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Dust dispersion modeling using fugitive dust model at an opencast coal project of Western Coalfields Limited, India

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This paper examines different sources of dust generation and quantifies dust emission rates from different point, area and line sources considering background dust concentration at one of the Opencast Coal Project (OCP) of Western Coalfields Limited. Air quality modeling using Fugitive Dust Model (FDM) reveals that dust generated due to mining activities does not contribute to ambient air quality significantly in surrounding areas beyond 500 m in normal meteorological conditions. Predicted values of total suspended particulate matter (TSPM) using FDM are 68-92% of observed values. A management strategy is formulated for effective control of air pollution at source and other mitigative measures including green belt design have also been recommended.

Keywords: Dust dispersion modeling, Fugitive dust model, Opencast coalmine

Introduction

Suspended particulate matter (SPM) and respiratory particulate matter (RPM) are major pollutants in air environment of open cast coalmines. Ambient air quality depends upon concentrations of specific contaminants, emission sources and meteorological conditions. Dust generation and its dispersion has been found to be a major concern in air quality modeling of opencast coalmines that requires monitoring, protection and control of air pollution for sustainable development of mining industry[1]. Various mining activities release particulate matter (mostly dust) and gaseous pollutants such as CO, NO_x, SO_2 etc. Hence, air quality modeling is restricted to determination of particulate matter concentration[2-5]. Coal dust is major pollutant in air of open cast coal mining areas[3,6]. Dust generated from surface mining sites is the result of a force applied to bulk material for economical extraction, handling, processing, storage, and transportation[7].

Vehicle haul road intersection has been identified as the most critical source producing dust (70%) emitted from surface coalmines[8] while it was accounted to be 80-90% of PM_{10} emission[9]. Such a large amount of dust generated cause safety and health hazards such as damage of lung tissues, black lung disease, poor visibility, failure of mining equipment, increased maintenance cost etc that ultimately lowers the productivity[10,11]. Fugitive emission from various source in opencast mines depend upon many parameters[12].

In present study, an attempt has been made to generate data of ambient air quality, micrometeorology, and dust material quality for opencast coalmine, Sasti Opencast Coal Project (OCP) of Western Coalfields Ltd. (WCL).

Materials and Methods

Dispersion coefficients of dust for vertical as well as horizontal direction have been estimated in case of source wise emission data along with micrometeorological data. Air quality modeling has also been attempted using Fugitive Dust Model (FDM) developed by United States Environment protection Agency (USEPA). FDM has been used for validation by comparing predicted and observed values. Drilling, overburden loading, coal loading, haul road, transport road, overburden unloading, coal unloading, exposed overburden dump, stock yard, work shop, exposed pit surface and mine as a whole were monitored to understand contribution of pollution load in surrounding area. Emission measurement were taken for whole mine along with activity wise emission. A management strategy was formulated for effective control of air pollution at source and other mitigative measures

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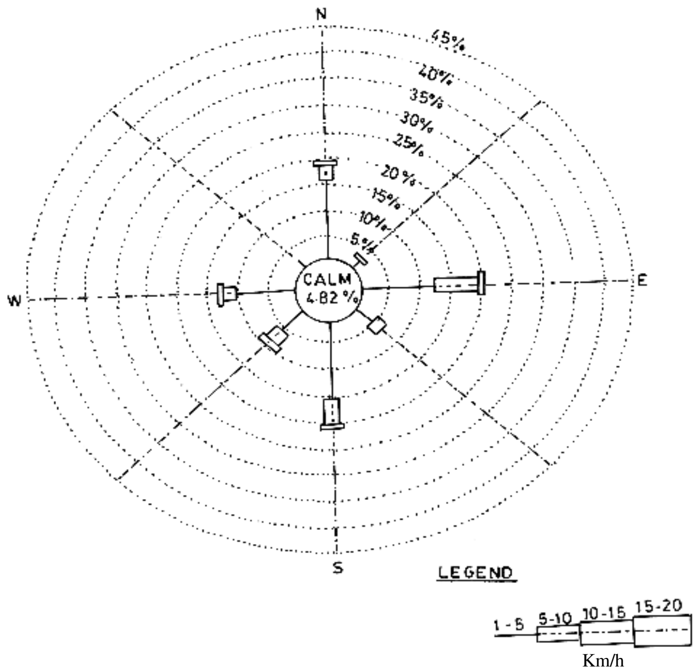

Fig.1— Wind rose diagram of Sasti OCP

including green belt design have also been devised for sensitive areas[13-17].

