Characteristics of Fugitive Dust Generated from Unpaved Mine Haulage Roads

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ABSTRACT

Fugitive dust is generated along unpaved mine roads from intermittent equipment traffic. Typically, the majority of such traffic consists of trucks hauling either mine product or waste from the surface mine pit and/or the processing plant. Fugitive dust generated along these unpaved mine roads includes particles of all sizes which become airborne. The potential hazards include the deleterious effects to human health of inhaled dust, traffic visibility hazards and environmental impacts on the localized area by the larger-sized visible airborne dust. Two field surveys were recently conducted to quantify fugitive dust generation and dispersion from truck traffic on unpaved and untreated mine haulage roads. For these surveys, airborne dust sampling was conducted at multiple sampling locations away from an unpaved haulage road at a limestone quarry/plant and at a coal mine preparation plant to measure the size characteristics, concentrations and dispersive behavior of the dust cloud generated from truck traffic. Results show that at least 80% of the airborne dust generated by haul trucks was larger than 10 µm. Airborne respirable, thoracic, and total dust concentrations all decreased and approached background concentrations 30.5 m (100 feet) from the road. This report describes the average and instantaneous peak dust levels that were measured up to 30.5 m (100 feet) from the haulage road.

Keywords: Unpaved mine road, fugitive dust, silica.

1. INTRODUCTION

Airborne dust is generated from various processes conducted at surface mining and mineral preparation operations. These various processes may include drilling, blasting, bulldozing, loading, transporting, dumping, crushing and processing mine ore and waste rock. The airborne dust generated can be composed of visible and invisible particulates as seen by the naked eye and can possess a significant amount of dust concentration spatial variation around the dust source. In the mining industry,

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prolonged exposure to airborne respirable coal dust and/or silica dust has been found to be responsible for the prevalence of occupational lung disease in mine workers [1, 2].

The U.S. Mine Safety and Health Administration (MSHA) enacts and enforces mine worker safety and health standards to mitigate mine worker injuries and occupational diseases. MSHA's permissible shift exposure limit is $2.0\,mg/m^3$ of airborne respirable dust for coal mine workers as defined by the Mining Research Establishment (MRE) criteria [3]. If more than 5% quartz mass is determined to be in the coal mine worker dust sample using MSHA's P7 infrared method [4], the applicable respirable dust standard is reduced to the quotient of 10 divided by the percentage of quartz in the dust. MSHA's nuisance dust limit (total dust) for non-coal miners is $10\,mg/m^3$ as defined by the American Conference of Governmental Industrial Hygienists (ACGIH) [3]. If more than 1% quartz mass is determined to be in the non-coal mine worker dust sample using NIOSH's X-ray method [4], the applicable standard is now a respirable dust standard of 10, divided by the total of the quartz percentage, plus 2. Both of these dust standards are designed to limit worker respirable crystalline silica (quartz) exposure to $0.1\,mg/m^3$ or less, *per* shift. Compliance with these dust standards is expected to reduce a worker's risk of occupational lung disease over an average life expectancy. Coal miner chest X-ray surveillance has shown a noticeable reduction in the prevalence of coal workers' pneumoconiosis (CWP) under the federal coal mine dust standards, but the incidence of CWP has not been eliminated [1].

Mine worker overexposure to the reduced dust standard due to quartz remains an ongoing problem at mining operations in the United States. The percentage of MSHA dust samples from 1996 to 2000 that were above the respirable dust standard due to quartz were 12.8% for sand and gravel mines, 12.9% for stone mines, 16.4% for non-metal mines, 17.6% for metal operations, and 19% for coal mines [5]. At surface mining operations, the occupations that have the highest frequency of exceeding the respirable dust standard are operators of mechanized equipment such as drills, bulldozers, scrapers, front-end loaders, haul trucks, and crushers [5, 6]. Most of the airborne dust generated is generally localized to a region where the equipment is operating, so dust control technology can be engineered to the particular process or environment of the equipment operator [7]. However, fugitive dust generated along unpaved haulage roads from truck traffic can encompass larger regions of the mine, possibly exposing other workers or neighboring residences to airborne dust when downwind of the haulage roads.

The most common method of fugitive dust control is road surface wetting, but others include adding hygroscopic salts, surfactants, soil cements, bitumens and films (polymers) to the road surface [7–10]. Although these road treatment methods have been shown to be effective, their application generally involves a continual maintenance process due to road degradation from traffic, dry climatic conditions, and material spillage on the road. Thus, some fugitive dust generation may be inevitable during the operation, until road maintenance is addressed.

