International Journal of Mining, Reclamation and Environment

ISSN: 1748-0930 (Print) 1748-0949 (Online) Journal homepage: http://www.tandfonline.com/loi/nsme20

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To cite this article: Ali Lashgari & Vladislav Kecojevic (2016) Comparative analysis of dust emission of digging and loading equipment in surface coal mining, International Journal of Mining, Reclamation and Environment, 30:3, 181-196, DOI: 10.1080/17480930.2015.1028516

To link to this article: http://dx.doi.org/10.1080/17480930.2015.1028516

International Journal of Mining, Reclamation and Environment, 2016
Vol. 30, No. 3, 181–196, http://dx.doi.org/10.1080/17480930.2015.1028516

Comparative analysis of dust emission of digging and loading equipment in surface coal mining

Ali Lashgari[a]* and Vladislav Kecojevic[b]

[a]*Department of Energy and Mineral Engineering, Pennsylvania State University, University Park, PA, USA;* [b]*Department of Mining Engineering, West Virginia University, Morgantown, WV, USA*

(*Received 21 January 2015; accepted 9 March 2015*)

This paper presents a comparative analysis of dust emission of digging and loading equipment in surface coal mining. Field measurements and laboratory studies were completed, and dust emission for front-end wheel loader and cable shovel was determined by three methods: (1) the EPA AP-42 emission factor estimation equations (AP-42 dust emission estimation), (2) the methodology used in the development of AP-42 equations (Type 2 dust emission estimation) and (3) the methodology used in the EPA AERMOD model (Type 3 dust emission estimation). Collection of data on dust emission was conducted at an operating surface coal mine in the eastern United States. Results of this study revealed that dust emission obtained by the AP-42 dust emission estimation method exceeded the field-based emission determined by both Type 2 and Type 3 dust emission estimation methods. It was also observed that the dust emission determined by the Type 2 method exceeded the emission obtained by the Type 3 method. This research may assist mining professionals in quantifying the dust emission of digging and loading equipment, and developing strategies for reducing its negative environmental impact.

Keywords: dust emission; surface mining; digging and loading; environmental impact

1. Introduction

Fugitive dust is one of the most prevalent pollutants that can result from surface coal mining operations. It can have adverse effects on mine workers, surrounding areas and communities [1]. These effects can be chronic, i.e. diseases that develop during a long period of time and are generally of low intensity, or acute, i.e. diseases or illnesses that develop during a brief period of time and are generally severe in nature [2,3]. In addition, dust particulate matter (PM) causes other problems such as visibility impairment [4].

Dust contains chemical components that are dispersed into the atmosphere by both natural and human activities. The major components of dust particles include oxides of silicon, iron, aluminium and some calcium compounds [5]. Huertas et al. [6] studied particle size distribution of dust samples collected from 15 dust measurement stations in Columbia.

Two major parameters in the determination of actual exposure include the concentration of dust and the duration of exposure. Suspended PM can be classified according to the size of the component particles [7]. Particles ranging in size from 0.1 to 30 µm in diameter are referred to as total suspended PM (TSP). Particles with a diameter of 10 µm

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*Corresponding author. Email: AXL5433@PSU.EDU collected with 50% efficiency by a PM_{10} sampling collection device are called respirable particles (PM_{10}). Fine particle ($PM_{2.5}$) is defined as PM with a diameter of 2.5 μm collected with 50% efficiency by a $PM_{2.5}$ sampling collection device [8]. In general, the particle sizes of 100 μm for inhalable, 10 μm for PM_{10}, 4 μm for respirable and 2.5 μm for $PM_{2.5}$ are median sizes (D_{50}). Based on EPA criteria for pollutant standards for mining operations, predictions of the dispersion of PM_{10} and $PM_{2.5}$ are of interest [8].

Two legislative acts that regulate the air quality from mining operations include the following: (i) the Federal Mine Safety and Health Act of 1977 [9], which regulates the amount of dust allowable in the air for health and safety purposes, and (ii) the Clean Air Act of 1970, amended in 1977 and 1990 [10], which regulates air quality from facilities from an environmental perspective.

Sources of dust emission may be categorised as point and fugitive source emissions. Point source emissions include substances that are exhausted into a stack or vent and emitted into the atmosphere through a single point source. The emissions that are not released through a stack or vent are called fugitive emissions. Equipment used in surface mining may contribute to a substantial portion of the emission of fugitive dust. Sources of fugitive dust from mining operations include drilling, blasting, bulldozing, digging and loading, hauling, dumping, crushing, the haul road, stockpiles, waste rock and unprotected open surfaces. Hauling operations are the main source of fugitive dust emission from surface mining operations [11–13].

Several models have been developed by different researchers to determine fugitive dust emission. Organiscak and Reed [14] described the average and instantaneous peak dust levels at 30.5 m from haul roads. The authors also published the results of research related to the evaluation of safe following distance for equipment in order to avoid overexposure to respirable dust from lead trucks [15]. Reed et al. [16] conducted research to compare dust sampling results from a 1500-pDR dust monitor and provided a detailed description of the sampling method. Lashgari and Kecojevic [17] modelled the dust emission of digging and loading equipment for an operating surface coal mine. Colinet et al. [18] listed various available engineering controls that may help the mining industry reduce dust exposure.

It is very important for mine operators to have an accurate model to estimate dust emission in various steps of the project. As a result of potential over-prediction of emission during the air quality modelling process, many facilities may be denied air quality permits. Therefore, an accurate method of emission estimation is needed by the mining industry.

