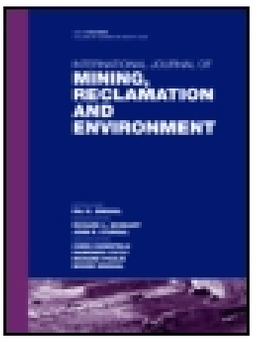

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Analysis of dust emission at coal train loading facility

Bisleshana B. Prakash[a], Vladislav Kecojevic[a] and Ali Lashgari[b]

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

ABSTRACT

The objective of this research was to conduct an analysis of dust emission for a coal train loading facility. Dust emission for the train loading point was determined by two methods: (i) the EPA AP-42 emission factor estimation equations (AP-42 Dust Emission Estimation) and (ii) the methodology used in development of AP-42 equations (Type-2 Dust Emission Estimation). Field measurements and data collection were carried out at a facility that operates along with a coal mine in West Virginia, U.S. Results of this study revealed that dust emission obtained by the former method exceeded the field-based emission determined by Type-2 Dust Emission Estimation method for this particular loading facility. This research may assist mining and environmental professionals in quantifying dust emission at train loading facilities, and developing strategies for reducing its health and environmental impacts.

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Dust emission; coal train; loading facilities; environmental impact

1. Introduction

Coal dust is a pollutant that can result from train loading operations. It can have an adverse effect on human health and the surrounding environment. Coal dust is a complex and heterogeneous mixture containing more than 50 different elements and their oxides [1]. The mineral content varies with the particulate size of the dust and with the coal seam. Common minerals associated with coal dust include quartz (crystalline silica), kaolinite, illite, calcite, pyrite and sulphur varying from 0.5% (by weight) to more than 10%. Exposure to respirable dust containing crystalline silica causes the death of more than 250 workers in the U.S. each year [2]. Quartz in respirable dust can cause lung emphysema and cancer [3]. The effects of dust on the agriculture and ecology of an area depend on the size distribution, the deposition rate and the concentration of dust particles in the ambient air. A thick coating of dust on vegetation can abrade plant surfaces, and bury organisms and photosynthetic organs [4].

According to the size of the component particles, dust is classified as follows: total suspended particulate (TSP), inhalable dust (PM_{10}), respirable dust (PM_4) and particulate matter 2.5 ($PM_{2.5}$). The TSP refers to particles ranging in size from 0.1 μm to about 30 μm in diameter [5]. Inhalable particles (PM_{10}) refer to particulate matters with a diameter of 10 μm collected with 50% efficiency by a PM_{10} sampling collection device. The particulate matters with a diameter of 2.5 μm collected with 50% efficiency by a $PM_{2.5}$ sampling collection device are called fine particles ($PM_{2.5}$). The particles less than 1 μm in diameter are referred to as PM_1.

CONTACT Vladislav Kecojevic vlad.kecojevic@mail.wvu.edu

Two legislative acts regulate air quality from mining operations: (i) the Federal Mine Safety and Health (MSHA) Act of 1977 [1], which regulates the amount of dust allowable in the air for health and safety purposes and (ii) the Clean Air Act of 1970, further amended in 1977 and 1990 [6], which regulates the air quality from facilities from an environmental perspective.

Previously, the TSP was regulated by the U.S. Environmental Protection Agency (EPA), but in last few years the focus has shifted to fine and inhalable particles [5], as inhalable particles pose the biggest threat due to their longer atmospheric lifetime, and tendency to get deep into the lungs and sometimes into the bloodstream. The atmospheric lifetime of particulate matter refers to the duration of time the particle is airborne and depends on the size of the particle. Coarse (large) particulate matter tends to deposit quickly and in relative proximity to its original point of source emission while fine particulate matter may remain suspended in the atmosphere for many days and travel many hundreds of kilometres. Table 1 summarises the atmospheric lifetime of particles and potential travel distances based on particle size [7].

The sources of air pollutants are primarily categorised into point sources and fugitive sources [8]. Point source emissions refer to discrete, stationary, identifiable sources of emissions that release pollutants into the atmosphere. There may be several individual 'emission points' within a given point source. Emission points refer to a specific stack, vent or other discrete point of pollution release. Fugitive source air emissions are distributed spatially over a wide area and not confined to a specific discharge point. They are generated in operations where exhausts are not captured and passed through a stack. Mobile sources include all non-stationary sources, such as automobiles, trucks, aircraft, trains and construction and farm equipment, and are a subcategory of area sources [9].

A number of studies and models have been conducted to analyse emissions and estimate dust emissions from different activities in mining. Reed [10] compared the performance of two dust dispersion models for haul trucks, i.e. dynamic component programme (DCP) and industrial source complex (ISC3) model developed by the EPA. Sivacoumar et al. [11] used Fugitive Dust Model (FDM) together with Industrial Source Complex (ISCST3) and AERMOD model in the study involving the simulation of fugitive dust emissions and control measures in the stone crushing industry. Singh et al. [12] compared the results of dust emission modelling by the Fugitive Dust Model (FDM) and EPA's industrial source complex (ISC3) for a mine in India and concluded that FDM performs better than ISC3. Lashgari and Kecojevic [13] modelled the dust emission of digging and loading equipment for an operating surface coal mine. The same authors also conduct a comparative analysis of dust emission of digging and loading equipment in surface coal mining, specifically front-end wheel loader and cable shovel [14]. Various available engineering controls have been listed that may help the mining industry reduce dust exposure [15].

A limited number of studies have been conducted on the emission rate of coal dust from coal trains at rail corridors.

Szabo [16] studied the primary and secondary environmental impacts resulting from transportation of coal by slurry pipeline, railroad, barge, truck and conveyor. Also, the impacts from coal preparation and associated activities, such as loading and unloading and energy efficiencies of the transport modes were analysed. The loss of particulates in transit varies with the type of coal shipped, moisture and fine content of coal, the speed of the train, the condition of the cars and wind speed. The author suggested the focus on research towards developing sprays that will hold the coal fines in place at a reasonable cost.

Table 1. Atmospheric lifetime and potential travel distance for particles of various size categories [7].

Particle size	Atmospheric lifetime	Travel distance
TSP	Minutes to hours	Typically deposits within the proximate area downwind of the point of emission
PM_{10}	Days	Up to 100 km or more
$PM_{2.5}$	Days to week	Hundreds to thousands of kilometres

Cope and Bhattacharyya [17] conducted a study to estimate fugitive coal dust emissions for the various coal mining operations from mine to end-use facility. A significant portion of the investigation focused on fugitive coal dust emission related to the transport of coal by rail in Canada, as the present emission factors (EFs) for estimating fugitive coal dust from unit trains were questioned. The basic Environment Canada's national Criteria Air Contaminants (CAC) inventory was modified using new PM_{10} and $PM_{2.5}$ scaling factors, precipitation factor, adjusted dust control factor of 99%, and linear distance factor to prorate emissions.