The purpose of this study was to measure the size characteristics, concentrations, and spatial variation of airborne dust generated along unpaved and untreated mine haulage roads to examine the potential human health and safety impacts of adjoining areas around the road. Total, thoracic, and respirable airborne dust concentrations were measured with personal dust sampling equipment. Dust sampling was conducted at multiple locations – next to, 15.2 m (50 ft), and 30.5 m (100 ft) away from the haulage road – to examine the airborne dust behavior as it was transported away from the road by the wind. Multiple stage personal impactors were also used at several locations near the road and at 15.2 m (50 ft) from the road to determine the relative mass size distribution of the dust generated. Field surveys were conducted along the road of a limestone quarry and along the road of a waste dump at a coal preparation plant. The study did not encompass any larger regional U.S. Environmental Protection Agency's (EPA) high volume particulate matter (PM) type area sampling at the mines' property boundaries. This report describes the details of this study and the results attained.

2. FIELD SAMPLING APPROACH

Dust sampling surveys were conducted along an unpaved haulage road at a limestone quarry in Virginia and at a coal preparation plant in Pennsylvania. Sampling was conducted during 3-day shifts for each mining operation in July and August of 2002. The limestone quarry had mostly multiple rear-axle on-road trucks and some off-road trucks passing through the test section in both directions. The coal preparation plant had a loop traffic pattern with only loaded off-road trucks passing through the test section on their way to the dump site. Since both of these operations routinely watered their haulage roads, a 91.4 m (300 ft) test section of unpaved road was not routinely watered during the sampling shift. Dust sampling was conducted along the middle 30.5 m (100 feet) of the 91.4 m (300 ft) test section of road. On several occasions, the road section was wetted prior to the dust sampling period and then dried out during the sampling shift. Weather conditions while sampling were generally hot and dry with a variety of clear sunny skies to overcast cloud cover.

To classify the size of dust generated and its spatial variability around the road, size-selective airborne area dust sampling was conducted at multiple locations away from the road. Side-by-side sampling of total, thoracic, and respirable dust was conducted at each location away from the road. Total, thoracic, and respirable airborne dust samples were each collected on 37 mm PVC filter cassettes using MSHA Elf personal sampling pumps calibrated to the desired flow rate of the particular dust sampling classifier. Total airborne dust was collected without a classifier by sampling at 1.7 L/min using only a closed-face 37 mm filter cassette. These samplers are commonly used to measure personal inhalable fractions of dust ($0 \leq$ aerodynamic diameter $\leq 100\,\mu m$). However, when used as area samplers, their performance is dependent on wind velocity, as are other inhalable sampler designs [11]. The total dust samples tend to undersample the larger sized inhalable fractions of dust (aerodynamic diameter $> 41\,\mu m$), as defined by the American Conference of Governmental Industrial Hygienists (ACGIH) [11]. Thoracic and respirable airborne dust concentrations were measured with reasonable agreement to the American Conference of Governmental Industrial Hygienists' (ACGIH) particle size-selective sampling criteria for airborne particulate matter [12]. BGI, Inc. GK2.69 cyclones were operated at 1.6 L/min to collect the thoracic fraction of airborne dust, having a median aerodynamic diameter defined as 10 µm [13]. Dorr-Oliver 10 mm nylon cyclones were operated at 1.7 L/min to collect the respirable fraction of airborne dust, having a median aerodynamic diameter defined as 4 µm [14, 15].

Instantaneous respirable dust samplers and multi-stage impactors were also used during the study to examine real-time dust behavior and relative size distribution of the dust, respectively. Instantaneous respirable dust levels were measured with Thermo-Anderson/MIE Personal DataRAMs (PDR) (Franklin, MA) actively sampling at 1.7 L/min with a Dorr-Oliver 10 mm nylon cyclone placed upstream and a 37 mm final filter cassette downstream of the light-scattering sample chamber. Instantaneous respirable dust levels were adjusted by a calibration factor, determined by the ratio of the average gravimetric concentration to the time-weighted average of instantaneous dust levels measured with the PDR. The instantaneous measurements were electronically logged every 2 s in the DataRAM's internal memory for subsequent computer retrieval and analysis. Relative size distributions were determined using Sierra 290 series personal sampling impactors operating at 2.0 L/min at several locations. Cut stages 1 through 6 were used. The impactor size cut stages measured at 2.0 L/min correspond to 21.3 µm, 14.8 µm, 9.8 µm, 6.0 µm, 3.5 µm, and 1.55 µm aerodynamic diameters with smaller-sized particulates collected on a final filter [16].