Field Observations and Data Collection

OCP is situated in Chandrapur district of Maharastra State having latitudes from 18^0 45' 5" N to 19^0 49' 5" N and longitudes from 79^0 18' 30" E to 79^0 18' 20" E. There is only one coal seam in Sasti OCP varying in thickness (17-18 m) including partings and bands. A thick cover of clay-soil overlies coal seam. Annual production is 1.5 million t with an average stripping ratio of 3.6 m^3/t. Coal produced from mine is non-coaking type of 'D' and 'E' grade. Scrapers remove topsoil up to a depth of 10 m. Dragline is used to evacuate overburden extending up to 31 m depth. Shovel dumpers are used to excavate coal. Simultaneous backfilling is also practiced with exploitation of coal.

Meteorological data has been collected from nearest Indian Meteorological Department (IMD) station at Nagpur with a tropical climate. Summer (April-June) is followed by rainy season (July-September) and winter (December-February); May is hottest (48°C) and December is coldest month (10°C). Mean annual rainfall is around 1250 mm. Wind direction is generally from East (velocity, 6-7 km/h during monsoon and 3-4 km/h in winter). Relative humidity (RH) varies from 74-83% during August-September and is about 15-20% during summer. Wind rose diagram is illustrated in Fig. 1.

Ambient air quality status in impact zone was assessed through a network of ambient air quality monitoring locations. Studies on air environment include identification of specific air pollutants for assessing impacts of proposed mining projects including other activities. Accordingly, air quality monitoring was carried out in winter season. Five ambient air quality stations have been selected to measure data of SPM, RPM and TSPM (Table 1). Ambient air quality parameters (SPM, RPM and TSPM) have been measured at 8 h intervals for 24 h using high volume sampler with RPM measurement technique using standard methods (Table 2). Other air quality parameters are not considered because of their concentrations below threshold value in the study area.

Field Observations on Emission Inventory

Emission inventory details have been collected by installing a set of high volume samplers at down wind sides as well as up wind side of different point, area and line sources. Two high volume samplers were placed; one at down wind side at a distance nearly 100 m from the source and one at up wind side to know the background concentration of TSPM. Emission data have been generated for overburden loading, mineral loading, haul road transportation, unloading of overburden, unloading of minerals, stockyard, exposed overburden dumps, mineral handling plant, exposed pit face and

Table 1— Ambient air quality of Sasti OCP

Sl. No	Sample sites	SPM, µg/ m^3		RPM, µg/ m^3		TSPM, µg/ m^3	
		Mean	S D	Mean	S D	Mean	S D
1	Area store	1106.62	85.50	312.12	35.56	1418.74	130.5
2	Guest house	207.03	17.62	115.66	15.65	322.69	30.45
3	SAM office	590.67	51.50	146.51	20.55	737.18	75.5
4	Workshop	1389.34	143.05	284.57	32.85	1673.91	175.05
5	Sasti village	425.95	52.72	277.18	27.72	703.13	70.55

Table 2 — Air pollutant analysis methods: coal mine standards[18]

Parameter	Time weighted av.	Concentration in ambient air, µg/ m^3	Method	Instruments
SPM	Annual 24 h	430 600	IS-5182 Part XIV	High volume sampler with RPM measurement arrangement (Av. flow rate not<Ã1.1 m^3/min)
RPM	Annual 24 ho	215 300	IS-5182 Part XIV	High volume sampler with RPM measurement arrangement (Av. flow rate not<1.1 m^3/min)

workshop. Haul road is the road inside open pit, which is temporary and unpaved whereas transport road is road outside the open pit, which is generally permanent and paved. Blasting, an instantaneous source, was monitored separately. Modified Pasquill & Gifford formula[19] for ground level emission has been used to calculate emission rate as