Kotchenruther [18] estimated coal train fugitive dust impacts in Tacoma, Washington, U.S. The author looked into rail routes from Powder River Basin to proposed U.S. Pacific Northwest Coal Terminals and found that the number of coal trains per day on rail routes would significantly increase if these terminals are built. The yearly emission of $PM_{2.5}$ for Tacoma was calculated based on Canadian EF as reported by Cope and Bhattacharyya [17].

Connell Hatch [19] conducted the environmental evaluation for Queensland Rail Limited to identify, quantify, and assess risk and propose mitigation measures relating to fugitive dust emissions from coal trains. Connell Hatch found that around 80% of coal dust emissions from moving trains occur from the surface of the wagon. The other major factors were spilled coal (9%) and door leakage (6%). The key factor that contributes to the emission rate of coal dust from wagons is the speed of the air passing over the coal surface that in turn is influenced by train speed and ambient wind speed. Also, TSP monitored did not exceed the guideline of 150 $\mu g/m^3$ provided by Australian Environmental Protection (Air) Policy of 2008 over the monitoring period for each site.

Burlington Northern Santa Fe Railway [20] conducted Super Trial in Powder River Basin to develop and provide information on coal dust suppression technologies that help coal shippers to implement effective coal dust control measures. In a body treatment, the chemical agent used for suppressing coal dust emissions from loaded trains was applied to the coal before the coal was loaded into the railcars. The chemical was also applied to the coal after it was loaded into railcars. The trial showed that treatment of loaded coal substantially reduces coal dust emissions with trains while those that were body treated showed only a limited reduction.

Jaffe et al. [21] examined the emissions of coal dust and diesel particulate matter (DPM) from both freight and coal trains in the Columbia River Gorge (CRG) in the state of Washington, U.S. Ferreira et al. [22] conducted full-scale tests on coal wagons in Portugal to evaluate the effectiveness of two different types of partial covers. Ferreira and Vaz [23] used scale model trains in a wind tunnel to show that more than 80 per cent reduction in dust emissions can be achieved by covering coal wagons.

Ryan and Wand [24] re-analysed Australian Rail Track Corporation's (ARTC) data on particle emissions from coal and other trains. They concluded that the trains operating on the Hunter Valley rail network are associated with elevated particulate matter concentrations as significant elevations in all four particle types – including TSP, PM_{10}, $PM_{2.5}$ and PM_1 – were observed when a train passed by the monitoring station. There was no evidence that loaded coal trains produce more dust compared to unloaded coal trains or freight trains. The findings also suggest that other contaminants such as diesel may be of more concern than coal dust. Ryan and Malecki [25] further extended the analysis of data from the ARTC on particle emissions from coal and other trains in the Hunter rail corridor based on the release of more data in the form of the number of locomotives pulling each train and precipitation records. The analysis suggests that the number of locomotives has little influence on the increased particulate levels associated with various types of trains passing (loaded and unloaded coal trains and freight trains). Rainfall data for two areas, Maitland and Cessnock, were taken into account. It was observed that the particulate levels were significantly influenced by whether or not it had rained the previous day in Maitland; however, once Maitland rainfall was taken into account, Cessnock rain had no significant influence on particulate levels.

Katestone [26] focused on current literature surrounding coal train dust management practices and measures relevant to the Hunter Valley rail corridor and other coal rail corridors in New South Wales (NSW). Irrespective of the type of train-loaded, unloaded, freight and passenger – the dust levels increased near the rail corridor. Water or veneer suppressant claimed to reduce top-of-wagon

emissions by 50–99%. Wagon lids were estimated to reduce dust off the top of the wagons by 99% but have significant disadvantages. NSW EPA [27] completed a compliance audit programme of 11 loadout facilities and 4 unloading facilities in NSW. In coal loading facilities, the audits examined management practices that could minimise primary sources of coal dust emissions from loaded coal trains during rail transport. The coal loading facilities that were fully automated and equipped with loading chutes achieved a consistent load profile height, shape, and distribution and reduced dust emissions during transport. Monitoring ensured that the wagon doors were firmly closed before the train departed the loading station, thereby ensuring that coal was not spilled from the bottom of loaded wagons during transit. Also, at coal unloading facilities, the audits examined management practices in order to help minimise coal dust emissions from unloaded coal trains during rail transport. Closed circuit television cameras at unloading facilities automatically identified large quantities of 'hung up' coal in unloaded wagons. Also, controls were present to ensure wagon doors were closed after unloading. Coal overflows were identified by high hopper alarms, preventing coal being transferred into adjacent ballast or building up on the wagon wheels and axles.

Based on the literature survey, since the Emission Factor Development Study (EDS) that was conducted in 1978 and 1979 [28] to develop Particulate Matter emission factors, no studies have been carried for the estimation of dust emission for coal loading facilities. The EDS forms one of the bases of EPA [29]-published Compilation of Air Pollutant Emission Factors (AP-42 documents). The primary objective of this study was to conduct a comparative analysis of dust emission by the EPA AP-42 emission factor estimation equations (AP-42 Dust Emission Estimation) and the methodology used in development of AP-42 equations (Type-2 Dust Emission Estimation).

Although the EPA's AP-42 emission factor estimation equations may over-estimate emissions, these equations are currently the only basis for dust emission estimation applications provided by the EPA. Therefore, EPA's emission estimation model is still widely used for permitting purposes. A previous publication by the authors [14] indicated three major causes of potential estimation error by EPA's emission factor estimation equations as follows:

(1) non-representative data collected from the mines,
(2) the methodology used in the development of emission factors and
(3) simplifications in the development of regression equations.

In the Type-2 model, emission factors were estimated directly based on the concentration values collected from the mine, instead of using multiple regression functions. Comparison of the results from Type-2 model with the values determined by EPA original equations demonstrates the impact of using non-representative data in the model development. Not only does this method avoid inaccurate estimation due to using non-representative data from western US coal mines, but it also helps avoid inaccuracies due to using regression functions. Type-2 dust emission estimation model can be used in case where application of EPA methodology using data collected from the field is desired.

2. Estimation of dust emission

For the determination of air emissions from non-stack sources, the most commonly used method is based on multiplication of the activity rate (in units of weight, volume, distance or duration per unit of time) by the appropriate EFs [29]. It can be expressed as:

$$E_i = A \cdot \mathrm{EF}_i \cdot \left(1 - \frac{CE_i}{100}\right) \tag{1}$$

where E_i is emission rate of pollutant i [kg/hr], A is production rate [t/hr], EF_i is uncontrolled emission factor of pollutant i [kg/t], CE_i is overall emission reduction efficiency of pollutant i [%] and $\mathrm{PM}_{2.5,}$ PM_{10} and TSP are pollutants i.

The overall emission reduction efficiency of pollutant for loading trains is given by 70% for enclosure, 99% for enclosure and use of fabric filters and 90% control allowed for water sprays with chemicals [30]. Also, the reduction efficiency when using surge bins and loadout bins is greater than 99% [31].