Dust concentration spatial variation around the road was measured by placing the dust samplers on tripod-supported stands over a 7-location sampling grid. The tripod stands were extended to their maximum height of approximately 1.5 m (5 ft). Figure 1 shows the general layout of this sampling grid with respect to the expected wind direction. Since the winds are generally from the west, one tripod was positioned on the west berm side (upwind) of the road and the other 6 tripods were positioned along the east berm side (downwind) of the road, at locations next to, 15.2 m (50 ft) away and 30.5 m (100 ft) away from the road. The 15.2 m (50 ft) and 30.5 m (100 ft) east berm side tripods were placed in an uncut grassy field that was approximately 0.9 m (3 ft) high (mid-thigh level). The tripods were spaced 30.5 m (100 ft) along the road with a Young wind speed and direction instrument (Model 06201 Wind Tracker,

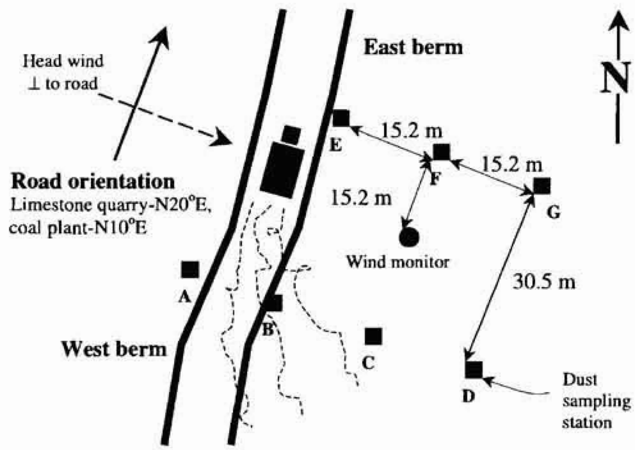

Fig. 1. Field sampling layout adjacent to haul road.

Traverse City, Michigan) located at the center of the 30.5 m (100 ft) by 30.5 m (100 ft) grid. Wind data were recorded at 30 s intervals with Metrosonics 331 data loggers (Rochester, NY). Each type of dust sampling instrument described above was used at all the sampling locations with the exception of the Sierra 290 impactors; they were only used at locations A, B, and C.

Other data collected during the surveys included traffic time study information, truck speed, road surface parameters, and silica dust content. The time study was conducted recording the time that trucks and other vehicles exited the sampling grid along the road. About half of the trucks were timed with a stopwatch as they passed the 30.5 m (100 ft) distance between sampling stations B and E to determine their average travel speed. Approximately 1 kg or more of road surface material was collected each day by sweeping up smaller samples of surface material from several spots across the road. The road surface material was analyzed for percentage of silt content (particle sizes $\leq 75\,\mu m$) [17], total moisture percent (mass basis) [18], specific gravity [19] and quartz content (X-ray method 7500) [20]. The airborne thoracic and respirable dust samples at sampling location B were also analyzed for quartz content by X-ray method 7500. The minimum airborne dust sample mass analyzed for quartz under this study was selected to be 0.2 mg. The side-by-side respirable dust samples (filters) from the personal sampler and the PDR were typically combined to achieve more than 0.2 mg of dust mass for quartz analysis. Thoracic dust samples generally had more than 0.4 mg of mass and could be analyzed individually. Many of the dust samples collected at other locations away from the road had lower masses and they were not analyzed for quartz content.

3. FIELD SURVEY RESULTS

The data collected from these two field studies have been summarized using general descriptive statistics, linear regressions, and selected days of instantaneous respirable dust data. The data analysis results are presented in numerous figures and a table which are briefly described below. Figures 2 and 3, respectively, show the airborne dust concentration statistics for the limestone quarry (LQ) and the coal plant (CP). These figures show the dust concentration means and standard deviations as categorized by their various distances from the road. Figure 4 shows the daily wind speed and direction data measured at the limestone quarry (LQ) and the coal plant (CP), presented by the median and the 10 to 90 percentile range. Figure 5 shows the

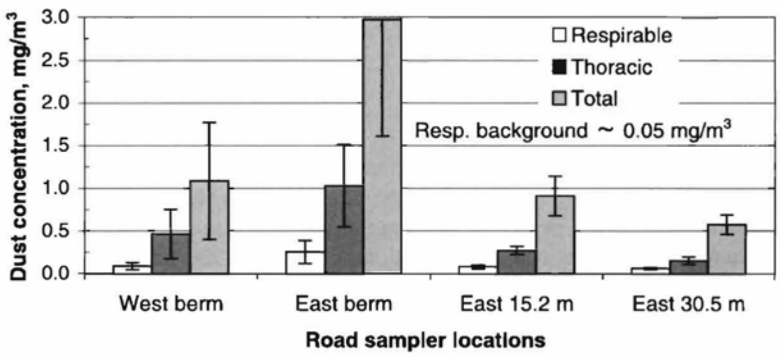

Fig. 2. Average road dust concentrations at the limestone quarry.