The overall objective of this research study was to conduct a comparative analysis of dust emission of digging and loading equipment in surface coal mining, specifically front-end wheel loader and cable shovel. The text that follows examines the current United States (US) Environmental Protection Agency (EPA) method for estimation of dust emission, description of data collection in the field and analysis of results obtained using the EPA method and data from the field. A case study on dust emission related to digging and loading equipment was conducted at an operating surface coal mine in the eastern US.

2. Estimation of dust emission

The most commonly used method for the determination of air emissions from non-stack sources is based on multiplication of the activity rate (in units of weight, volume, distance or duration per unit of time) by the appropriate emission factors (EFs). It can be expressed as [19]:

$$E_{\mathrm{i}} = A_{\mathrm{i}} \times \mathrm{EF}_{\mathrm{i}} \times \left(1 - \frac{\mathrm{CE}_{\mathrm{i}}}{100}\right) \tag{1}$$

where 'E_{i}' represents emission rate of pollutant 'i' in kg/h, 'A' is activity rate in tonne/h, 'EF_{i}' is emission factor of pollutant 'i' in kg/tonne and 'CE_{i}' represents overall percentage of control efficiency of pollutant 'i'.

The Compilation of Air Pollutant Emission Factors (AP-42) published by EPA is predominantly used to estimate emission rates. The fifth edition of AP-42 (published in 1995) includes a number of equations to determine fugitive dust EFs. However, some sections were updated later. The latest version of these equations can be found on the EPA website [19]. Emission factor estimation equations as well as process information for more than 200 classes of air pollution source have been given in this publication. These equations are based on observations of dust concentrations from specific industrial operations and can determine the amount of dust produced by a certain operation.

Information regarding western US surface coal mining was provided in section 9 of chapter 11 of the EPA's AP-42 [21]. This section includes EF estimation equations for blasting, truck loading, bulldozing, dragline, grading and active storage pile. Table 1 shows EF estimation equations provided by EPA in AP-42 Compilation of Air Pollutant Emission Factors for western US surface coal mines. In its original report, Axetell and Cowherd [20] indicated that these EF equations should only be used for western surface coal mines. Therefore, no assumption will be made that these equations would be appropriate for surface mining operations in other geographic areas without further evaluations.

Section 2.4 of chapter 13 in AP-42 document (AP-42 13.2.4) provides EFs for aggregates handling and storage piles, including loading equipment. For either type of loading and unloading operation (i.e. wheel loader, backhoe loader and rope shovel), EPA recommends the following empirical expression for estimation of the quantity of fugitive dust generated per tonne of moved material (kg/tonne):

Table 1. EF equations for uncontrolled open dust sources [21].

		Emissions by particle size range				
		EF equations		Scaling factors		
Operation	Material	TSP	PM_{15}	PM_{10}/ PM_{15}	$PM_{2.5}$/ TSP	Units
Blasting	C&O	$0.00022A^{1.5}$	–	0.52	0.03	kg/blast
Truck loading	C	$0.58M^{-1.2}$	$0.0596M^{-0.9}$	0.75	0.019	kg/tonne
Bulldozing	C	$35.6s^{1.2}M^{-1.3}$	$8.44s^{1.5}M^{-1.4}$	0.75	0.022	kg/h
Bulldozing	O	$2.6s^{1.2}M^{-1}$	$0.45s^{1.5}M^{-1.4}$	0.75	0.105	kg/h
Dragline	O	$0.0046d^{1.1}M^{-0.3}$	$0.0029d^{0.7}M^{-0.3}$	0.75	0.017	kg/m^3
Grading	–	$0.0034S^{2.5}$	$0.0056S^{2.0}$	0.60	0.031	kg/VKT
Active storage pile	C	$1.8u$	–	–	–	kg/ (hectare) (h)

Notes: A: horizontal area (m^2), with blasting depth <21 m. Not for vertical face of a bench; M: material moisture content (%); s: material silt content (%); u: wind speed (m/s); d: drop height (m); C: coal; S: mean vehicle speed (km/h); VKT: vehicle kilometres travelled; O: overburden.

$$E = k \times 0.0016 \times \left(\frac{u}{2.2}\right)^{1.3} \times \left(\frac{M}{2}\right)^{-1.4} \quad (2)$$

where 'u' is mean wind speed (m/s) and 'M' is material moisture content (%).

The aerodynamic particle size multipliers 'k' for TSP, PM_{15}, PM_{10}, PM_5 and $PM_{2.5}$ are 0.74, 0.48, 0.35, 0.20 and 0.053, respectively. The ranges of source conditions used in developing EF estimation equation for loading operation include silt content of 0.44–19%, wind speed of 0.6–6.7 m/s and moisture content of 0.25–4.8%.

A total of 265 tests (245 of them on uncontrolled sources) were conducted during four sampling periods to develop EF estimation equations for western US surface coal mining (AP-42 11.9). However, some of the samples were not used in development of the equations. Five different sampling techniques were used in the study by EPA, including quasi-stack, balloon, upwind–downwind, profiling and wind tunnel. Table 2 summarises the tests by source.

The upwind–downwind method is often used for collecting dust concentration data. In this method, only a small portion of the emissions are captured and emissions are estimated based on sampling at different distances from the source. This technique is applicable to the major types of sources and has been used universally to quantify emissions from a variety of sources.