EPA [29] published the Compilation of Air Pollutant Emission Factors (AP-42), which is primarily used to estimate emission rates. The AP-42 document is based on data collected from western surface coal mines and also includes equations for train loading facilities. This document includes a number of equations to determine fugitive dust EFs as well as process information for more than 200 classes of air pollution sources. These equations are based on the observations of dust concentrations from specific industrial operations and can be used to determine the amount of dust produced by a particular operation. In section 9 of chapter 11 of the EPA's AP-42, information regarding western U.S. surface coal mining is provided. This section includes EF estimation equations for blasting, truck loading, bulldozing, dragline, grading, aggregates handling, storage piles and train loading facilities.

Fugitive dust emissions are expected from the loading of coal into trains. The empirical EF estimation equation of particulate emissions generated by either type of drop operation for loading of aggregate onto storage piles (batch or continuous drop operations) is provided in section 2.4 of chapter 13 in the AP-42 document (AP-42 13.2.4). The emission estimations from the loading of coal into trains uses the same equations as that used for emissions generated by either type of drop operation for loading of aggregate onto storage piles [32]. The quantity of dust emissions from the loading of aggregate onto storage piles varies with volume of aggregate passing through the storage cycle. The EF for the quantity of emissions per quantity of material is estimated using the following equation:

$$\mathrm{EF}_i = K \cdot 0.0016 \cdot \left(\frac{U}{2.2}\right)^{1.3} \cdot \left(\frac{M}{2}\right)^{-1.4} \tag{2}$$

where EF_i is uncontrolled emission factor of pollutant i [kg/t], U is mean wind speed [m/s] and M is material moisture content [%], and K for TSP, PM_{10}, and $\mathrm{PM}_{2.5}$ are 0.74, 0.35 and 0.053, respectively.

The ranges of source conditions used in developing Equation (2) include silt content of 0.44–19%, wind speed of 0.6–6.7 m/s and moisture content of 0.25–4.8%. Thus, the AP-42 Dust Emission Estimation method used in the methodology calculates dust emission based on the Equation (2) proposed in the EPA AP-42.

The EPA employed stability classes along with Pasquill–Gifford (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 provide a qualitative approach to determine atmospheric stability. The Pasquill stability class refers to the stability of air layers near the ground. It is based on wind speed and insolation (incoming solar radiation). Insolation is the rate of radiation from the sun received per unit of earth's surface [6]. The six categories of Pasquill stability classes are given in Schnelle and Dey [6].

After the computation of the stability class, the plume spread (σ_y and σ_z) used in the development of AP-42 11.9 equations can be computed at a certain downwind distance x by choosing one of the several available equations:

(a) The plume spread (σ_y and σ_z) is presented in an analytical form by Green et al. [33] as

$$\sigma_y(x) = \frac{K_1.x}{\left[1 + \left(\frac{x}{K_2}\right)\right]^{K_3}} \tag{3}$$

$$\sigma_z(x) = \frac{K_4 \cdot x}{\left[1 + \left(\frac{x}{K_2}\right)\right]^{K_5}} \tag{4}$$

where the constants K_1, K_2, K_3, K_4 and K_5 for various stability classes are given in Green et.al. [33] and the downwind distance x is in metres.

The above σ_y, σ_z values were derived [34] primarily from a diffusion experiment in flat terrain, where a non-buoyant tracer gas was released near the surface and measured (3-min averages) downwind up to a distance of 800 m from the source.

(b) A second set of equations that approximately fit the Pasquill–Gifford curves [35] is used to calculate σ_y and σ_z (in metres) for the rural mode. These equations are being used in EPA's Industrial Source Complex (ISC3) model.

$$\sigma_y = 465.11628 \cdot (x) \cdot \tan(\mathrm{TH}) \tag{5}$$

where

$$\mathrm{TH} = 0.017453293 \cdot [c - d \cdot \ln(x)] \tag{6}$$

In Equations (5) and (6) the downwind distance x is in kilometres, and the coefficients c and d for various Pasquill Stability Categories are given in EPA [36].

The equation used to calculate σ_z is of the form:

$$\sigma_z = a \cdot x^b \tag{7}$$

where the downwind distance x is in kilometres and σ_z is in metres. The coefficients a and b for various Pasquill Stability Categories are also given in EPA [36].

The ISC3 model is based on the Gaussian Equation (8) for point source emissions, which is given as the following for the ISC3 model [36]:

$$\chi = \frac{Q \cdot K \cdot V \cdot D}{2\pi \cdot u_s \cdot \sigma_y \cdot \sigma_z} \exp\left[-0.5 \cdot \left(\frac{y}{\sigma_y}\right)^2\right] \tag{8}$$

where Q is pollutant emission rate [g/s]; K is scaling coefficient to convert calculated concentrations to desired units (default value of 1×10^6); V is vertical term (dimensionless); D is decay term (dimensionless); u_s is mean wind speed at release height [m/s]; σ_y and σ_z are standard deviation of lateral and vertical concentration distribution [m]; χ is hourly concentration at downwind distance x [μg/m^3]; and y is crosswind distance from source to receptor [m].

Mean wind speed u_s [m/s] at release height is

$$u_s = u_{\mathrm{ref}} \cdot \left(\frac{h_s}{z_{\mathrm{ref}}}\right)^p \tag{9}$$

where u_{ref} is observed wind from a measured reference height (z_{ref}) [m/s]; h_s is stack height [m]; p is wind profile exponent (dimensionless) and given by EPA [36] for various stability categories; and z_{ref} is measured reference height for wind speed [m].

EPA completed a three-phase study at a surface coal mine in Wyoming in 1994–1995 to review the entire mining operation for dust dispersion and validate ISC3 [37,38]. The amount of emissions from the operation was determined using the emissions factors equations from the EPA's AP-42 document. These calculated emissions were used as input for the ISC3 model to complete dispersion modelling. Field testing was completed by placing six PM_{10} sampling stations throughout the surface mining operation to validate the ISC3 model. According to the study, there was a significant over-prediction of PM_{10} emissions from the surface coal mining operation by the ISC3 model [38]. Also, the study showed an over-prediction of more than a factor of 2 at a single site where modelled versus measured results were compared [37]. In the above EPA study, no attempt was made to determine the source of the over-prediction of PM_{10}. Consequently, it is not known whether the over-prediction was caused by the emission estimation methods (AP-42), by the dispersion model, or both.