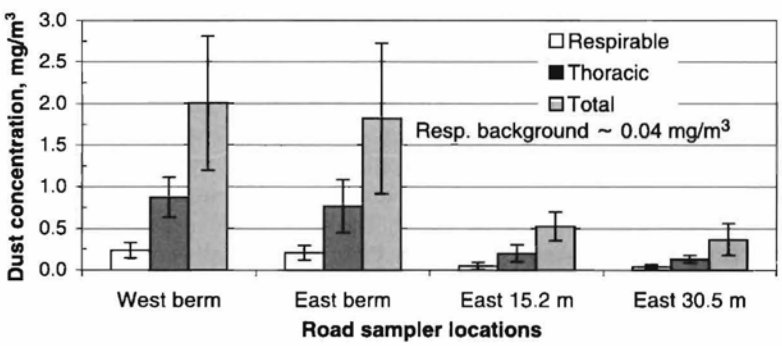

Fig. 3. Average road dust concentrations at the coal preparation plant.

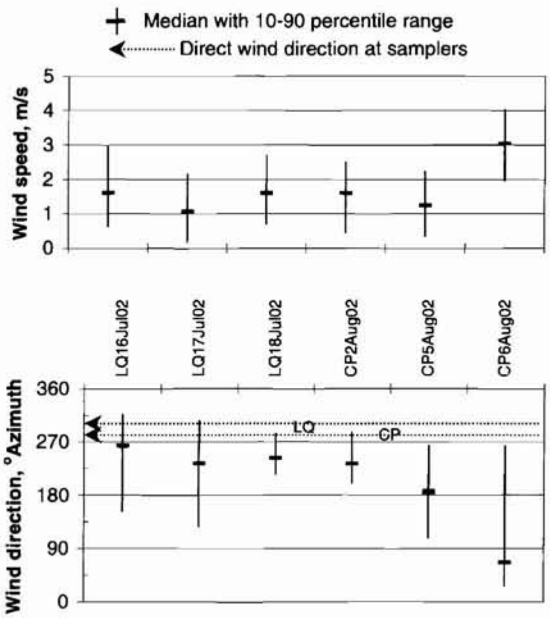

Fig. 4. Wind speed and direction data for both surveys.

instantaneous respirable dust levels for the LQ at location B and the wind data during a shift when the road was initially wet in the morning and dried out by early afternoon on July 16, 2002. Figure 6 shows the PDR time related average instantaneous respirable dust concentrations and upper confidence levels (95%) measured at sampling stations B, C, and D for 51 trucks at the CP on August 2, 2002. These time related average concentration and upper confidence level curves were calculated from instantaneous concentrations measured every 2 s over identical 1.5 min time periods when each truck passed the sampling grid. Figures 7 and 8 show the relationships between side-by-side airborne respirable, thoracic, and total dust concentrations at the LQ and CP operations, respectively. Figure 9 shows the cumulative aerodynamic diameter size distribution statistics (mean and standard deviation) measured with the impactors at both operations. Table 1 shows the road surface and dust content analysis data. Instantaneous dust data were not analyzed for truck type, speed, or load status, since distance, wind and road surface conditions (wet/dry) appeared to be the most dominant survey variables affecting dust concentrations along the road during this study.

Results from both the LQ and CP surveys show that a majority of the airborne dust generated by trucks was non-respirable, with all airborne dust concentrations notably