Several studies have noted that various atmospheric dispersion models by EPA may lead to over-prediction of dust concentration and the relevant air quality impact of fugitive dust emission in surface mines [22–25]. Singh et al. [26] compared results of dust emission modelling by the Fugitive Dust Model (FDM) and EPA's industrial source complex (ISC3) for a mine in India. The result from this study shows a better performance for the FDM model. Chaulya et al. [27] compared the emission estimation results for various mining operations in a surface mine in India for two different dust modelling packages, including the FDM and the Point, Area and Line sources model (PAL2). Authors selected eight coal mines and three iron ore mines and studied several operations: drilling, loading and unloading (overburden and ore), material handling, stock yard, exposed overburden dump, exposed pit surface, workshop, haul road and

Table 2. Summary of tests performed [21].

Source	Material Type	Sampling Technique	Mine 1	Mine 1 (winter)	Mine 2	Mine 3	Total
Drilling	O	Quasi-stack	11	12	–	7	30
Blasting	C	Balloon	3	–	6	7	16
Blasting	O	Balloon	2	–	–	3	5
Loading	C	UW–DW	2	–	8	15	25
Bulldozing	O	UW–DW	4	–	7	4	15
Bulldozing	C	UW–DW	4	–	3	5	12
Dragline	O	UW–DW	6	–	5	8	19
Haul truck	–	Profiling	7	10	9	9	35
Scrapers	–	Profiling	5	2	6	2	15
Graders	–	Profiling	–	–	5	2	7
Exposed area	O	Wind tunnel	11	3	14	6	34
Exposed area	C	Wind tunnel	10	6	7	16	39
Light and medium duty Trucks	–	Profiling	5	–	5	3	13

Note: UW–DW: Upwind–Downwind; O: Overburden; C: Coal.

transport road. The results showed that FDM had better performance than the PAL2 model. Neshuku [28] compared the performance of two models: the EPA's AERMOD and the Atmospheric Dispersion Modelling System (ADMS) for air pollution sources of surface mines. This research concluded that ADMS had better performance than the AERMOD model. Reed [22] compared the performance of two dust dispersion models for haul trucks, including dynamic component programme and ISC3.

One of the major causes of discrepancy between observed and predicted values by dispersion models is that the EF estimation equations developed by EPA may have over-predicted the amount of dust generated by mining operations. This over-prediction has been noted by the National Stone, Sand and Gravel Association [29] and several other publications [22,30,31].

Three sequential steps were followed by EPA to develop EF estimation equations (Figure 1):

(1) Dust concentrations at different locations around each operation were collected using an appropriate sampling method.
(2) The concentration data were converted into corresponding emission rates using a Gaussian dispersion equation. In this way, emission rates in unit of g/s were calculated using dust concentrations in g/m^3.
(3) Stepwise multiple linear regression technique was used to develop EF estimation equations.

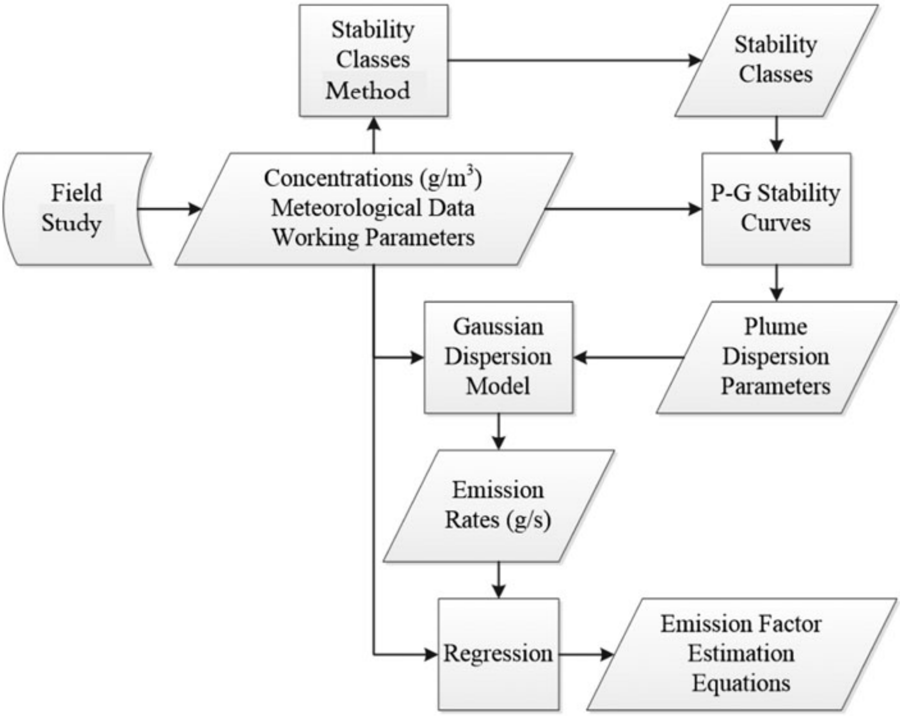

Figure 1. EPA methodology used to develop the emission factor estimation equations.

Three major causes of potential over-estimation by EPA's EF estimation equations may include the following: (1) non-representative data collected from the mines, (2) the methodology used in the development of EFs and (3) simplifications in the development of regression equations.

