J. ENVIRONMENTAL SYSTEMS, Vol. 31(3) 279-288, 2004-2005

FUGITIVE DUST EMISSIONS FROM MINING AREAS

B. CHAKRADHAR
Regional Research Laboratory, Bhopal, India

ABSTRACT

Mining operations are one of the most predominant sources of atmospheric fugitive dust, released to the air with a size smaller than 100 microns. Field studies were carried out on an unpaved road stretch of 1 km length at a mine site by installing dust samplers in upwind and downwind directions. The total weight of the 6- to 12-wheeled vehicles traveling with mine materials is in the range of 6-15 tons. The loaded vehicle speeds run from 15 to 25 kmph with an ambient wind speed of 0.5 to 8.5 kmph. The silt content of road surface ranges from 7% to 9.4%; moisture content varies between 2.5% and 7.4%. The test runs were carried out five times daily for 30 minutes. Fugitive dust concentrations observed at three downwind directions were between 5132 $\mu g/m^3$ and 17282 $\mu g/m^3$. The emission factors estimated varied between 0.22 to 0.74 g/vkt with a predicted dust particulate matter varying from 4888 $\mu g/m^3$ to 16444 $\mu g/m^3$.

INTRODUCTION

Fine particles that are generated and suspended in the atmosphere by various activities, especially from mining activities, are referred as fugitive dust. Dust particles as small as a few nanometers and as large as 100 microns can be measured in the atmosphere [1]. Fugitive dust is formed when fine particles generated from mine excavation and transportation of mined materials become entrained in the air

doi: 10.2190/ES.31.3.e
http://baywood.com

by the turbulent action of wind through mechanical disturbances of fine soil materials. Depending upon the factors such as climate, geology, and method of mining, the potential exists for greatly increased dust levels in the environment surround the mine site. The open cut mining method often involves the excavation, transport and handling of large tonnages of material, increasing the potential of dust to be produced. The fugitive dust generated from vehicular traffic on unpaved roads, and from mine material transport and handling, will damage the vegetation and agriculture surrounding the mine area, through mechanics such as the blocking of leaf stomata or reduced photosynthesis because of smothered surfaces.

DUST GENERATING SOURCES IN MINING

In open cut and strip mining, the process of accessing the ore locations involves the removal of the natural land surface and creates new, unvegetated surfaces in the forms of pits, overburden dumps and tailing disposal areas [2]. The main activities carried out in open cut mines that lead to emissions to air are:

- Removing vegetation and topsoil
- Drilling and blasting of overburden
- Drilling and blasting of ore material
- Removing overburden and ore
- Transporting and stockpiling overburden
- Extracting, transporting, and dumping ore
- Workshop repair operations

The principal air emissions from mining activities consist of wind-borne dust and mine transportation on unpaved roads. The fugitive dust generation process is caused by the basic physical phenomena of pulverization and abrasion of surface materials by application of mechanical force through implements, and entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by larger wind speeds.

When a heavily-loaded vehicle travels on unpaved roads at the mining site, the force of wheels on the road surface pulverizes the surface material and dust particles are lifted and dropped from the rolling wheels. The road surface is exposed to strong air currents in turbulent shear with the surface, and dust generation is generated [3].

The main sources of fugitive dust generation considered are various types of heavy equipment used for the extraction of minerals, viz., reclaimers, stackers, bucket wheel excavators, dumpers, and bulldozers.

FUGITIVE DUST EMISSION FACTORS

In most cases, fugitive dust emissions can be estimated using emission factors which, when combined with site-specific information, can be used to determine emissions from a particular operation [4]. These factors relate the quantity of a substance emitted from a source to some measure of activity associated with the source. Common measures of activities in mining operations include distance traveled, quantity of material handled, and the duration of the mining activity. The process of calculating the emissions of fugitive dust proceeds as follows: 1) identify the unpaved road from where dust generations; 2) obtain information on basic data required to apply the equations; 3) collect data on the physical characteristics of the heavy vehicles and the unpaved road surface material, and 4) collect meteorological data at mine site.