Cole and Zapert [39] completed a study and concluded that ISC3 model overpredicted the actual PM_{10} concentrations ranging from a factor of less than 1 (87% over-prediction) to a factor of 5. Authors concluded two reasons of over-prediction – (i) the model failed to account any deposition of the particulates and (ii) the EF for unpaved roads overpredicted the amount of emissions from haul trucks. Reed et al. [40] also completed a study on the ISC3 model using a theoretical rock quarry and concluded that the majority of PM_{10} concentrations are caused by hauling operations and the haul truck emissions factors may be part of the cause of the over-prediction of PM_{10} concentrations by the ISC3 model. Reed [41] described a model called the Dynamic Component Programme (DCP) based on a Gaussian equation similar to that used by the ISC3 model for predicting dust dispersion from haul trucks.

$$\chi = \frac{Q \cdot K}{2\pi \cdot u \cdot \sigma_y \cdot \sigma_z} \exp\left[-0.5 \cdot \left(\frac{y}{\sigma_y}\right)^2\right] \tag{10}$$

where Q is pollutant emission rate [g/s]; K is scaling coefficient to convert calculated concentrations to desired units (default value of 1×10^6); u is mean wind speed [m/s]; σ_y and σ_z are standard deviation of lateral and vertical concentration distribution [m]; χ is hourly concentration at downwind distance x [μg/m^3]; and y is crosswind distance from source to receptor [m].

The main difference between the DCP and the ISC3 model is the methodology of applying the source emissions when predicting dust dispersion from that source [41]. In the DCP, the use of the vertical and the decay terms are eliminated. The decay term D is assumed to be one as the default value of decay coefficient is zero. The vertical term V is calculated using the stack or emission height, the receptor height, and the mechanical mixing height. As the receptor height and the emission height for haul trucks are nearly equal, and also the emission of the haul trucks will never be above the mechanical mixing height, V can be eliminated [41]. Similarly, in the loading of trains using surge bins, emission height and receptor height are nearly equal. Therefore, the equations used in the development of DCP can be used. For the Type-2 Dust Emission Estimation method, EFs are determined based on data collected from the mine. This method uses the conversion of concentration values into emission rates using the P–G dispersion curves and the backward Gaussian dispersion model (Equation 11).

$$Q = \frac{2\pi \cdot u \cdot \sigma_y \cdot \sigma_z \cdot \chi}{K \cdot \exp\left[-0.5 \cdot \left(\frac{y}{\sigma_y}\right)^2\right]} \tag{11}$$

This is the same approach that was employed by EPA in the conversion of concentration values into emission rates.

3. Methodology

Data on dust emission were collected at a loading facility that operates along with a coal mine in West Virginia. Train cars are loaded through the surge bin at the production rate of 3265 t/hr. The time to load a train car is approximately 90 s. A total of 131 cars were loaded during the collection period on the first day and a total of 130 cars were loaded during the second day. Dust concentrations at different distances and locations were collected during the field trip (Figures 1–3). TSI DustTrak DRX 8534 real-time aerosol monitoring instrument was used for collecting real-time measurements of dust concentration. The instruments provide particle matter concentrations in five size ranges – TSP, PM_{10}, PM_4 (Respirable), $PM_{2.5}$ and PM_1. The Kestrel 4500 Weather Metre was used to collect necessary weather parameters required for the study such as wind speed, wind direction, temperature, humidity and atmospheric pressure. Various collected metrological and other parameters are displayed in Table 2. The loading point for trains had enclosures and fluid was being sprayed into the empty train cars before

Figure 1. Dust sampling at location 1 (5.18 m away from the source).

Figure 2. Dust sampling at location 2 (13.9 m away from the source).

being loaded. Overcast conditions were present on the first day and the data were collected at night, while on the second day, the data were collected in the afternoon and the sky was clear.

Dust sampling was conducted around the loading point at different locations. On the first day, two samples (1 and 2) were collected at different distances (Location 1 and 2) from the emission source.

Figure 3. Dust sampling at location 3 (4.24 m away from the source).

Table 2. Parameters collected at the site.

Location	Sample number	Distance from source (m)	Start time (pm)	Sample duration (min)	Moisture (%)	Silt (%)	Wind speed (m/s)	Temp (°C)	Stability class
1	1	5.18	9.50	47	5.9	0.72	1.12	11	D
2	2	13.9	10.46	8	5.9	0.72	1.12	10.5	D
3(a)	3	4.24	12.29	38	6.05	0.74	1.07	9	B
3(b)	4	4.24	1.33	62	6.05	0.74	1.3	9	B
3(c)	5	4.24	3.22	15	6.05	0.74	0.09	9.8	B
3(d)	6	4.24	3.42	120	6.05	0.74	0.36	9.8	B

Figure 4. Dust sampling at location 3 (4.26 m from the ground level).

The instrument was placed on a table at a height of 1 m. Four samples (3, 4, 5 and 6) were collected on the second day at different time durations of the day, keeping the instrument constant at a particular location 3. The height of the instrument from the ground level at location 3 is 4.26 m (Figure 4). The coal properties such as silt content and moisture content were provided by the mine. After the field measurements were completed, dust emission for the train loading point was estimated based on two methods: (a) emission determined directly using the EPA AP-42 EF estimation equations (AP-42 Dust Emission Estimation) and (b) emission estimated based on the methodology used in the development of AP-42 equations (Type-2 Dust Emission Estimation). Once the emission rates were calculated by the EPA AP-42 method (Equation (2)) and by the Type-2 estimation method (Equation (11)), comparative analysis was conducted.

4. Results and discussion

Dust concentration data were collected for different size fractions, including PM_1, $PM_{2.5}$, PM_4, PM_{10} and TSP. Figure 5 shows the concentration data for different dust size fractions collected for a 47-min period of coal train loading at Location 1. It can be observed that there was no significant change in the initial concentration of each size fraction. The initial concentrations of PM_1, $PM_{2.5}$, PM_4, PM_{10} and TSP are 0.004, 0.006, 0.008, 0.009 and 0.009 mg/m^3, respectively. However, a few seconds after dumping coal into the train car, the concentrations increased rapidly followed by a decrease in concentration. After 90 s, the concentrations of PM_1, $PM_{2.5}$, PM_4, PM_{10} and TSP increased to 0.003, 0.007, 0.01, 0.024 and 0.024 mg/m^3, respectively. Thus, a cycle of low concentration followed by high concentration and again low concentration was observed. The maximum concentration of TSP was 0.139 mg/m^3 at 10:27:40 pm at Location 1. Figure 6 shows the concentration data for different dust size fractions collected for an 8-min period of coal train loading at Location 2. The maximum concentration of TSP was 0.049 mg/m^3 at 10:46:30 pm at Location 2. In both Figures 5 and 6, the concentration of PM_1 and $PM_{2.5}$ did not change significantly. The value of PM_1 in Figure 5 varies from 0.003 to 0.006 mg/m^3 and in Figure 6 varies from 0.004 to 0.006 mg/m^3. The value of $PM_{2.5}$ in Figure 5 varies from 0.004 to 0.007 mg/m^3 and in Figure 6 varies from 0.006 to 0.007 mg/m^3.