The EPA's AP-42 EF estimation equations use a few number of variables (one or two variables for different operation types) to estimate fugitive dust emission. For instance, the emission estimation equation for coal loading operation uses material moisture content as the only predictor parameter for dust emission. However, many variables, i.e. wind speed and material silt content, may affect the quantity of dust emitted from coal loading operations. This simplification causes a higher rate of error in estimates.

Also, the equations were developed based on a small numbers of datasets and do not have high coefficients of determination in most cases. As an example, the EPA's AP-42 suggests using the following equation to estimate dust emission from coal loading operations in surface mines [21]:

$$\mathrm{EF}_{\mathrm{TSP}} = \frac{0.58}{M^{1.2}} \tag{3}$$

where '$\mathrm{EF}_{\mathrm{TSP}}$' is total suspended particulate EF in kg/tonne and 'M' is moisture content in per cent. This function has been derived based on 24 concentration data collected from three western US surface coal mines. Figure 2 shows a logarithmic view of '$\mathrm{EF}_{\mathrm{TSP}}$' vs. '$M$' based on the used data. The coefficient of determination for this equation is $R^2 = 0.451$. It means that the function is able to describe 45.1% of variation among the values for 24 datasets.

The comparison of observed emissions for 24 concentration data with estimated values shows that the mean absolute percentage error of this equation is 90.5%. It means that the values estimated by this equation are on average 90.5% higher than the observed concentration values used in the development of the equation. However, in some cases the estimated values are more than three time higher than the observed concentration rates. The maximum error of the equation is 315.5%. Figure 3 shows residual plot of emission rates. It should be noted that these error rates were calculated for

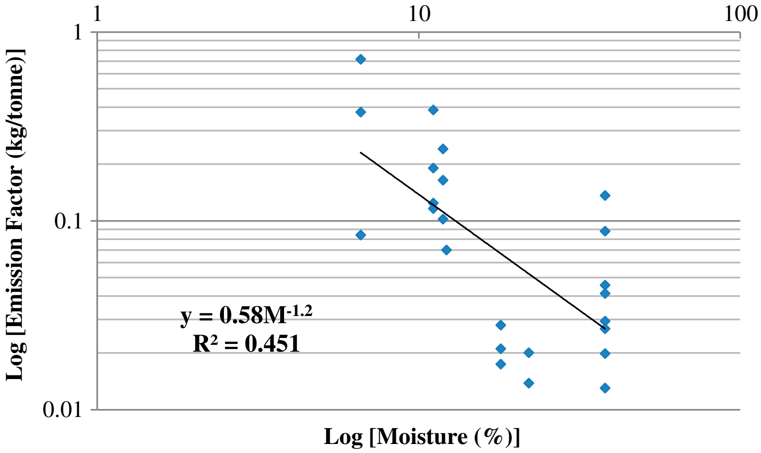

Figure 2. A logarithmic view of 'EFTSP' vs. 'M' (data from [20]).

the datasets used in development of the function. The errors might be even higher if the function is going to be used for estimation of emission in a coal mine located in another geographic area or with different meteorological and working conditions. Statistical analysis of the data shows that the power of the moisture content 'M' can change from −0.6 to −1.8. This wide range of variability causes an extensive range of error in the estimation of EF.

The EPA employed stability classes along with Pasquill–Gifford dispersion curves (P-G dispersion curves) to determine vertical and horizontal measures of plume spread ('σ_y' and 'σ_z') in the development of AP-42 11.9 equations. The stability classes employ a qualitative approach to determine atmospheric stability. Moreover, this method was developed in 1950s through empirical analyses of observations from field studies of dispersion in the surface boundary layer.

The P-G dispersion curves are assumed to be valid for downwind distances from 100 m to 10 km. Since AP-42 11.9 EF estimation equations were developed based on concentration data collected at distances less than 100 m, the use of this method to determine vertical and horizontal measures of plume spread may be suspect [32]. On the other hand, the P-G dispersion curves are based on observations made at distances less than 1 km from the source. The estimations of 'σ_y' and 'σ_z' for larger distances in this scheme are based on extrapolations from a few measurements made in England [33]. The other concerns which may cause inaccurate estimate of dust emission are as follows:

- The functions are intended to bracket 'worst case' conditions.
- Test methods were designed to estimate TSP, while PM_{10} and $PM_{2.5}$ are of major concerns in health studies.
- For most of the operations, samples were collected in a specific season and during the daytime. Therefore, the models may not be representative for all working conditions.
- Emission data were averaged for the whole sampling duration, regardless of activity rate and operation cycles, while for most mining equipment, only a part

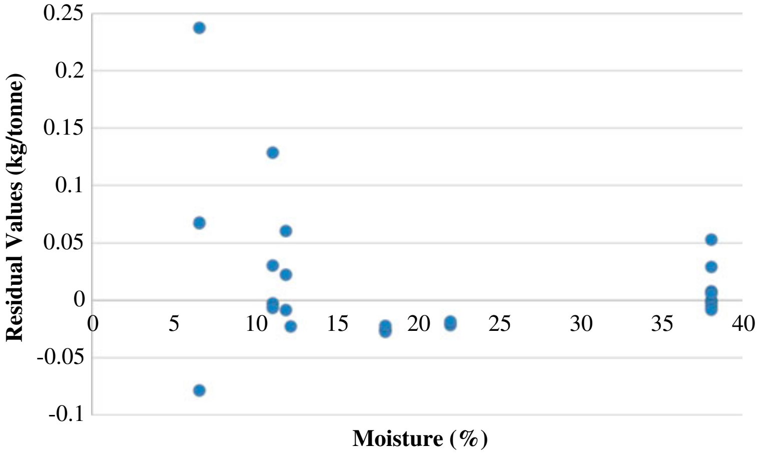

Figure 3. Residual plot of emission rates.

of the working cycle generates dust. Moreover, the quantity of dust emitted is highly dependent on the number of cycles per unit of time. Therefore, the model should consider the number of cycles and equipment operational behaviour in the calculations.

