\text{g}/\text{m}^3$)	PMresp.- Cr Concentration (mg/kg-abr.)	PMresp. Emission Factor (mg/kg-abr.)	PM-Cr to PM-resp. Ratio $\mu\text{g}/\text{g}$ (ppm)
Phase 1	SS-01	2.66	10.34	0.472	3119	151
	SS-02	4.92	10.35	0.226	756	299
	SS-03	2.94	10.22	0.391	152	2566
	SS-04	2.54	14.64	0.591	426	1387
	SS-05	2.37	24.94	1.218	2545	479
	SS-06	3.03	10.49	0.384	2314	166
	SS-07	2.63	27.16	0.939	1510	622
	SSDS-01	2.81	10.72	0.394	1123	351
	SSDS-02	2.57	15.27	0.636	568	1120
	SSDS-03	2.74	9.95	0.419	630	665
Phase 2.	SS-04	8.16	63.17	0.578	2303	251
	SS-DS	9.73	46.81	0.316	485	652

**Table 2. Emission Factors and PM Respirable Mn in Exhaust
(based on the NIOSH 1998 data, Refs. 7 and 8)**

NIOSH 1998 Reports	Abrasive Media	Abrasive Media (kg/min)	Exhaust Fixed Station # 3 Mn Concentration ($\mu\text{g}/\text{m}^3$)	PMresp.- Mn Concentration (mg/kg-abr.)	PMresp. Emission Factor (mg/kg-abr.)	PM-Mn to PMresp. Ratio $\mu\text{g}/\text{g}$ (ppm)
Phase 1	SS-01	2.66	60.0	2.74	3119	878
	SS-02	4.92	47.6	1.04	756	1375
	SS-03	2.94	53.1	2.03	152	13342
	SS-04	2.54	355.7	14.35	426	33704
	SS-05	2.37	135.1	6.60	2545	2593
	SS-06	3.03	4.6	0.17	2314	73.0
	SS-07	2.63	181.7	6.28	1510	4163
	SSDS-01	2.81	92.8	3.41	1123	3034
	SSDS-02	2.57	350.8	14.61	568	25734
	SSDS-03	2.74	61.7	2.60	630	4125
Phase 2.	SS-04	8.16	947.0	8.64	2303	3752
	SS-DS	9.73	326.0	2.20	485	4536

**Table 3. Emission Factors and PM Respirable Ni in Exhaust
(based on the NIOSH 1998 data, Refs. 7 and 8)**

NIOSH 1998 Reports	Abrasive Media	Abrasive Media (kg/min)	Exhaust Fixed Station # 3 Ni Concentration ($\mu\text{g}/\text{m}^3$)	PMresp.- Ni (mg/kg-abr.)	PMresp. Emission Factor (mg/kg-abr.)	PM-Ni to PMresp. Ratio $\mu\text{g}/\text{g}$ (ppm)
Phase 1	SS-01	2.66	10.3	0.472	3119	151
	SS-02	4.92	10.4	0.226	756	299
	SS-03	2.94	10.2	0.391	152	2566
	SS-04	2.54	16.3	0.659	426	1547
	SS-05	2.37	10.4	0.507	2545	199
	SS-06	3.03	10.5	0.384	2314	166
	SS-07	2.63	15.3	0.527	1510	349
	SSDS-01	2.81	10.3	0.379	1123	337
	SSDS-02	2.57	10.3	0.430	568	757
	SSDS-03	2.74	10.0	0.419	630	665
Phase 2.	SS-04	8.16	36.1	0.329	2303	143
	SS-DS	9.73	22.4	0.151	485	311

**Table 4. Emission Factors and PM Respirable Pb in Exhaust
(based on NIOSH 1998 data, Refs. 7 and 8)**

NIOSH 1998 Reports	Abrasive Media	Abrasive Media (kg/min)	Exhaust Fixed Station # 3 Pb Concentration ($\mu\text{g}/\text{m}^3$)	PMresp.- Pb (mg/kg-abr.)	PMresp. Emission Factor (mg/kg-abr.)	PM-Pb to PM-resp. Ratio $\mu\text{g}/\text{g}$ (ppm)
Phase 1	SS-01	2.66	4.76	0.217	3119	69.7
	SS-02	4.92	10.4	0.226	756	299
	SS-03	2.94	4.09	0.157	152	1027
	SS-04	2.54	5.23	0.211	426	496
	SS-05	2.37	4.36	0.213	2545	83.7
	SS-06	3.03	3.98	0.146	2314	63.0
	SS-07	2.63	7.73	0.267	1510	177
	SSDS-01	2.81	2.06	0.076	1123	67.4
	SSDS-02	2.57	4.95	0.206	568	363
	SSDS-03	2.74	1.79	0.075	630	119
Phase 2.	SS-04	8.16	14.2	0.130	2303	56.4
	SS-DS	9.73	11.0	0.074	485	153