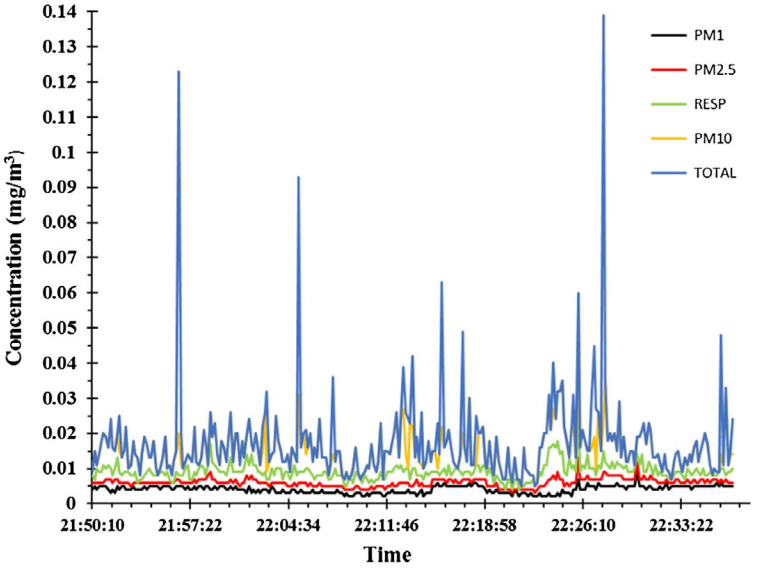

Figure 5. Dust concentration for a 47-min period of coal train loading at Location 1 (Sample 1).

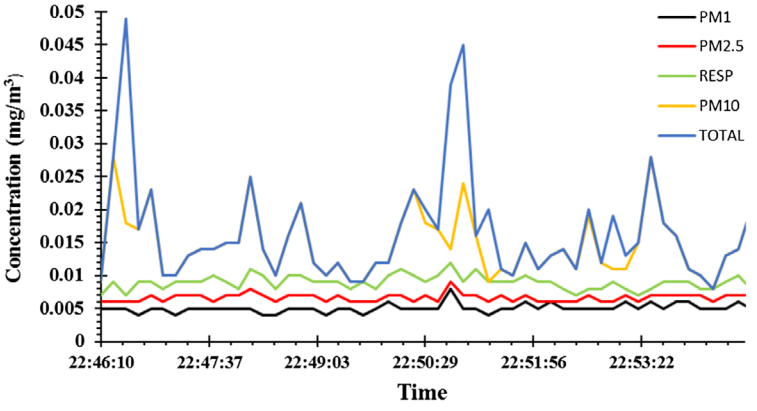

Figure 6. Dust concentration for an 8-min period of coal train loading at Location 2 (Sample 2).

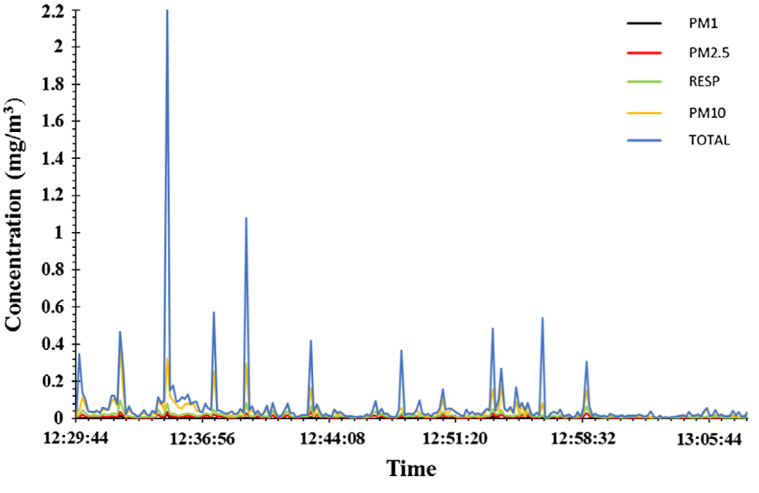

Figure 7. Dust concentration for a 38-min period of coal train loading at Location 3 (Sample 3).

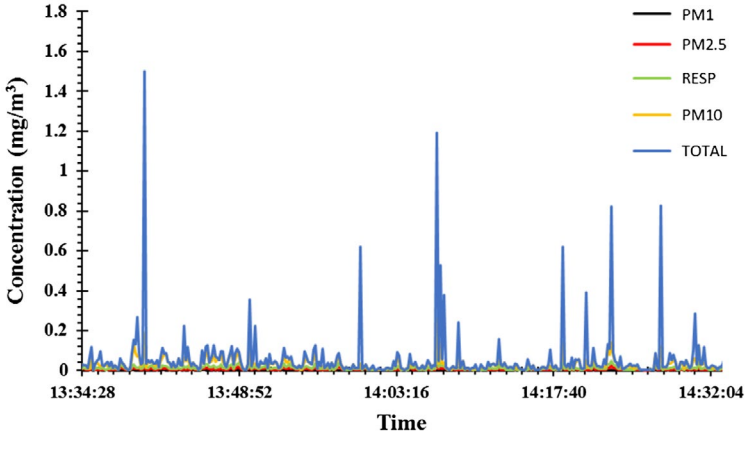

Figure 8. Dust concentration for a 62-min period of coal train loading at Location 3 (Sample 4).

Figures 7–10 show the concentration data for different dust size fractions collected at different time intervals as well as periods of coal train loading at Location 3. The dust concentration for a 38-min period of coal train loading at Location 3 at a distance 4.24 m from loading point is shown in Figure 7. It can be observed that the dust concentration of all particulates was constantly low after 12:58:32 pm due to a break in train loading. The dust concentration for 62- , 15- and 120-min periods of train loading at Location 3 is shown in Figures 8–10. A cycle of low concentration followed by high concentration and again low concentration is observed. The value of PM_1 in Figure 10 varied from 0 to 0.015 mg/m^3, while $PM_{2.5}$ varied from 0.002 to 0.026 mg/m^3. The concentration of PM_1 and $PM_{2.5}$ does not significantly change (Figure 10). However, the concentration of TSP changed significantly. The maximum concentration of TSP was observed at 5:15:39 pm, which is 1.6 mg/m^3 and the minimum observed value of TSP was 0.003 mg/m^3.