In addition to technical concerns that may cause the over-prediction tendency in AP-42 fugitive dust EFs, the atmospheric dispersion models established by the EPA for regulatory compliance assessment may also lead to over-prediction of the air quality impact of fugitive dust emission. During last two decades, the EPA has developed several dispersion models to be used in the air pollution regulatory process for the purposes of air quality modelling of different sources with given meteorological data and EFs. Most of these models use the variations of σ_y and σ_z as functions of distance from the source and use P-G dispersion curves to determine 'σ_y' and 'σ_z'. For example, the Industrial Source Complex Model (ISC3), established in 1995, which is a dispersion modelling tool based on Gaussian dispersion model to evaluate pollutant concentrations from sources associated with an industrial complex, uses P-G dispersion curves in its algorithm. In the user guideline of this model, the user is cautioned that concentrations at receptors less than 100 m from a source may be suspect, because the P-G dispersion curves are basically valid for distances more than 100 m.

Development of more accurate dust emission estimation model and EFs requires several steps: (1) investigation of the major causes of potential dust over-estimation in current models, (2) re-examining the applicability of AP-42 EFs, (3) re-examining the particle size distribution published by EPA and (4) adjustment of current EFs and emission estimation methods, as necessary, to obtain an accurate estimation of dust emission from mining operations.

3. Methodology

Collection of data on dust emission was conducted at an operating surface coal mine in the eastern US The mine has been active since the early 1970s. The geologic formations in the mine consist of sandstone overburden, with some shale streaks, five coal seams of varying thicknesses interspersed between layers of interburden. The mine produces approximately 2.3 Mtonne of coal and about 32 Mm^3 of overburden per year. The operation uses diverse mining equipment: dragline, cable (electric) shovel, drills, bulldozers, hydraulic shovel, graders, haul trucks, front-end loaders, water trucks and auxiliary equipment. Data on production rates and number of working hours for digging and loading equipment (cable shovel and front-end wheel loader) were obtained from the mine and sorted in an Excel spreadsheet. The dust concentrations at different distances from the operations were collected during the field trip.

Real-time measurements of PM concentrations were performed using TSI DustTrak DRX 8534 real-time aerosol monitoring instrument. This fast response dust monitor provides particle matter concentrations in the five size ranges TSP, PM_{10}, PM_4, $PM_{2.5}$ and PM_1 with a user-defined time resolution. The weather parameters required for this study were collected using Kestrel 4500 Weather Metre. This instrument is able to track wind speed, wind direction, moisture, temperature and atmospheric pressure.

The dust sampling was conducted around each loading point using upwind–downwind sampling technique. Several samples were collected at upwind and downwind sides of operation at different distances from the emission source. Dust concentration monitoring instrument was mounted on a tripod stand at a height around human breathing height. After the concentrations measured upwind and downwind, upwind concentration (background concentration resulted from other sources) was subtracted from the downwind concentrations, the net downwind concentrations (the quantity of emission from studied source) were then used as input to dispersion equations. The field study was completed for overburden loading operations using rope shovel and front-end wheel loaders. Figure 4 shows an example of dust sampling in the mine.

A total of 35 dust samples, including 17 samples from overburden loading by cable shovel and 18 samples from overburden loading by front-end wheel loader, were collected during the field trip. All samples were collected in uncontrolled dust emission conditions. A time study was also conducted to obtain durations that specific equipment spends on different duties. Moreover, material samples were collected from different loading points and were taken to the laboratory separately to measure different material specifications, e.g. silt content and moisture content.

After the field measurements and laboratory study were completed, dust emission for front-end wheel loader and cable shovel was estimated based on three methods: (1) emission determined directly using the EPA AP-42 EF estimation equations (AP-42 dust emission estimation), (2) emission estimated based on the methodology used in the development of AP-42 equations (Type 2 dust emission estimation) and (3) emission determined by the methodology suggested in AERMOD model (Type 3 dust emission estimation). Comparative analysis was conducted among the results obtained from these three different dust estimation methods.

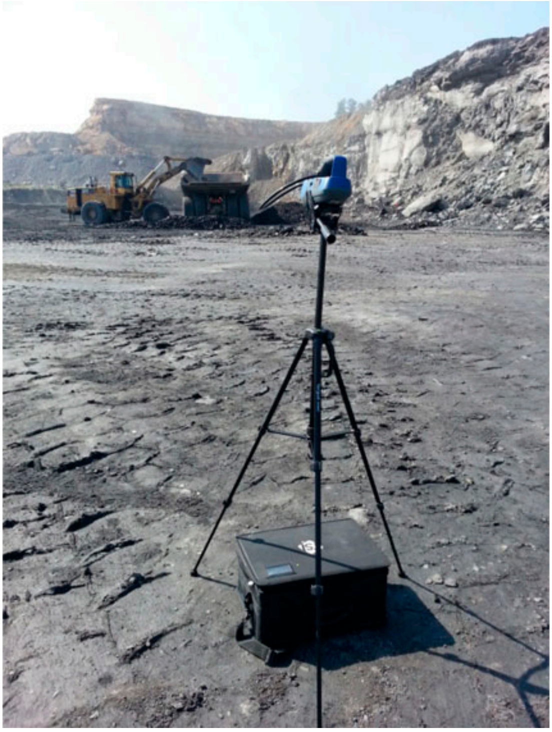

Figure 4. Dust measurement in the mine.