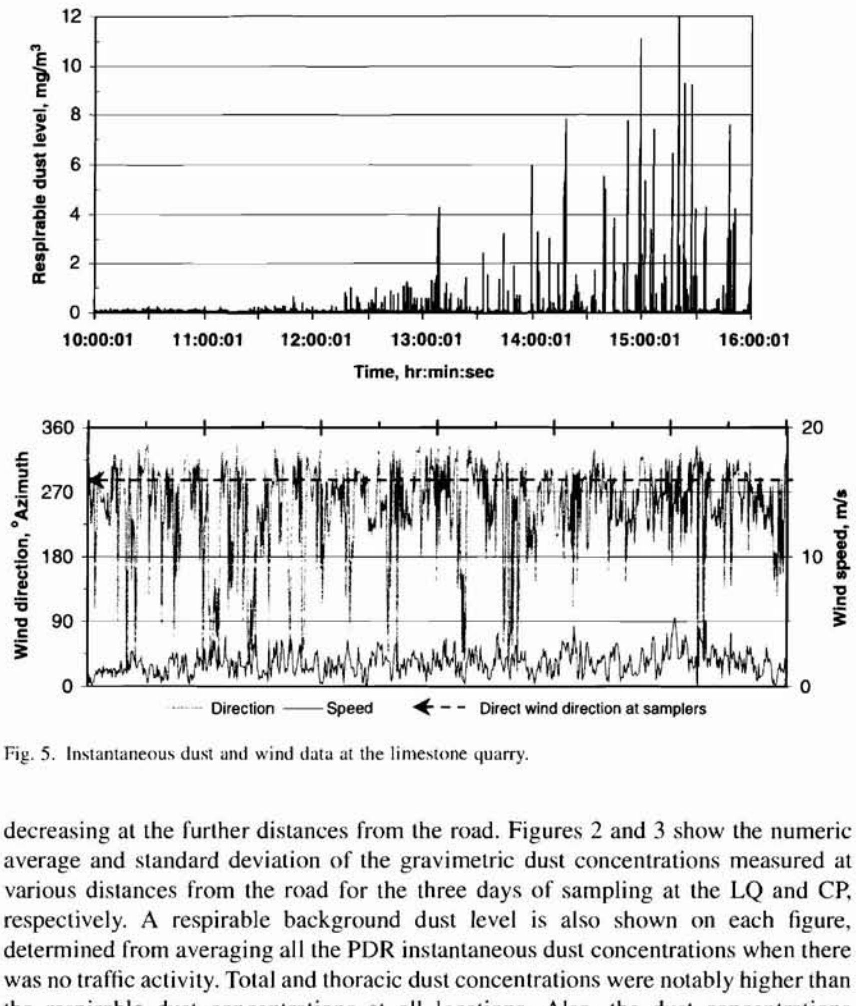

Fig. 5. Instantaneous dust and wind data at the limestone quarry.

decreasing at the further distances from the road. Figures 2 and 3 show the numeric average and standard deviation of the gravimetric dust concentrations measured at various distances from the road for the three days of sampling at the LQ and CP, respectively. A respirable background dust level is also shown on each figure, determined from averaging all the PDR instantaneous dust concentrations when there was no traffic activity. Total and thoracic dust concentrations were notably higher than the respirable dust concentrations at all locations. Also, the dust concentrations diminished most noticeably from the east-berm to the 15.2 m (50 ft) locations with a further reduction at the 30.5 m (100 ft) locations. The dust concentrations at the LQ were generally higher than at the CP, but a significantly larger number of trucks passed through the LQ test section, 230 to 308 daily, as compared to the CP which had 47 to 64 trucks (see Table 1).

During the LQ survey the winds mostly came out of the southwest towards the sampling grid, with wind speeds commonly between 0.2 (0.4) and 3.0 m/s (6.6 mph)

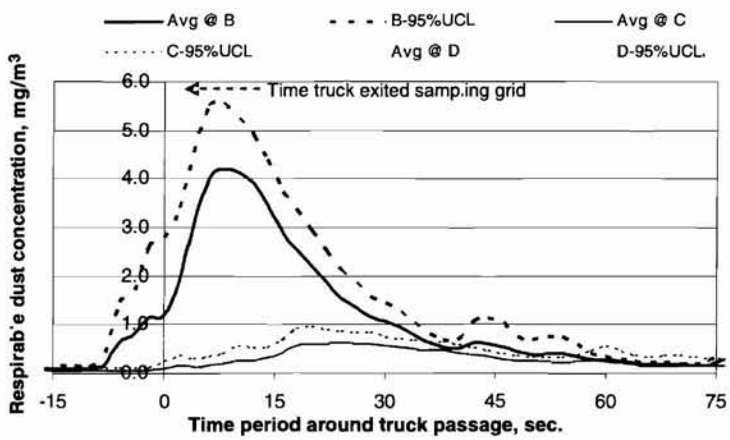

Fig. 6. Average of instantaneous truck dust levels at the coal preparation plant.

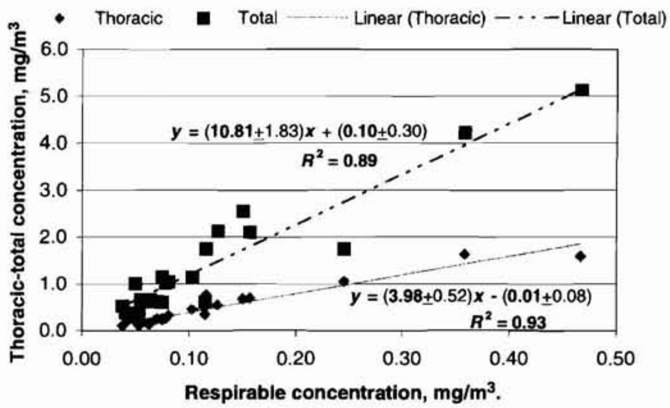

Fig. 7. Dust concentration relationships at the limestone quarry.

(see Fig. 4). The winds for the CP survey were more variable, ranging from out of the northeast to the southwest direction at speeds between 0.4 m/s (0.8 mph) and 4.0 m/s (9.0 mph) (see Fig. 4). Although the west berm sampling location was located on the side of the road most likely upwind, this sampling location was observed to be exposed to some of the dust plume spanning the width of the road behind the trucks and the occasional wind directional shifts towards the west berm side of the road. At the LQ, the wind direction tended to be mostly in the direction of the east berm side of the road and