The AP-42 Dust Emission Estimation method is based on the AP-42 EF estimation Equations (1 and 2). The loading facility uses surge bin to load the train cars, so the reduction efficiency (*CE*) is 99% [31]. Table 3 shows the calculation of dust emissions using Equations (1) and (2). The wind speed at Locations 1 and 2 was 1.12 m/s and the moisture content of coal was 5.9%. The emission rate of TSP, PM_{10} and $PM_{2.5}$ at Location 1 and 2, based on the AP-42 estimation method, is 0.0035, 0.0017 and 0.0002 kg/hr, respectively. The wind speed at Location 3 varied with time of data collection while

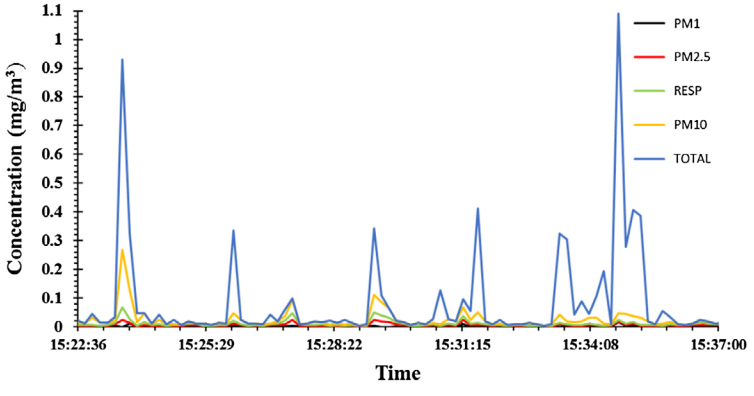

Figure 9. Dust concentration for a 15-min period of coal train loading at Location 3 (Sample 5).

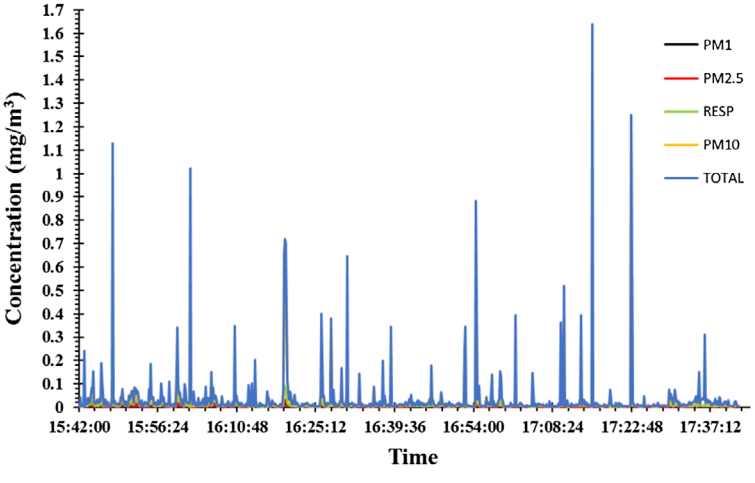

Figure 10. Dust concentration for a 120-min period of coal train loading at Location 3 (Sample 6).

Table 3. Calculation of AP-42 dust emissions based on Equations (1) and (2).

	Sample	Location	EF (kg/t) (Equation 2)	*E* (kg/hr) (Equation 1)
$PM_{2.5}$	1	1	7.7×10^{-6}	0.0002
	2	2	7.7×10^{-6}	0.0002
	3	3(a)	7.1×10^{-6}	0.0002
	4	3(b)	9.0×10^{-6}	0.0003
	5	3(c)	2.8×10^{-7}	9.14×10^{-6}
	6	3(d)	1.7×10^{-6}	5.54×10^{-5}
PM_{10}	1	1	5.1×10^{-5}	0.0017
	2	2	5.1×10^{-5}	0.0017
	3	3(a)	4.7×10^{-5}	0.0015
	4	3(b)	5.9×10^{-5}	0.0019
	5	3(c)	1.8×10^{-6}	6.04×10^{-5}
	6	3(d)	1.1×10^{-5}	0.0004
TSP	1	1	1.0×10^{-4}	0.0035
	2	2	1.0×10^{-4}	0.0035
	3	3(a)	9.8×10^{-5}	0.0032
	4	3(b)	1.2×10^{-4}	0.0041
	5	3(c)	3.9×10^{-6}	0.0001
	6	3(d)	2.3×10^{-5}	0.0008

the moisture content was 6.05%. The wind speeds were 1.07, 1.3, 0.09 and 0.36 m/s, respectively. The emission rate of TSP, PM_{10} and $PM_{2.5}$ at Location 3(a), based on the AP-42 estimation method, is 0.0032, 0.0015 and 0.0002 kg/hr, respectively. The emission rate of TSP, PM_{10} and $PM_{2.5}$ at Location 3(b) is 0.0041, 0.0019 and 0.0003 kg/hr, respectively. The emission rate of all the particulates at Location 3 (c) and 3 (d) are relatively lower than other locations. The emission rate of TSP, PM_{10} and $PM_{2.5}$ at Location 3(c) is 0.0001, 6.04×10^{-5} and 9.14×10^{-6} kg/hr, respectively. The emission rate of TSP, PM_{10} and $PM_{2.5}$ at location 3(d) is 0.0008, 0.0004 and 5.54×10^{-5} kg/hr, respectively.

As the cloud cover was full on the first day of data collection, the stability class is D for locations 1 and 2. The stability class for location 3 was B as the cloud cover was nil, and the daytime insolation was slight. The plume spread σ_y and σ_z are calculated using Equations (3) and (4). Table 4 shows the calculation of Type-2 dust emissions based on Equations (3) and (4). The measured reference height for wind speed (z_{ref}) is 1.6 m, and the stack height (h_s) is 4.34 m for Locations 1 and 2. For Location 3 the measured reference height for wind speed (z_{ref}) is 4.32 m. The mean wind speed calculated at Location 1, 2, 3(a), 3(b), 3(c) and 3(d) is 1.12, 1.12, 1.07, 1.3, 0.09 and 0.36 m/s, respectively. The average concentration (χ in mg/m^3) of respective particulate at a particular location is used in the calculations.

Table 4. Calculation of Type-2 dust emissions based on Equations (3) and (4).

	Sample	Location	χ (mg/m^3)	*Q* (g/s) (Equation 11)	*Q* (kg/hr)
$PM_{2.5}$	1	1	0.006	4.89×10^{-6}	1.76×10^{-5}
	2	2	0.007	4.08×10^{-5}	1.4×10^{-4}
	3	3(a)	0.008	1.88×10^{-5}	6.7×10^{-5}
	4	3(b)	0.007	1.98×10^{-5}	7.1×10^{-5}
	5	3(c)	0.006	1.18×10^{-6}	4.2×10^{-6}
	6	3(d)	0.005	3.95×10^{-6}	1.4×10^{-5}
PM_{10}	1	1	0.015	1.22×10^{-5}	4.4×10^{-5}
	2	2	0.015	8.7×10^{-5}	3.1×10^{-4}
	3	3(a)	0.037	8.69×10^{-5}	3.1×10^{-4}
	4	3(b)	0.044	1.2×10^{-4}	4.4×10^{-4}
	5	3(c)	0.025	4.94×10^{-6}	1.7×10^{-5}
	6	3(d)	0.022	1.7×10^{-5}	6.2×10^{-5}
TSP	1	1	0.018	1.4×10^{-5}	5.2×10^{-5}
	2	2	0.019	1.1×10^{-4}	3.9×10^{-4}
	3	3(a)	0.066	1.5×10^{-4}	5.5×10^{-4}
	4	3(b)	0.085	2.4×10^{-4}	8.6×10^{-4}
	5	3(c)	0.096	1.89×10^{-5}	6.8×10^{-5}
	6	3(d)	0.04	3.16×10^{-5}	1.1×10^{-4}

Table 5. Calculation of Type-2 dust emissions based on Equations (5) and (7).