The AP-42 dust emission estimation method calculates dust emission based on the equations proposed in the EPA AP-42. The data on wind speed and material moisture content were used in estimation of EFs.

Type 2 dust emission estimation method determines EFs based on the data collected from the mine (Figure 5). The same approach that was employed by EPA in conversion of concentration values into emission rates (backward Gaussian dispersion model as well as P-G dispersion curves) was used in this method. No regression equation was developed in this method. Therefore, EFs were estimated directly based on the concentration values, instead of using multiple regression functions. Not only does this method avoid inaccurate estimating due to using non-representative data from western US coal mines, but it also helps avoid inaccuracies due to using regression functions.

Type 3 dust emission estimation method calculates emission based on methodology suggested in AERMOD (Figure 6). This method also estimates EFs based on concentration data from the mine. However, the methodology employed to convert concentrations to emission rates is not the same as the method employed by the EPA's AP-42. This method uses a backward calculation of the Gaussian dispersion model as the general method to estimate EFs based on dust concentrations. It helps to convert concentrations measured at different distances from each operation in the mine site into mass-based emission rates. The primary difference between this method and the EPA's AP-42 scheme is in the methodology used to estimate the plume dispersion variables ('σ_y' and 'σ_z'). In this method, the plume dispersion variables are estimated using Monin–Obukhov length, instead of P-G stability categories. This path can be a good replacement for P-G dispersion curves that were used in the EPA's AP-42 procedure. This method provides a quantitative approach to estimate horizontal and vertical plume

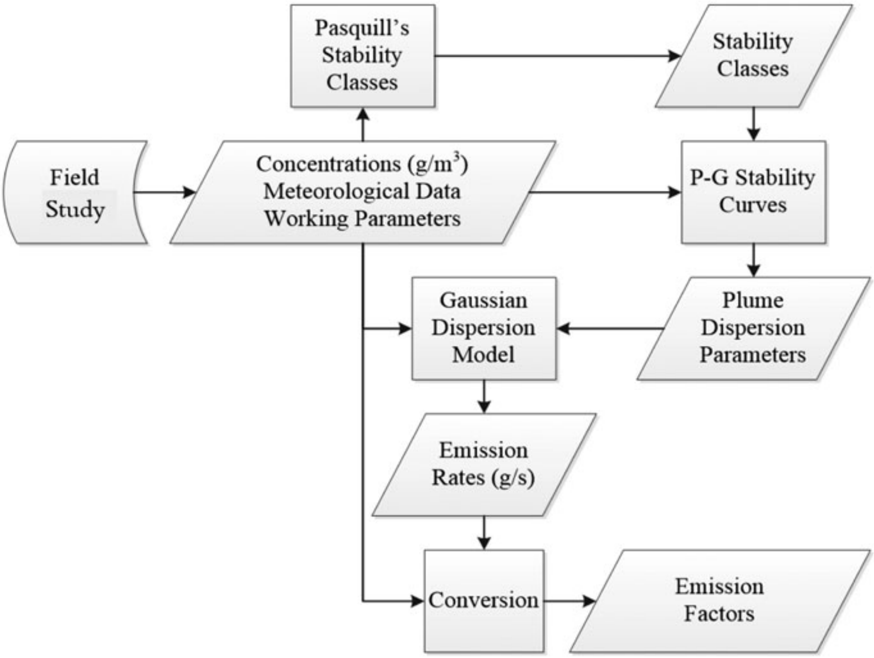

Figure 5. A schematic view of the methodology used for Type 2 emission estimation.

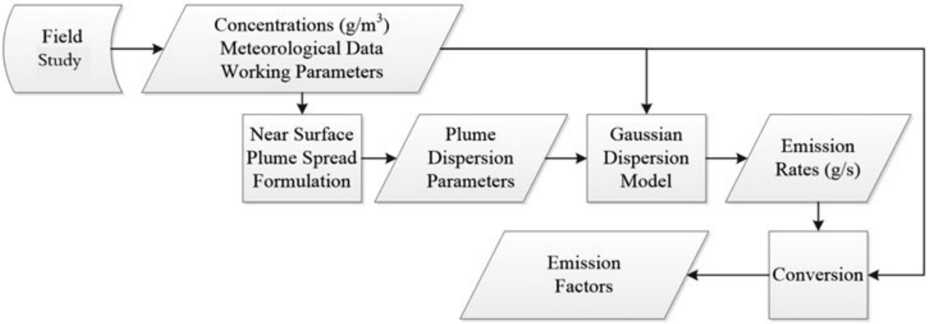

Figure 6. A schematic view of the methodology used for Type 3 emission estimation.

spreads, instead of using the linkage of stability classes to P-G dispersion curves, which are based on qualitative parameters.