The site studied for fugitive dust dispersion is a fluorspar mine at Kadipani near Baroda, India. The annual production of mine is 75,000 tons per year with a stripping ratio of 1:5. The overburden removal in the identified mine site area is around 6 million tons. The climate at the mine site is humid, with annual maximum temperature of 43 °C and a minimum of 5 °C. The average rainfall in the region is around 750 mm. The wind velocity observed in the mine area ranges between 0.5 to 8.5 kmph. Some 20 heavy-duty trucks operate in the mine, transporting the excavated mine product to stockpiles.

The fugitive dust generated during the transportation of mine overburden and mined material mainly depends upon the soil properties and vehicular characteristics [5], principally the silt content of unpaved road, vehicle weight and speed, and the number of wheels.

Emission factors for different mining activities can be estimated by collecting field data across all the related parameters and applying the following (AP-42) unpaved road emission factor equation for fugitive dust emission [6, 8, 9]:

$$E_{fd} = 1.7\,K\left[\frac{S}{12}\right]\left[\frac{U}{48}\right]\left[\frac{M}{3}\right]^{n}\left[\frac{W}{4}\right]^{m}$$

where

E_{fd} = dust emission factor for mine road, g/vehicle kilometer traveled (vkt)
k = particle size multiplier specific to the mine road
S = silt content of the mining road surface (%)
U = mean vehicle velocity, km/hr
M = mean vehicle weight, tons
W = mean number of wheels.
m, n = empirical constants

The unpaved roads at the fluorspar mine site have a hard, generally non-porous surface that usually dries quickly after a rainfall or watering, because traffic enhances natural evaporation rates.

FIELD EXPERIMENTAL DATA

Before starting the field sampling program at the mine site, the study area of interest is defined and the number of samples that can be collected and analyzed is determined. In the present case, an unpaved road stretch of 1 km length roadway was selected near the mine site.

The dust collection samplers were installed downwind direction and one upwind. The samplers were 15 m from the edge of the road surface, as shown in Figure 1.

The field data was collected for 30 minutes in each "exposure." Surface soil samples were collected at three locations on the unpaved road to measure silt and moisture contents. The results:

Total weight of each vehicle traveling with mined materials tons	6–12
No. of wheels of various vehicles traveled	15–25
Vehicles speeds observed (kmph)	15–25
Silt content on the road surface (%)	7.0–9.4
Moisture content (%)	2.5–7.4
Wind velocity (kmph)	0.5–8.5
Duration of dust sampling (minutes)	30
Temperature variations (°C)	5–43

The basic technique used for these measurements is the "upwind–downwind sampling method" [7]. The distance between the samplers is maintained at 250 m. A micro-processor based weather-monitoring station is installed near the mine site to collect the weather parameters prevailing in the region. Five test runs were carried out each day at timed intervals corresponding to daytime operational schedules. The samplers collected dust particles with aerodynamic diameters ranging 10 to 100 microns by drawing a constant flow rate of ambient air through a filter medium. The net weight of the filter paper and the knowledge of the total air flow during the test through the filter gives an average concentration of fugitive dust in grams per cubic meter of air.

DISCUSSIONS AND CONCLUSIONS

The results are given in Table 1. Dust concentrations at three downwind locations were observed in the range of 5132 µg/m^3 to 17282 µg/m^3. As vehicle moved from the first downwind sampler location to the third downwind location, cumulative dust plume generation is seen, with higher dust concentrations observed at the end of the unpaved road.

Critical parameters identified in the relationships between the dust emission factors and wind speed and silt content are climatic conditions and the characteristics of the vehicles moving in the mine sites. The emission factors estimated