Table 5. Emission Factors and Cr PM10 Concentrations (data:US EPA 1995, Ref. 6)

Net sand use rate lb/min	Net sand use rate kg/min	Gas flow rate dscm/min	PM10-Cr Emission concentration µg/dscm	PM10 Concentration mg/dscm	PM10-Cr to PM10 µg/g	PM10-Cr to PM10 %	PM10-Cr Emission factor mg/kg	PM10 Emission factor kg/kg
6.5	2.95	690	10.4	73.6	141	0.0141	2.4	0.017
9.9	4.50	1802	15.9	20.2	787	0.0787	6.4	0.0081
9.8	4.45	2562	16.4	7.86	2087	0.2087	9.5	0.0045
11.5	5.23	842	24.5	36.7	668	0.0668	4.0	0.0059
10.3	4.68	1876	20	129.6	154	0.0154	8.0	0.052
9.7	4.41	2525	31.6	15.8	2000	0.2000	18	0.0091
11.3	5.14	901	7.8	32.5	240	0.0240	1.4	0.0057
9.6	4.36	1766	12.5	33.4	374	0.0374	5.1	0.014
11.5	5.23	2413	14.9	6.44	2314	0.2314	6.9	0.003

Table 6. Emission Factors and Mn PM10 Concentrations (data: US EPA 1995, Ref. 6)

Net sand use rate lb/min	Net sand use rate kg/min	Gas flow rate dscm/min	PM10-Mn Emission concentration µg/dscm	PM10 Concentration mg/dscm	PM10-Mn to PM10 µg/g	PM10-Mn to PM10 %	PM10-Mn Emission factor mg/kg	PM10 Emission factor kg/kg
6.5	2.95	690	5.4	73.6	73.4	0.0073	1.3	0.017
9.9	4.50	1802	5.1	20.2	252	0.0252	2.1	0.0081
9.8	4.45	2562	2.8	7.86	356	0.0356	1.6	0.0045
11.5	5.23	842	8.7	36.7	237	0.0237	1.4	0.0059
10.3	4.68	1876	8	129.6	62	0.0062	3.2	0.052
9.7	4.41	2525	5.2	15.8	329	0.0329	3	0.0091
11.3	5.14	901	13.7	32.5	422	0.0422	2.4	0.0057
9.6	4.36	1766	16.3	33.4	488	0.0488	6.6	0.014
11.5	5.23	2413	4.3	6.44	668	0.0668	2	0.003

Table 7. Emission Factors and Ni PM10 Concentrations (data: US EPA 1995, Ref. 6)

Net sand use rate lb/min	Net sand use rate kg/min	Gas flow rate dscm/min	PM10-Ni Emission concentration µg/dscm	PM10 concentration mg/dscm	PM10-Ni to PM10 µg/g	PM10-Ni to PM10 %	PM10-Ni Emission factor mg/kg	PM10 Emission factor kg/kg
6.5	2.95	690	8.6	73.6	117	0.0117	2.0	0.017
9.9	4.50	1802	11.1	20.2	550	0.0550	4.4	0.0081
9.8	4.45	2562	13.1	7.86	1667	0.1667	7.6	0.0045
11.5	5.23	842	11.8	36.7	322	0.0322	1.9	0.0059
10.3	4.68	1876	10.4	129.6	80	0.0080	4.2	0.052
9.7	4.41	2525	44.8	15.8	2835	0.2835	2.6	0.0091
11.3	5.14	901	7	32.5	215	0.0215	1.2	0.0057
9.6	4.36	1766	15.5	33.4	464	0.0464	6.3	0.014
11.5	5.23	2413	17	6.44	2640	0.2640	7.8	0.003

Table 8. Emission Factors and Pb PM10 Concentrations (data:US EPA 1995, Ref. 6)

Net sand use rate lb/min	Net sand use rate kg/min	Gas flow rate dscm/min	PM10-Pb Emission concentration µg/g/dscm	PM10 concentration mg/dscm	PM10-Pb to PM10 µg/g	PM10-Pb to PM10 %	PM10-Pb Emission factor mg/kg	PM10 Emission factor kg/kg
6.5	2.95	690	7.6	73.6	103	0.0103	1.8	0.0170
9.9	4.50	1802	3.3	20.2	163	0.0163	1.3	0.0081
9.8	4.45	2562	6.7	7.86	852	0.0852	3.9	0.0045
11.5	5.23	842	21.6	36.7	589	0.0589	3.5	0.0059
10.3	4.68	1876	26.1	129.6	201	0.0201	1.0	0.0520
9.7	4.41	2525	13.8	15.8	873	0.0873	7.9	0.0091
11.3	5.14	901	39.8	32.5	1225	0.122	7.0	0.0057
9.6	4.36	1766	13.9	33.4	416	0.0416	5.6	0.0140
11.5	5.23	2413	18.1	6.44	2811	0.281	8.4	0.0030