$$Q= C (x,0).\quad u\ \text{Ã}y\ \text{Ã}z$$

$$C(x,0)=DN_{max} - UP$$

where, C (x, 0), difference in pollutant concentration, g/m^3; DN max, maximum concentration in down wind direction; UP, background concentration in up wind direction; Q, pollutant emission rate, g/s; , 3.14159; u, mean wind speed, m/s; Ãy standard deviation of horizontal plume concentration, evaluated in terms of downwind distance x, m (Fig. 2)[19]; Ãz, standard deviation of vertical plumes concentration, evaluated in terms of downwind distance x, m (Fig. 3)[19]. Stability class is determined by guidelines shown in Table 3[19].

In present case, emission rates have been expressed for point sources (g/s), line sources (g/m.s), and area sources (g/m^2.s). Activity wise emission inventory has been shown in Table 4. Source wise emission properties (moisture content silt content etc.) have been measured from samples collected during field study. Frequency of vehicle movement on haul road and transport road per day, frequency of drilling operation per day, etc. has also been monitored (Table 5).

Results and Discussion

Air Quality Modeling using FDM

FDM, a computerized Gaussian Plume Air Quality Model, specifically designed for estimation of concentration and deposition impacts from fugitive dust sources, employs an advance transfer particle deposition algorithm[20] and represents particles behavior in atmosphere most accurately. Utilizing mine plan for locating different activities, activity-wise emission rate and meteorological data, FDM can find out dispersion pattern of pollutant and impact of dust generated due to different mining activities on surrounding environment.

Ambient air quality at five sites of Sasti is well within the limit except area store, workshop, however at SAM office, SPM concentration is also almost touching prescribed limit by CPCB. Variation between measured and predicted values (Fig. 4) may be due to non-accountability of emission from various other sources like non-mining area activities, domestic use of fuels,

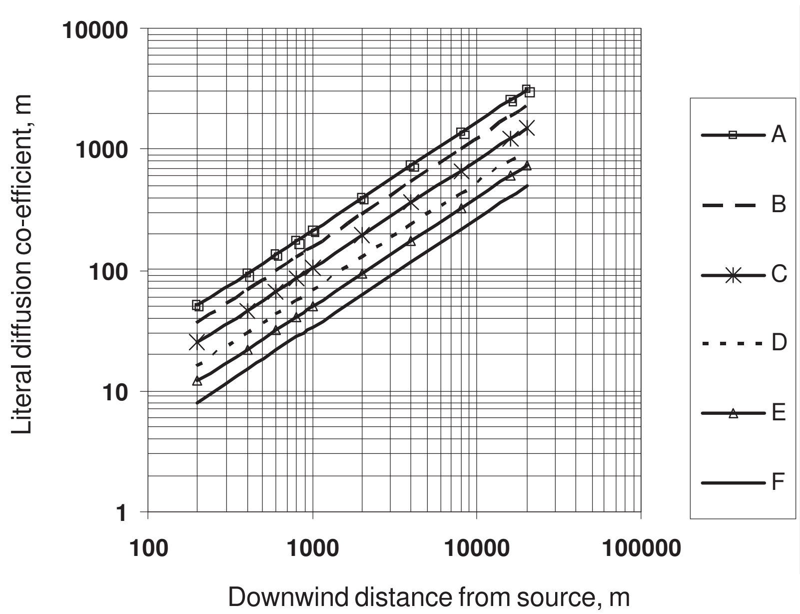

Fig. 2—Lateral diffusion coefficient vs downwind distance from source[19]