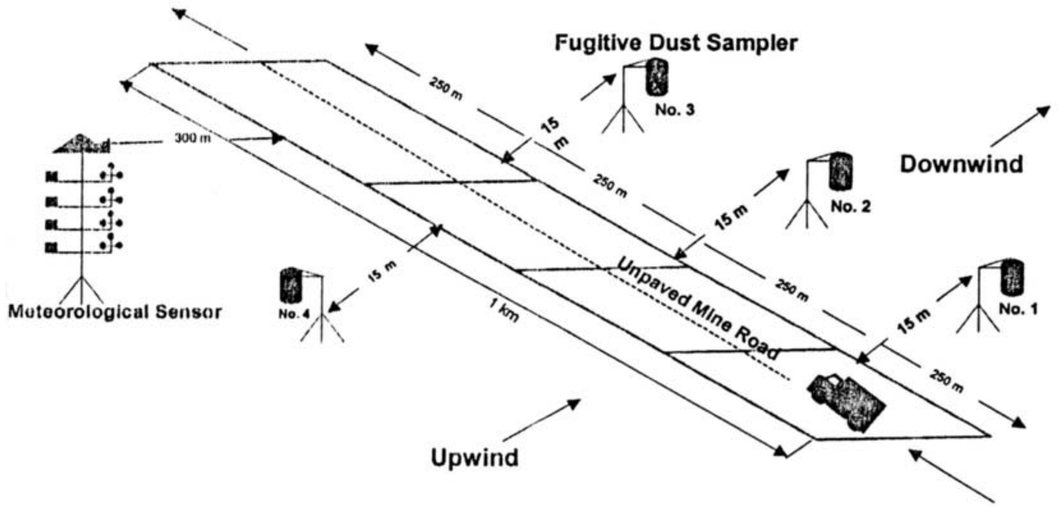

Figure 1. Conceptual diagram for fugitive dust monitoring.

Table 1. Field Data for Unpaved Road Tests

		Meteorology		Vehicle information			Site information					
Experimental details	Duration (min.)	Temp (°C)	Avg. wind speed (kmph)	Weight (tons)	No. of wheels	Vehicle speed (kmph)	Silt (%)	Moisture (%)	Predicted emission factor (gm/vkt)	Predicted PM concen. (μg/m^3)	Obs. PM concen. (μg/m^3)	Percent variation
Field Experiment: Sampling Location – I												
Test-1	30	25	3.0	6.0	6	15	7.0	7.4	0.22	4,888	5,132	4.8
Test-2	30	28	3.1	10.0	6	17	7.0	7.4	0.35	7,777	8,165	4.7
Test-3	30	33	3.9	10.0	6	18	7.0	7.4	0.37	8,222	8,568	4.0
Test-4	30	32	3.0	12.0	10	20	7.0	7.4	0.62	13,777	13,364	3.0
Test-5	30	30	2.7	12.0	10	22	7.0	7.4	0.68	15,111	15,625	3.3
Field Experiment: Sampling Location – II												
Test-1	30	25	3.0	6.0	6	15	7.4	7.3	0.23	5,111	5,352	4.5
Test-2	30	28	3.1	10.0	6	17	7.4	7.3	0.37	7,777	8,103	4.0
Test-3	30	33	3.9	10.0	6	18	7.4	7.3	0.40	8,888	9,072	2.0
Test-4	30	32	3.0	12.0	10	20	7.4	7.3	0.64	14,222	14,776	3.7
Test-5	30	30	2.7	12.0	10	22	7.4	7.3	0.70	15,555	15,928	2.4
Field Experiment: Sampling Location – III												
Test-1	30	25	3.0	6.0	6	15	7.6	7.0	0.24	5,333	5,594	4.6
Test-2	30	28	3.1	10.0	6	17	7.6	7.0	0.39	8,666	8,964	3.3
Test-3	30	33	3.9	10.0	6	18	7.6	7.0	0.41	9,111	9,748	6.5
Test-4	30	32	3.0	12.0	10	20	7.6	7.0	0.67	14,888	14,084	5.4
Test-5	30	30	2.7	12.0	10	22	7.6	7.0	0.74	16,444	17,282	4.7

from experimental data varied between 0.22 to 0.74 grams per vehicle-kilometer traveled and the predicted dust particulate matter varied between 4888 $\mu g/m^3$ to 16444 $\mu g/m^3$. The data collected during field experiments and the predicted emission factors for the unpaved roads were checked by calculating the emission levels by using the prediction equation.