Table 9. Concentration of Cr in bulk abrasive, PMresp., and PM10

NIOSH 1998			EPA 1995	
Abrasive Media	Virgin (Pre-blast) Bulk Cr (µg/g)	Virgin (Post-blast) Bulk Cr (µg/g)	PM-Cr to PMresp. µg/g (ppm)	PM10-Cr to PM10 (µg/g)
SS-01	2.0	2.0	151	141
SS-02	2.0	2.0	299	787
SS-03	2.0	2.0	2566	2087
SS-04	2.7	3.2	1387	668
SS-05	3.7	2.6	479	154
SS-06	2.8	2.5	166	2000
SS-07	2.0	2.0	622	240
SSDS-01	2.0	2.0	351	374
SSDS-02	2.8	2.9	1120	2314
SSDS-03	2.0	2.0	665	
SS-04	3.0	5.0	251	
SS-DS	2.0	2.0	652	

Table 10. Concentration of Mn in bulk abrasive, PMresp., and PM10

NIOSH 1998			EPA 1995	
Abrasive Media	Virgin (Pre-blast) Bulk Mn (µg/g)	Virgin (Post-blast) Bulk Mn (µg/g)	PM-Mn to PMresp. µg/g (ppm)	PM10-Mn to PM10 (µg/g)
SS-01	0.13	5.0	878	73
SS-02	0.61	4.4	1375	252
SS-03	0.31	2.4	13342	356
SS-04	88	440	33704	237
SS-05	2.1	5.0	2593	62
SS-06	16	20	73	329
SS-07	14	5.8	4163	422
SSDS-01	2	6.0	3034	488
SSDS-02	80	57	25734	668
SSDS-03	0.38	3.6	4125	
SS-04	110	65	3752	
SS-DS	0.17	26	4536	

Table 11. Concentration of Ni in bulk abrasive, PMresp. and PM10

NIOSH 1998			EPA 1995	
Abrasive Media	Virgin (Pre-blast) Bulk Ni (µg/g)	Virgin (Post-blast) Bulk Ni (µg/g)	PM-Ni to PMresp. µg/g (ppm)	PM10-Ni to PM10 µg/g
SS-01	2	2	151	117
SS-02	2	2	299	550
SS-03	2	2	2566	1667
SS-04	2	2	1547	322
SS-05	2	2	199	80
SS-06	2	2	166	2835
SS-07	2	2	349	215
SSDS-01	2	2	337	464
SSDS-02	2.5	3.3	757	2640
SSDS-03	2	2	665	
SS-04	2.0	2.0		
SS-DS	2.0	2.0		

Table 12. Concentration of Pb in bulk abrasive, PMresp., and PM10

NIOSH 1998			EPA 1995	
Abrasive Media	Virgin (Pre-blast) Bulk Pb (µg/g)	Virgin (Post-blast) Bulk Pb (µg/g)	PM-Pb to Preps. µg/g (ppm)	PM10-Pb to PM10 µg/g
SS-01	0.89	0.84	69.7	103
SS-02	0.39	0.57	299	163
SS-03	0.33	0.54	1027	852
SS-04	0.47	1.0	496	589
SS-05	0.62	0.67	83.7	201
SS-06	0.64	0.6	63.0	873
SS-07	0.2	0.25	177	1225
SSDS-01	0.41	0.38	67.4	416
SSDS-02	1.3	1.2	363	2811
SSDS-03	0.42	0.45	119	
SS-04	2	2	56.4	
SS-DS	2	2	153	

Table 13. Emission factors for PM_{resp}. Metals.

Emission Factors – 95 % UCL of mean				
Abrasive Materials	Chromium (mg/kg-abr.)	Manganese (mg/kg-abr.)	Nickel (mg/kg-abr.)	Lead (mg/kg-abr.)
Coal Slag	7.82	20.4	6.65	0.99
Copper Slag	28.2	218	4.75	48.3
Garnet	2.51	261	0.684	0.224
Silica Sand	0.71	9.65	0.476	0.232
Steel Grit	22.5	125	11.6	0.15