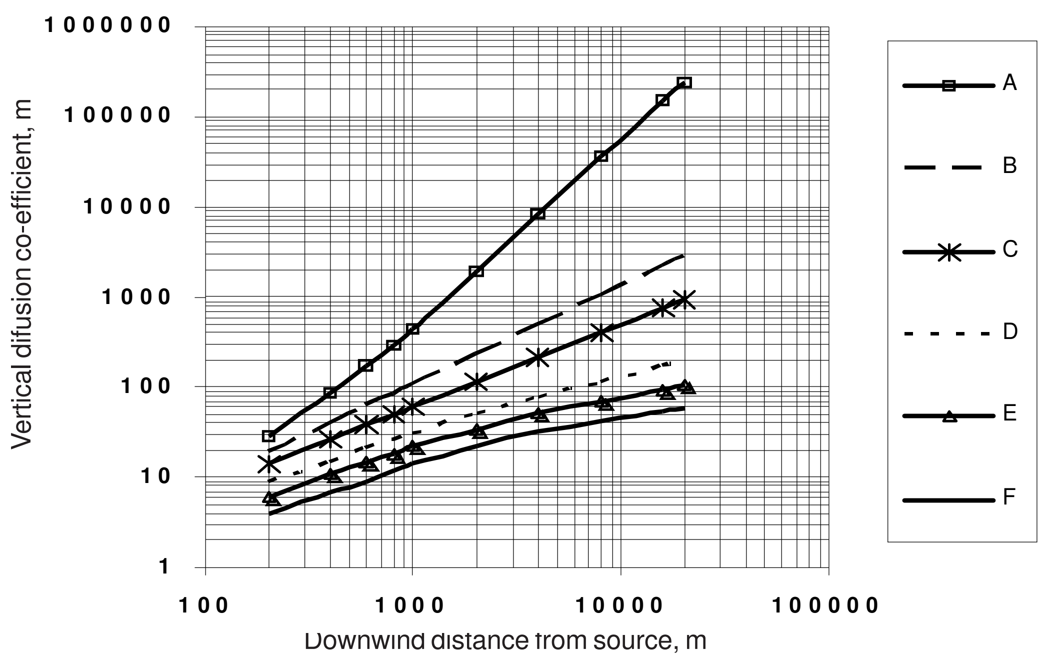

Fig. 3—Verticall diffusion coefficient vs downwind distance from source[19]

Table 3 — Guidelines for stability class determination[19]

Stability class (Pasquill)	Nature of Sodar Echograms
Strongly unstable (A)	Well defined thermal plumes
Moderately unstable (B)	Well defined thermal plumes up to shallow heights
Slightly unstable (C)	Thermal plumes of very shallow heights
Neutral (D)	Spiky top layers of shallow heights
Slightly stable	Stratified layer
Moderately/Hightly stable	Surface based layer

Table 4 — Activity-wise TSPM emission inventory at Sasti OCP

Source of TSPM	TSPM conc., μg/m³				Wind velocity	Diffusion coefficient		Emission rate
	DN Min	DN Max	UP	C x, 0	m/s	σy m	σy m	Value
Drilling	1410	1805	1261	544	2.0	14	8	0.3877 g/s
OB loading	1202	1596	1100	496	2.4	14	8	0.4186 g/s
Coal loading	1798	2166	1712	454	2.5	14	8	0.4872 g/s
Haul road	2041	2615	1369	1246	3.0	14	8	0.0132 g/ms
Transport road	2184	2747	1496	1251	3.2	14	8	0.0140 g/ms
OB unloading	1078	1552	902	650	1.7	20	16	1.1103 g/s
Coal unloading	1454	1950	1203	747	2.9	14	8	0.7681 g/s
Exposed OB dump	1069	1440	1021	419	2.4	24	16	0.000037 g/m²s
Stockyard	1465	1903	1011	892	2.7	14	8	0.00021 g/m²s
Workshop	1272	1548	1052	496	1.9	25	15	0.000111 g/m²s
Exposed pit surface	981	1258	920	338	1.2	15	32	0.00002 g/m²s

transportation network, nearby thermal power plant, cement plant etc. From modeling study, TSPM concentrations have been identified at certain receptor locations, which have been selected such that these are exactly same of one where ambient air quality measurement was carried out. Predicted values at receptor locations have been added to regional background levels to get predicted TSPM concentration. Regional background data are average of monitored data in no activity zone.