The validation analysis reveals a variation of 2.4% to 4.5% between observed and predicted fugitive dust levels. The relationships between the fugitive dust predicted and vehicle speeds during summer season, with a silt content variation between 8.2 to 9.4%, are as follows:

$E_{fd} = 0.089U - 1.27$ — (8.2% silt)
$E_{fd} = 0.094U - 1.37$ — (8.6% silt)
$E_{fd} = 0.098U - 1.39$ — (9.4% silt)

where

E_{fd} = emission factor for dust, g/vkt, and
U = vehicle speed, kmph

The relationships between the fugitive dust predicted and loaded vehicles speeds are:

$E_{fd} = 0.032S + 0.05$ (18 kmph speed)
$E_{fd} = 0.055S + 0.04$ (20 kmph speed)
$E_{fd} = 0.057S + 0.05$ (21 kmph speed)
$E_{fd} = 0.102S + 0.05$ (22 kmph speed)
$E_{fd} = 0.118S + 0.06$ (25 kmph speed)

The emission factor equation has been normalized by dividing the weight by a default vehicle weight of 3 tons, representing an empty vehicle weight used in the mine. The maximum silt content in the mine site is 12% which is taken as normalizing factor for the silt component in the equation. Similarly, the maximum vehicle speed expected by an empty vehicle on unpaved roads is 46 kmph and the number of wheels of an average truck is taken to be four. These factors were used to normalize the equation in the final dimensions of the emission factor. The proportionality constant in the equation suggested will have the dimensions which provided the emission factor (in g/vkt).

The test results also show that the fugitive dust emissions are likely to change over seasons and even over diurnal periods, owing the differences in the material available for suspension. Fugitive dust concentration varied throughout a single day due to the changes in prevailing wind speeds.

The linear relationship calculated for fugitive dust generation with reference to silt content and vehicle velocity shows that silt content plays a dominant role in producing higher dust levels. The dependence of silt content on the dust level is derived by plotting the ratio of emission factor to silt content (E_{fd}/S) with reference to variable vehicle speeds in all the three seasons. The relationship observed