	Sample	Location	χ (mg/m^3)	Q (g/s) (Equation 11)	Q (kg/hr)
$PM_{2.5}$	1	1	0.006	9.0×10^{-6}	3.2×10^{-5}
	2	2	0.007	6.25×10^{-5}	2.2×10^{-4}
	3	3(a)	0.008	3.17×10^{-5}	1.1×10^{-4}
	4	3(b)	0.007	3.35×10^{-5}	1.2×10^{-4}
	5	3(c)	0.006	2.0×10^{-6}	7.2×10^{-6}
	6	3(d)	0.005	6.68×10^{-6}	2.4×10^{-5}
PM_{10}	1	1	0.015	2.25×10^{-5}	8.1×10^{-5}
	2	2	0.015	1.3×10^{-4}	4.8×10^{-4}
	3	3(a)	0.037	1.4×10^{-4}	5.2×10^{-4}
	4	3(b)	0.044	2.1×10^{-4}	7.5×10^{-4}
	5	3(c)	0.025	8.3×10^{-6}	3.0×10^{-5}
	6	3(d)	0.022	2.93×10^{-5}	1.0×10^{-4}
TSP	1	1	0.018	2.7×10^{-5}	9.7×10^{-5}
	2	2	0.019	1.6×10^{-4}	6.1×10^{-4}
	3	3(a)	0.066	2.6×10^{-4}	9.4×10^{-4}
	4	3(b)	0.085	4.0×10^{-4}	1.4×10^{-3}
	5	3(c)	0.096	3.2×10^{-5}	1.2×10^{-4}
	6	3(d)	0.04	5.34×10^{-5}	1.9×10^{-4}

The emission rate of $PM_{2.5}$ using Equation 11 at Locations 1 and 2 is 1.76×10^{-5} and 1.4×10^{-4} kg/hr, respectively. The emission rate of PM_{10} using Equation 11 at Locations 1 and 2 is 4.4×10^{-5} and 3.1×10^{-4} kg/hr, respectively. Also, the emission rate of TSP using Equation 11 at Locations 1 and 2 is $5.2\times10^{-5}$and 3.9×10^{-4} kg/hr, respectively. The emission rate of the particulates for Location 3 varies greatly because of variation in the wind speed observed at different durations of the day. Among four observations at Location 3, the emission rate of $PM_{2.5,}$ PM_{10} and TSP are highest at location 3(b). The values at location 3(b) are 7.1×10^{-5}, 4.4×10^{-4} and 8.6×10^{-4} kg/hr, respectively.

Table 5 shows the calculation of Type-2 dust emissions based on Equations (5) and (7). The cloud cover was full on the day of data collection, so the stability class is D. The stability class for Location 3 was B, as the cloud cover was nil, and the daytime insolation was slight. The plume spread σ_y and σ_z are calculated using Equations (5) and (7). The average concentration (χ in mg/m^3) of respective particulate at a particular location is used in the calculations. The emission rate of $PM_{2.5}$ using Equation 11 at Location 1 and 2 is 3.2×10^{-5} and 2.2×10^{-4} kg/hr, respectively. The emission rate of PM_{10} using Equation 11 at Locations 1 and 2 is 8.1×10^{-5} and 4.8×10^{-4} kg/hr, respectively. Also, the emission rate of TSP using Equation 11 at Locations 1 and 2 is 9.7×10^{-5} and 6.1×10^{-4} kg/hr, respectively. The emission rate of the particulates for Location 3 varies greatly because of variation in the wind speed observed at different durations of the day. Among four observations at Location 3, the emission rate of $PM_{2.5,}$ PM_{10} and TSP are highest at location 3(b). The values at Location 3(b) are 1.2×10^{-4}, 7.5×10^{-4}, and 1.4×10^{-3} kg/hr.

Figure 11 shows the comparison of $PM_{2.5}$ emissions at coal train loading facility using AP-42 dust emission and Type-2 dust emission using different equations. The AP-42 dust emissions for $PM_{2.5}$ exceeds on average 4.9 times the field-based emissions determined by the Type-2 method using Equations (3) and (4), while the AP-42 dust emissions for $PM_{2.5}$ exceeds on average 2.8 times the field-based emissions determined by the Type-2 method using Equations (5) and (7).

As per Figure 12, the AP-42 dust emissions for PM_{10} exceeds on average 10.2 times the field-based emissions determined by the Type-2 method using Equations (3) and (4). Also, the AP-42 dust emissions for PM_{10} exceeds on average 5.8 times the field-based emissions determined by the Type-2 method using Equations (5) and (7).

Figure 13 indicates that the AP-42 dust emissions for TSP exceeds on average 15.7 times the field-based emissions determined by the Type-2 method using Equations (3) and (4). Also, the AP-42 dust emissions for TSP exceed on average 8.9 times the field-based emissions determined by the Type-2 method using Equations (5) and (7).

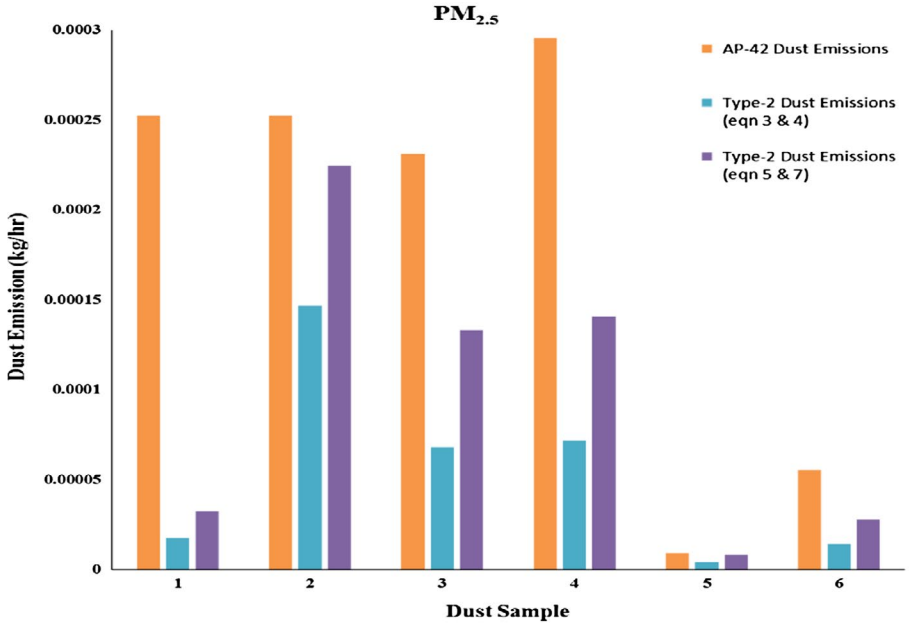

Figure 11. Comparison of $PM_{2.5}$ emissions at coal train loading point.