Among point sources (drilling, overburden loading, overburden unloading and coal unloading), highest emission rate has been found in case of unloading of overburden (Table 5). Among line sources, emission rates have been found as: Haul, 0.0132; and transport road, 0.0140 gm/mt/s. Predicted value of TSPM, which is averaging 68% of observed value, indicates contribution from other sources of emission at the area. Dispersion pattern indicates that dust generated due to mining activities does not have any impact beyond 500 m from the source under normal meteorological condition. As far as mining is concerned, maximum contribution of emission is by loading and unloading of coal, overburden and haul road.

An exponential fall in TSPM concentration with distance from the source has been observed (Fig. 5). Dust generated due to mining activities does not contribute to ambient air quality in surrounding areas beyond 500 m in normal meteorological condition.

Performance of FDM models has been evaluated through a set of statistical parameters like correlation coefficients (CC), regression coefficients (RC) and index of agreement (IA). Value of CC (0.72) between predicted value by FDM and observed value shows a fairly good agreement between

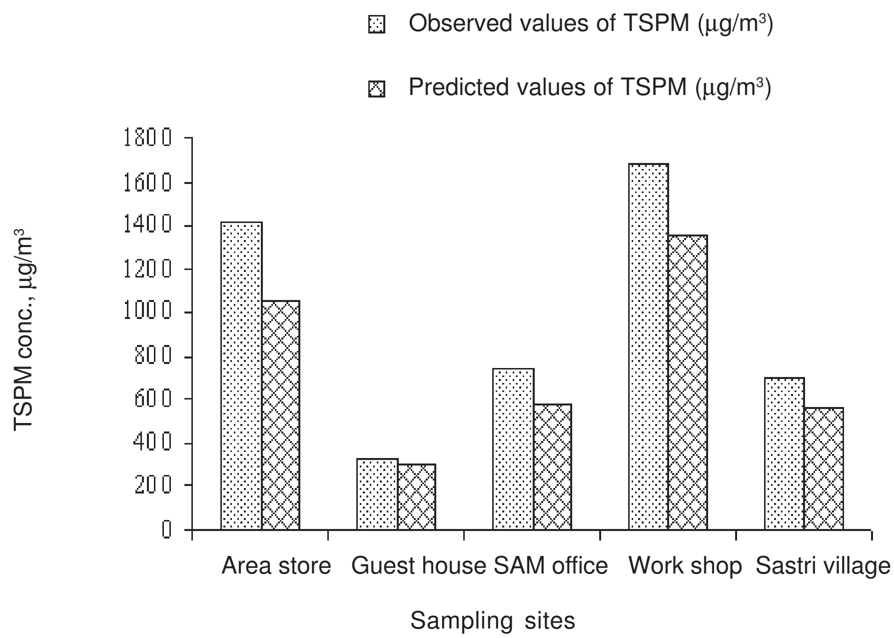

Fig. 4—Comparison between observed values and values of TSPM

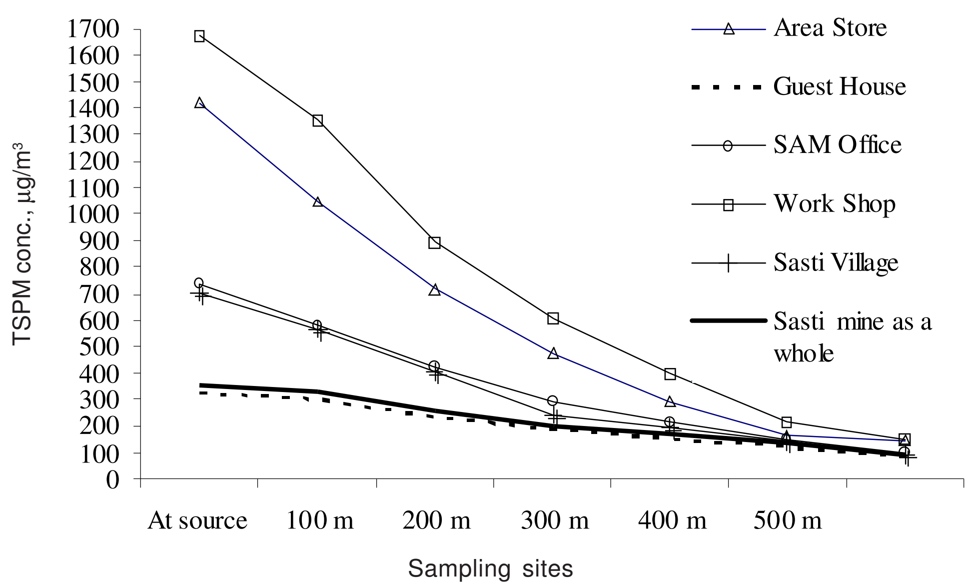

Fig. 5—Relation of TSPM concentration with distance from sampling sites

measured and predicted values. Values of IA show the extent to which the model performs and degree to which the model predictions are error free. In this study, average IA value for FDM has been calculated to be 0.71, which indicates contribution from other sources also. CC gives an idea how far measured values are related to predicted values. RC represents status of best-fit line between measured and predicted values.

Haul road and transport road have been found major contributors to pollution load of ambient air quality. Prevailing practice of water sprinkling does not seem to be adequate proper dust suppression. Therefore, installation of continuous atomized spraying system for haul roads should be used. Exposed overburden dump, another major contributor of pollution load, not only contributes to air pollution by way of wind erosion but

Table 5 — Source wise TSPM emission properties

Source of TSPM	Source type	Moisture content, %	Silt content %	Remarks
Drilling	Point	8.9	34.0	Hole dia 259 mm; 84 hole/day
Overburden Loading	Point	8.6	13.2	Drop height 1.5 m; frequency 22 no/h