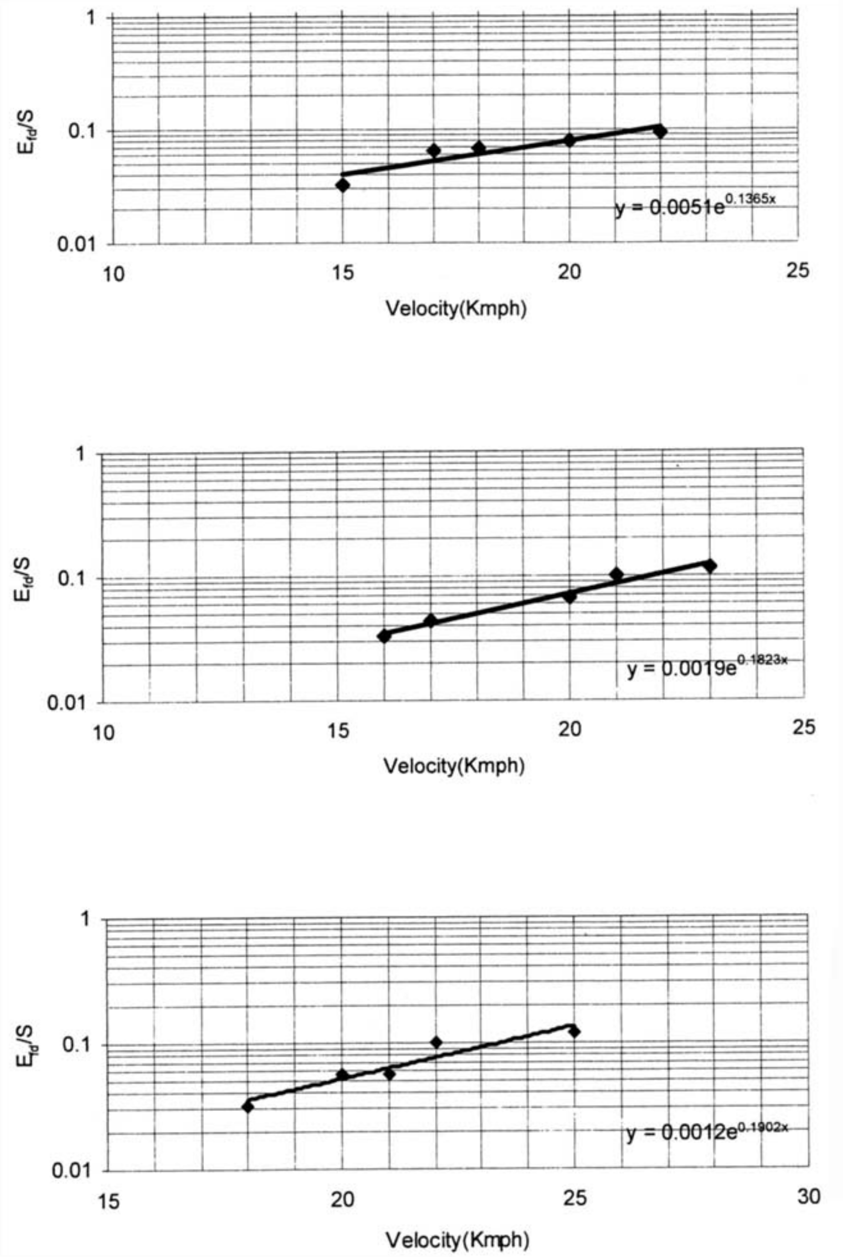

Figure 2. Variation of (E_{fd}/S) Vs velocity.

displays an exponential behavior and is shown in Figure 2. The relationships observed during different seasons are as follows:

Post monsoon: $E_{fd}/S = 0.0051e^{0.1365v}$
Winter: $E_{fd}/S = 0.0019e^{0.1823v}$
Summer: $E_{fd}/S = 0.0012e^{0.1902v}$

The dust emission data thus predicted and measured from unpaved straight roads can be incorporated into the dispersion model for estimating the various ground level concentrations of dust within the fluorspar mining area.

The test results indicate that total fugitive dust emissions from unpaved roads increases in proportion to the average vehicle speeds in the speed range of 15 to 25 kmph. The results obtained confirm the linear dependence of dust emissions on vehicle speeds on the dust roads. As the silt content of the road surface increases, fugitive dust generation increases linearly. The emission factors developed during the field experiments are incorporated into the dispersion model for line sources for estimating the ground level concentrations of dust within the fluorspar mining area.

ACKNOWLEDGMENT

The author is thankful to Director, RRL Bhopal for providing facilities and guidance in carrying out the project studies.

REFERENCES

1. U.S. Environmental Protection Agency, *Emission Inventory Requirements,* Research Triangle Park, PM-10, North Carolina, 27711, 1994.
2. National Pollutant Inventory (NPI), *Emission Estimation Technique Manual for Sand Mining and Processing,* Version 1.0, 2001.
3. NPI, Environment Australia, *Emission Estimation Technique Manual for Fugitive Emissions,* 1999.
4. NPI, Environment Australia, *Emission Estimation Technique Manual for Mining,* Version 2-3, Canberra, 2001.
5. Sustainability in Mining Dust Control, Environment, Australia, Best Practice Environment Management in Mining, 1998.
6. U.S. Environmental Protection Agency, compilation of *Pollution Emission Factors,* Vol. 1, Station and Point Area Sources, AP-42 (5th Edition), 13.2.2, Unpaved Roads, North Carolina, 1998.
7. C. Cowherd, Jr., *Development of Emission Factors for Fugitive Dust Sources,* USEPA, EPA-450/3-74-037, Research Triangle Park, North Carolina, 1974.
8. EPA, Approaches to the Modelling of Emissions from Point, Line and Area Based Sources, Victoria, 2001.

9. M. D. LaGrega, P. L. Buckingham, J. C. Evans, and Environmental Resources Management, *Hazardous Waste Management* (2nd Edition), McGraw-Hill, New York.

Direct reprint requests to:

Dr. B. Chakradhar
Scientist
NEERI Zonal Laboratory
11CT Campus, Uppal Road
Hyderabad, Pradesh
India 500 007, AP
e-mail: bcdhar1@yahoo.com –or– bchakradhar@rrlbpl.org