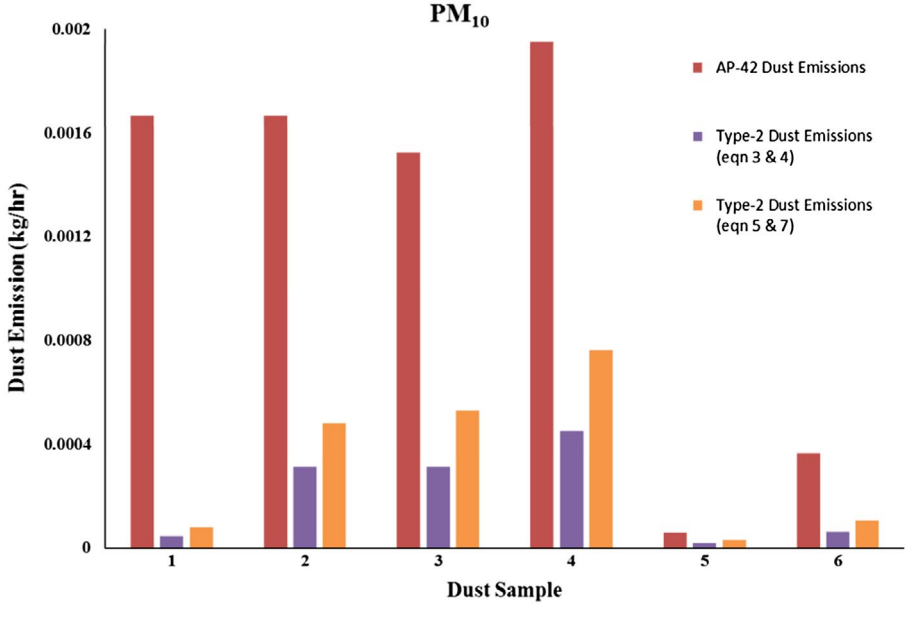

Figure 12. Comparison of PM_{10} emissions at coal train loading point.

The results show that the AP-42 Dust Emission Estimation method overestimates the emissions from coal train loading for this particular loading facility in West Virginia. The development of the AP-42 equations based on train loading facilities in west may not be applicable for train loading facilities in east. Also, with the increase in particle size, the ratio of dust emissions based on the AP-42 method and the Type-2 method increases.

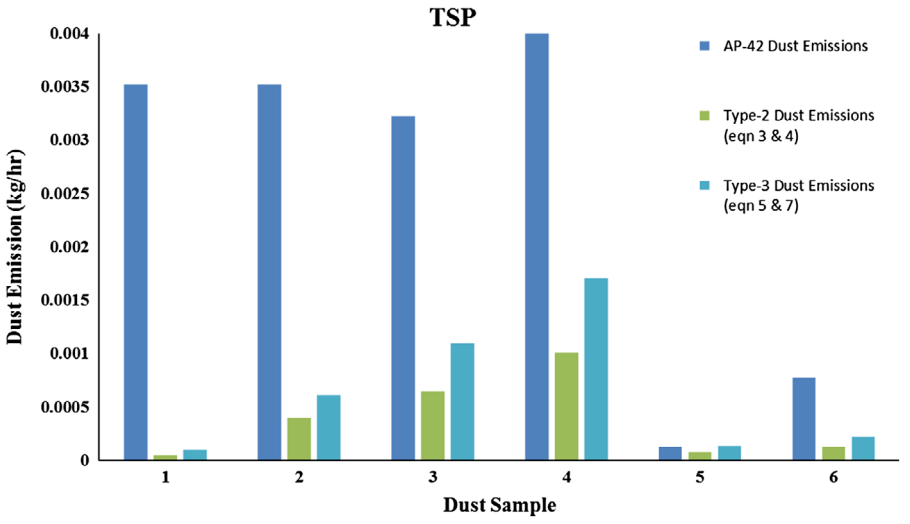

Figure 13. Comparison of TSP emissions at coal train loading point.

In future work, the Dust Emission Estimation should be based on the methodology suggested in the AERMOD model, which is the preferred dust dispersion model for regulatory applications in the estimation of dust dispersion. The EFs estimated by the AERMOD method are also based on concentration data from the mine. However, the method employed to convert concentrations to emission rates is not the same as the method used by the EPA's AP-42. The main difference between the EPA's AP-42 and the AERMOD method is the way the plume dispersion variables (σ_y and σ_z) are calculated. The EPA's AP-42 method uses P-G dispersion curves, whereas AERMOD uses Monin– Obukhov length to estimate the plume dispersion variables.

5. Conclusions

In this study, the current EPA method for estimation of dust emission for coal loading facilities has been examined, and a comparative analysis of dust emission between AP-42 Dust Emission Estimation and Type-2 Dust Emission Estimation has been carried out for a particular loading facility in West Virginia. The comparison shows that the AP-42 Dust Emission Estimation method overestimates the emissions from loading of coal trains for this specific loading facility.

Major causes of over-prediction may include the following:

(i) The methodology used for calculation of the emission rates. The original AP-42 Dust Emission Estimation was developed by EPA primarily for TSP; however, the focus has shifted to fine and inhalable particles, i.e. PM_{10} and $PM_{2.5,}$ because they pose the biggest environmental and health threat. Cowherd [42] conducted studies on fine particles and found that concentration measurements used to develop EFs for $PM_{2.5}$ in AP-42 were higher by a factor of two, as compared to $PM_{2.5}$ measurements from EPA federal reference method (FRM) samplers. Currently, the ratio of $PM_{2.5}$ / PM_{10} in AP-42 ranges from 0.15 to 0.4 for most fugitive dust sources. However, studies showed the ratio to be in the range of 0.1 to 0.15. Based on the results of the study, EFs for $PM_{2.5}$ in AP-42 were revised for the following four fugitive dust source categories: paved roads, unpaved roads (public and industrial), aggregate handling and storage piles and industrial wind erosion.

(ii) Only two variables, i.e. moisture content and wind speed, are considered for AP-42 emission estimation calculations, which may be inadequate.

(iii) The functions are intended to bracket 'worst case' conditions.
(iv) For the most of the operations, samples were collected in a specific season and during daytime. Therefore, the models may not be representative for all working conditions.

The results of this study suggest the following:

(i) A reconsideration of EFs for train loading operations and development of improved methods for estimation of EFs.
(ii) The use of on-site meteorological data where the estimation of dust particulate concentration is required for train loading operations for a particular site.

This research may assist mining and environmental professionals in quantifying dust emission at train loading facilities.

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ORCID

Bisleshana B. Prakash http://orcid.org/0000-0002-7859-1766
Vladislav Kecojevic http://orcid.org/0000-0002-6102-4378
Ali Lashgari http://orcid.org/0000-0002-5174-8882

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