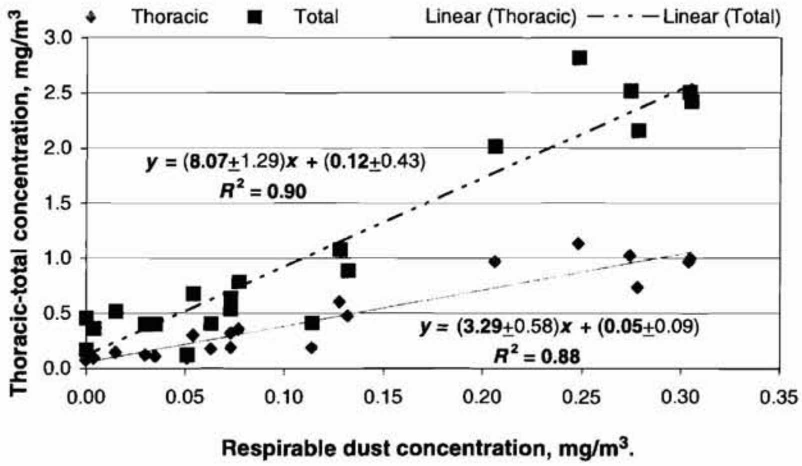

Fig. 8. Dust concentration relationships at the coal preparation plant.

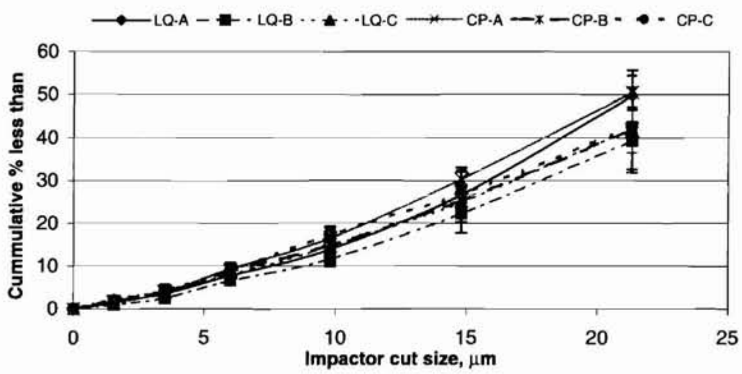

Fig. 9. Impactor cumulative size distribution data.

is reflected in the higher concentrations on that side of the road (see Figs. 2 and 4). The wind was more spread out in all directions with respect to the road at the CP and is reflected in similar dust concentrations on both sides of the road (see Figs. 3 and 4).

The highest standard deviations for the dust concentrations occurred next to the road at the source of generation. A notable amount of this variation was likely caused by wind variability and changing road surface conditions. The wind variability for

Table 1. Airborne dust and bulk road surface material analysis.

Sample analysis	Limestone quarry (LQ)			Coal plant (CP)		
	16 July 2002 *308 trucks* *24.6 ± 0.7 km/hr*	17 July 2002 *263 trucks* *26.6 ± 0.7 km/hr*	18 July 2002 *230 trucks* *24.6 ± 0.7 km/hr*	2 August 2002 *57 trucks* *24.8 ± 1.2 km/hr*	5 August 2002 *47 trucks* *21.7 ± 1.7 km/hr*	6 August 2002 *64 trucks* *28.0 ± 0.9 km/hr*
Respirable dust quartz content (%)[a]	**8.0**[b]	3.3[b]	**16.4**	12.7	NA	9.7[b]
Thoracic dust quartz content (%)[a]	4.1[b]	3.1	4.4[b]	22.3	NA	20.5
Bulk road surface quartz content (%)	2.0	2.9	3.2	17.0	NA	15.0
Bulk road surface silt, % wt. $\leq 75\,\mu m$ (%)	27.0	20.3	19.5	21.2	26.2	18.3
Bulk road surface total moisture (%)	0.26	0.17	0.06	0.65	0.68	0.54
Bulk road surface specific gravity	2.85	2.85	2.87	2.44	2.49	2.52

Note. [a]Samples analyzed from sampling station B.

[b]Quartz mass in sample between the level of quantification (0.03 mg) and detection (0.01 mg).

Bold numbers – sample masses analyzed were between 0.2 and 0.26 mg.

NA – Not analyzed.

both surveys can be seen in Figure 4. The instantaneous respirable dust level response to wind variation and road condition can be seen in Figure 5 for sampling location B on July 16. On this day, the road test section was wetted before dust sampling began and dried out by noon. The amount of respirable dust generated in the morning of the day was negligible compared to the much higher concentrations measured in the afternoon when the road was drier. In the afternoon, the instantaneous peak dust levels were highly variable and are reflective of the changing wind conditions, especially wind direction, with respect to the sampling location. As the wind blew the road generated dust towards the sampling location, the dust levels increased, while they decreased as the wind blew dust away from the sampling location.