The plume dispersion parameters in AERMOD are derived from profiles of turbulence, not from radiation base turbulence surrogates as it is applied in the P-G dispersion curves scheme. However, the Type 3 dust emission estimation method requires more input parameters than the previous two Type 1 and Type 2 methods. AERMOD provides more realistic estimates of pollutant concentrations. The third method employs a re-formulated method of plume dispersion parameters estimation for near-source dispersion [34]. Since the calculation in this method follows the methodology used in the AERMOD model, the EFs calculated based on this scheme are more compatible with the AERMOD model. This method provides more realistic estimates of EFs with regards to more parameters from the field with fewer simplifications.

4. Results and discussion

As indicated in methodology section, dust sampling was conducted around a cable shovel and a front-end wheel loader. As an example, Figure 7 shows the concentration data collected for a 1-min period of overburden loading operation by front-end wheel loader (one pass of overburden loading), measured at distance of 17.8 m. The concentration data were collected for different size fractions, including PM_1, $PM_{2.5}$, PM_4 (respirable), PM_{10} and TSP.

It can be noted in Figure 7 that the concentration of each size fraction of the dust does not change significantly for the first 20 s. This concentration can be a good indicator of background concentration. This period indicates loading and positioning sequences for the wheel loader. A few seconds after dumping material into truck bed, the concentrations rapidly go up. However, this period does not last long, and after just a few seconds, the concentrations start to come back to the background concentration. However, studying the concentration for a longer period of time, which includes more passes of loading operation, results in more complex concentration diagrams. It should be mentioned that the dust concentration values from different loading passes may differ significantly. However, the concentration changes and follows the path shown in Figure 7. These changes in concentration values for each loading cycle cause a different range of overall dust concentration values for long-time measurement. Figure 8 shows the concentration data for different dust size fractions collected for multiple

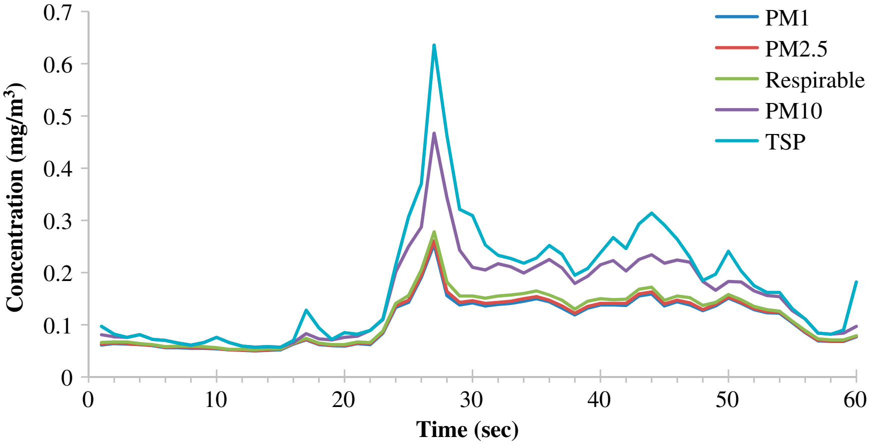

Figure 7. Dust concentration for 1-min period of overburden loading by wheel loader.

passes of overburden loading by front-end wheel loader during a time period of 5 min. It should be noted that Figures 7 and 8 represent two different samples observed during two different periods.

Figure 9 shows the results on dust emissions for 18 samples for front-end wheel loader. It can be noted that values of $PM_{2.5}$ obtained by the AP-42 dust emission estimation method exceed on average 3.44 times the field-based emissions determined by Type 2 dust emission estimation method and 4.59 times the field-based emissions determined by Type 3 dust emission estimation method. Type 2 dust emission estimation method provides the results that exceeds on average 2.26 times the results obtained by Type 3 dust emission estimation method.

Figure 10 shows the results on dust emissions for 17 samples for cable shovel. It can be noted that values of $PM_{2.5}$ obtained by the AP-42 dust emission estimation

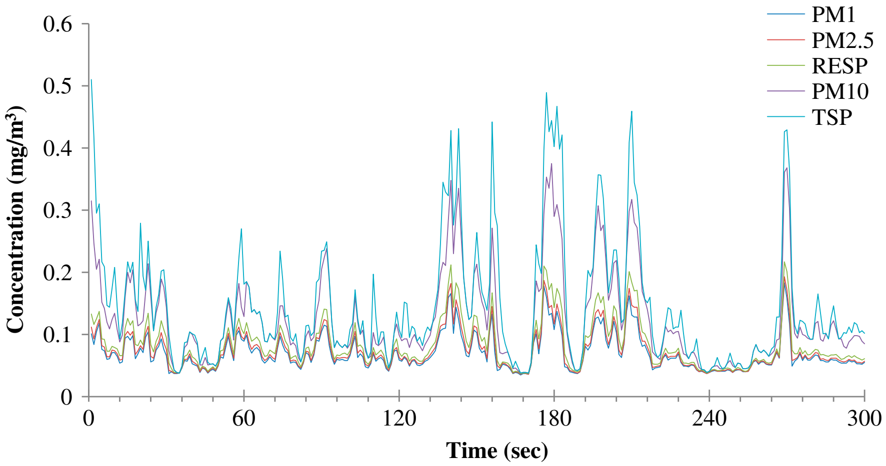

Figure 8. Dust concentration for 5-min period of overburden loading by wheel loader.