Coal Loading	Point	8.7	9.0	Drop height 1.0 m; frequency 28 no/h
Haul Road	Line	15.2	32.0	Frequency 18 no/h; average speed 2.7 m/s
Transport Road	Line	10.5	29.9	Frequency 27 no/h; Av speed 10 m/s
OB Unloading	Point	8.2	4.5	Frequency 10 no/h; drop height 14.3 m
Coal Unloading	Point	8.2	10.4	Frequency 7 no/hr; drop height 2.5 m
Exposed OB dump	Area	7.8	8.0	Dump area 0.033 km^2
Stockyard	Area	7.2	10.3	Unloading frequency 3 No/h; loading frequency 12.0 No/h
Workshop	Area	11.8	34.2	Area 10000 m^2
Exposed pit	Area	7.4	8.2	Exposed area 0.04 m^2

Table 6 — Dust retarding plant species for green belt development

Species	Family	Local name of plants	Evergreen or deciduous
Anthocephalus cadamba	*Rubiaceae*	Kadam	Deciduous
Butea monsperma	*Moraceae*	Palas	Deciduous
Cassia fistula	*Caesalpiniaceae*	Amaltas	Deciduous
C. siamea	*Caesalpiniaceae*	Minjari	Deciduous
Fiscus infectoria	*Moraceae*	Pakur	Evergreen
Spathodea companulata	*Bignoniaceae*	Sapeta	Evergreen

also spreads dump itself. Therefore, a green belt of pollutant-tolerance trees (evergreen and deciduous) for mitigating air pollution is in an effective manner by filtering, intercepting and absorbing pollutants[15-17]. A few plant species that can be grown around highly polluted areas where dust (TSPM) is main pollutant (Table 6) reduce air pollutants and retard water and soil pollution. Biological reclamation of overburden dumps and wastelands is also essential. Effective control measures at the coal handling plant, excavation area and overburden dumps should also be implemented to mitigate TSPM emissions at source.

Conclusions

Predicted values of TSPM using FDM are observed 68-92% of observed values. Difference between observed values and predicted values of TSPM indicates that there are non-mining sources of emission (domestic transportation network nearby mine sites and other industries etc). Dispersion modeling using FDM indicates that dust generated due to mining activities does not contribute to ambient air quality in surrounding area beyond 500 m in normal meteorological conditions. Using FDM, dust dispersion modeling could be satisfactorily practiced for Sasti OCP only but it cannot be suitable for dispersion modeling at regional scale of Wardha valley coalfield of WCL as a whole. For haul road and transport road, which are major contributor to pollution load of ambient air quality, installation of continues atomized spraying system is recommended. Judicious plantations on exposed overburden dumps will not only stabilize dump but also attenuate dust emission.

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