Instantaneous dust concentration variation for truck passage notably diminishes with increased distance from the road. Figure 6 illustrates this, showing average instantaneous respirable dust concentrations with 95% upper confidence levels measured for 51 trucks over identical 1.5 min periods at location B, C, and D at the CP on August 2. Truck passage at this mine could be individually isolated into equal time periods, and on this particular day the wind was mostly directional towards the sampling grid on the east berm side of the road. As can be seen from this figure, the dust concentration quickly peaked next to the road (location B) as the trucks passed and quickly decayed as the dust cloud passed the sampler location. The dust concentrations measured further back from the road (location C – 15.2 m (50 ft), location D – 30.5 m (100 ft)) were notably lower with a less distinguished peak. Also, truck-to-truck dust concentration variation was further reduced at greater distances from the road as illustrated by the lower upper-confidence levels measured further from the road. Dust concentrations at all three locations converged to near background levels within a minute after the truck passed. Thus, the dust generated by the trucks was quickly diluted and diffused over the 30.5 m (100 ft) distance from the road.

Although the dust concentration was notably reduced with distance from the road, the relative airborne size makeup of the dust was similar over the 30.5 m (100 ft) distance from the road. Figures 7 and 8 show the respirable-to-thoracic and respirable-to-total dust concentration associations for all sampling locations at the LQ and CP, respectively. As can be seen in these figures, there were reasonably good linear relationships between the different size classification concentrations. Linear regression model parameters and their 95% confidence levels are shown next to the line of best fit with its coefficient of determination (R^2). These relationships show that, on average, the thoracic dust concentration was 4 and 3.3 times higher than the respirable dust concentration for the LQ and CP, respectively. The total dust concentration was, on average, 10.8 and 8.1 times higher than the respirable concentration for the LQ and CP, respectively. All the linear relationships had intercept parameters near zero and explained 88% or more of the data (R^2, which is the proportion of variation in y that can be explained by x). Given the model parameters confidence levels, the relationships observed at both mines were reasonably similar.

The airborne dust mass size distributions measured with the impactors confirmed that a large portion of the dust mass was composed of particles greater than 10 μm. Figure 9 shows the average cumulative dust size distributions with standard deviations for the various sampling locations at both mines. The size distributions were fairly similar, with more closely aligned distributions measured at the same sampling location at each mine site. At least 80% of the dust mass was composed of dust particles larger than 10 μm (aerodynamic diameter) with geometric mean mass diameters greater than 20 μm (50% less or greater than). Thus, these data also confirm that most of the airborne dust mass generated by trucks was non-respirable.

The bulk road surface material analysis shows similarities in silt size content and bulk specific gravity between the mine sites, but also indicates notable differences in the silica content. Table 1 shows the sample analysis of bulk road surface material and airborne dust. All the road surface samples were collected at about the mid-afternoon of the sampling shifts when the roads were observed to be dry and dusty. They were well below the 2% total moisture content believed necessary to control the fugitive road dust [9]. The silt content of the samples was comparable for both mine sites, ranging between 18.3 and 27%. The bulk specific gravity was slightly higher, and the total moisture content was slightly lower for the LQ road surface as compared to the CP road surface. The most significant differences in the road surface material were that the CP road surface had notably higher silica content percentages, ranging between 15 and 17%, as compared to the LQ road surface, ranging between 2 and 3.2%. This could be attributed to the different materials used to construct the road surface bed. The LQ used limestone material and the CP used coal mine waste rock, likely composed of shale and mudstone that was mined with the coal.

The silica content measured in the airborne dust was not always consistent with what was measured in the road surface material. From Table 1 it can be observed that the thoracic dust had slightly higher but relatively consistent quartz content in comparison to the road surface material. However, the silica content in the respirable dust was quite variable as compared to the quartz content in the thoracic and road surface material. Part of this inconsistency can be attributed to the lower respirable mass weights analyzed. Respirable dust samples analyzed had about half of the weight of the thoracic samples analyzed, with several samples having between 0.2 and 0.26 mg of mass. Given that the silica masses (masses ranging from 0.02 to 0.04 mg) measured on all respirable dust samples analyzed were below, to slightly above, the level of quantification (0.03 mg), the accuracy of the determined silica content percentages is suspect at the lower sample masses analyzed (bolded numbers in table). This is due to the propagation of error of smaller gravimetric measurements used in determinations of quartz percentage [21]. Since all the thoracic samples analyzed had masses greater than 0.4 mg, there is much more certainty in their accuracy.

4. DISCUSSION

The scope of this study was limited to the examination of wind, distance, and road treatment condition on the generation and behavior of fugitive dust by haulage trucks. This study showed that reasonably high peak levels of respirable dust were generated next to the untreated haul road and these peak levels decreased rapidly to near background levels as the dust cloud moved 30.5 m (100 ft) from the road. This study also showed that, on average, the thoracic and total dust concentrations measured were about 3 to 4 times higher and 8 to 11 times higher, respectively, than the respirable dust concentrations measured. Thus, both peak thoracic and total dust concentrations would be expected to be much higher and behave similarly to the instantaneous respirable dust levels measured at, and away from, the road. These high levels of airborne dust generated provide the potential for high personal dust exposure levels near the trucks.