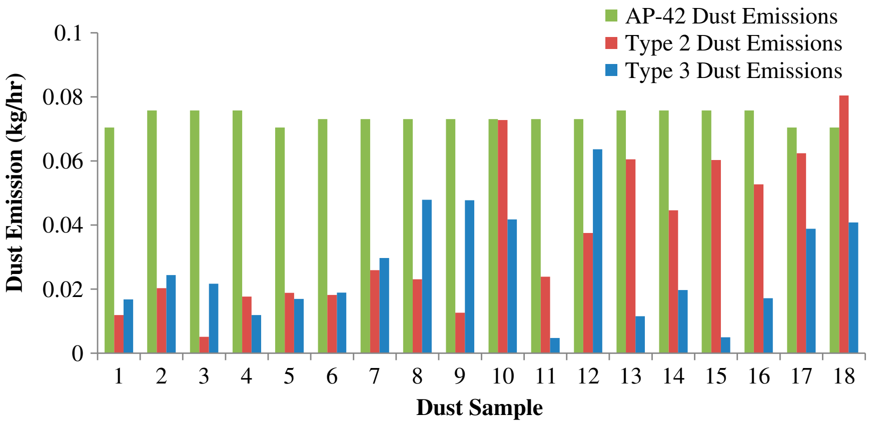

Figure 9. $PM_{2.5}$ emissions from overburden loading by front-end wheel loader.

method exceed on average 5.7 times the field-based emissions determined by Type 2 dust emission estimation method and 11.45 times the field-based emissions determined by Type 3 dust emission estimation method. Type 2 dust emission estimation method provides the results that exceed on average 1.76 times the results obtained by Type 3 dust emission estimation method.

The results show that the AP-42 dust emission estimation method overestimates emissions from overburden loading for this particular coal mine in the eastern US. Comparisons between the AP-42 dust emission estimation method and the Type 2 dust emission estimation method show that the data used in development of AP-42 equations may be non-representative for surface coal mines in the eastern US. Additionally, using regression functions may significantly increase the rates of error in estimation of emission using the AP-42 dust emission estimation method. The comparisons between the results of Type 2 and Type 3 dust emission estimation methods show that estimation of plume dispersion variables (‘σ_y’ and ‘σ_z’) using profiles of turbulence leads to a discrepancy between the values on dust emission. Estimation of plume dispersion variables using profile of turbulence, instead of P-G dispersion curves, may provide a

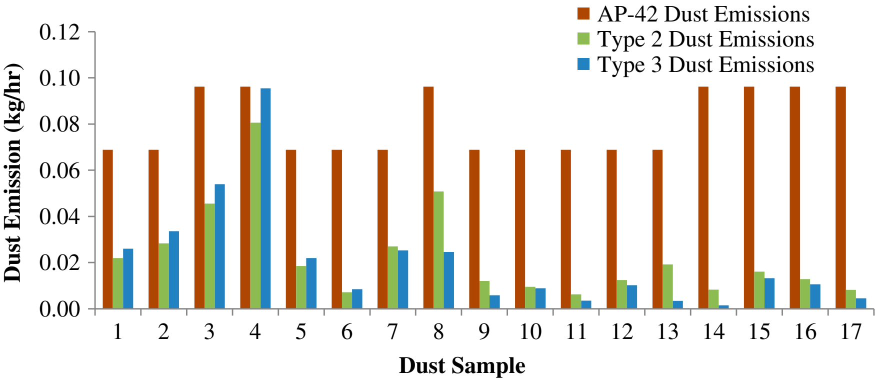

Figure 10. $PM_{2.5}$ emissions from overburden loading by cable shovel.

significant improvement in the estimation of dust emission. The results from this study demonstrate that dust emissions determined by Type 3 method are more accurate than Type 2 method. However, more comprehensive dust studies are needed to validate this EF estimation method for different mining operations.

Conclusions

This study examined the current EPA method for estimation of dust emission and provided a comparative analysis of dust emission of digging and loading equipment at an operating surface coal mine in the eastern US.

The comparison of the dust emissions by the EPA AP-42 EF estimation equations (AP-42 dust emission estimation) vs. field study results shows that the EPA AP-42 emission factor method over-predicted dust emission for overburden loading operations in this specific surface coal mine. Three major causes of over-prediction may include the following:

- Non-representative data used in development of AP-42 EF estimation equations due to the small number of variables used in emission calculations.
- The methodology used for calculation of emission rates. The P-G curves may not be valid for mining emission estimation. Additionally, emission calculations were originally developed for TSP, and now, the focus is on PM_{10} and $PM_{2.5}$.
- Simplifying assumption caused using regression equations. Regression analysis of a small number of data points does not result in satisfactory results in explaining the variability of the data.

The results of this study suggest the following:

- A re-consideration of EFs for digging and loading operations in surface coal mines,
- The use of on-site meteorological data where the estimation of dust concentration is required for digging and loading operations for a particular site, and
- Development of improved methods for estimation of EFs.

More studies are required to define a specific framework to estimate EFs due to different operations, such as drilling, blasting, loading, and haulage in surface coal mines and a good understanding of the impact of different parameters, such as moisture content, wind speed and deposition of dust particles by distance on the overall amount of dust emitted from surface coal mines.

Disclosure statement

No potential conflict of interest was reported by the authors. The views, opinions and recommendations expressed herein are solely those of the authors and do not imply any endorsement by ARIES employees, other ARIES-affiliated researchers or industrial members. Their financial contribution is gratefully acknowledged.

Funding

This study was sponsored by the Appalachian Research Initiative for Environmental Science (ARIES).

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