Since the truck-generated dust appears to dilute and diffuse rapidly away from the road, the most susceptible persons for exposure are the truck workers themselves. Exposure is not as likely from their own truck, but from dust plumes of opposing truck traffic and when following behind trucks in the same direction. Between 4.4 and 9.7% of MSHA truck driver dust samples collected across all the mining sectors exceed the respirable dust standard from 1996–2000 [5]. Other occupations that can be exposed to fugitive truck dust are the operators of shovels and front-end loaders that fill the trucks and bulldozer and crusher operators that may be working in the close proximity to the dump, processing, and storage facilities.

Since surface mine facilities are dynamic operations exposed to changing weather conditions, day-to-day dust levels can be highly variable. However, several general precepts can be followed to assist with maintaining worker exposures below mandated standards. It is desirable to use multiple dust control practices to compensate for operational anomalies that may make some of the individual dust control practices ineffective at times. The first line of control should be a method targeted at reducing dust generation at the source, such as road treatment. As illustrated in Figure 5 and other fugitive dust studies, this practice is very effective [7–10]. Road treatment also has secondary benefits of reducing environmental pollution in the surrounding area. Secondly, environmentally controlled operator cabs should be used on the mobile mining equipment. Environmental controls not only include heating and air-conditioning capabilities, but a good external air filtration system positively pressurizing the interior of a well-sealed cab [22, 23]. The air filtration system should be capable of efficiently removing inhalable dust down into the respirable size range. Many original equipment manufacturers (OEMs) offer these systems, while other companies offer retrofit systems for existing cabs. Finally, road layout and traffic patterns that can be economically incorporated into the mine plan should isolate the dust sources from other workers. An example of this would be one-way loop type haulage routes as practiced at the CP operation during this study. This layout can eliminate opposing traffic exposure to dust with the side benefit of reducing haulage accidents.

One attribute of both mine dust sampling surveys that could not be assessed as a control factor on the airborne dust behavior away from the road was the thigh-high grassy meadow. This attribute is only mentioned because of the noticeable coating of fugitive dust that was on the grass. This is likely from normal fallout of the larger dust particles over the 30.5 m (100 ft) distance from the road. Other researchers developing computational Lagrangian fluid particle models for particulate matter dispersion in localized regions have predicted considerable differences in vertical dispersion of dust concentrations generated at 5 m above the ground level due to wind velocity boundary layer effects [24]. Ground-level wind velocity boundary profiles are dependent on a roughness length or ground surface factor, affecting the vertical component of particulate dispersion and horizontal settling distance. Notable vertical particulate dispersion effects were modeled over larger horizontal distances 100 m (328 ft) than those sampled in this study 30.5 m (100 ft). Additional studies would be needed to determine the extent of regional dust control effects from vegetation around ground sources of generation.

5. CONCLUSIONS

This truck haulage dust study showed that primarily wind, distance, and road treatment condition notably affected the dust concentrations measured next to, 15.2 m (50 ft), and 30.5 m (100 ft) away from the unpaved haulage road. Airborne dust measured along unpaved haul roads at a limestone quarry and coal preparation plant showed that high concentrations of fugitive dust can be generated with the concentrations rapidly decreasing to nearly background levels within 30.5 m (100 ft) of the road. Total, thoracic, and respirable gravimetric dust measurements showed the highest concentrations near the road with a rapid decrease in concentrations out to 30.5 m (100 ft) of the road.

Instantaneous respirable dust measurements illustrated that the trucks generate a real-time dust cloud that has a peak concentration with a time-related decay rate as the dust moves past the sampling locations. The respirable dust concentrations and peak levels were notably diminished as the dust cloud was transported, diluted, and diffused by the wind over the 30.5 m (100 ft) distance from the road. Individual truck concentrations and peak levels measured next to the dry road surface test section were quite variable and dependent on wind conditions, particularly wind direction, with respect to reaching the sampling location. Instantaneous dust measurements on one particular day also demonstrated that road wetting was very effective in suppressing the respirable dust generated by the haulage trucks, negating the factors of wind and distance on airborne dust concentrations.

The vast majority of the fugitive airborne dust generated from unpaved and untreated haulage roads was non-respirable. At least 80% of the airborne dust sampled by impactors was larger than 10 μm (aerodynamic diameter size). This was also reflected in the thoracic and total concentrations, which were from 3 to 4 times higher and 8 to 11 times higher, respectively, than the respirable dust concentrations for this study.

The quartz content of the road surface material for each mine was found to be reflective of the quartz content found in the thoracic dust samples. Quartz content inconsistencies for the respirable dust samples are suspect because of lower masses analyzed. Other road surface and truck variable factor effects on airborne dust generation and behavior could not easily be differentiated from the primary effects of wind, distance, and road treatment condition.

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