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Estimation of Particle Movement Parameters in Iron Ore Mines

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Abstract. Earlier studies on dust dispersion in opencast mines primarily focused on estimation of source strength of each mining activity and application of Gaussian dispersion equation to estimate the dispersion of the pollutants away from mines. No study has focused on dispersion of particles within the mine in terms of time taken for dispersion of particles from workplace, and enhanced concentration at workplace during and after the mining. However, this is important because particle generated at workplace in the mine can contribute to prolonged exposure at work place as well as places away from it. The paper presents the results of the experiments conducted in two opencast iron ore mines to address the above in terms of particle travel time, residual time and fraction at workplace. Results show that particle travel time from one bench to a higher bench varied from 2 to 17 min. Particle residual time at the workplace varied from 10 to 13 min. During this period the residual fraction varied from 7 to 40% of the PM generated during the mining, indicating significant exposure after the mining activity stops. Residual fraction and residual time are strongly related.

Keywords: opencast mine, particulate matter, residual time and fraction, travel time.

1. Introduction

Different operations (drilling, blasting, loading, transportation and unloading, etc.) in opencast mining contribute huge amounts of particulate matter (PM) to the surrounding atmosphere [1]. Earlier studies show that increased airborne concentration of PM has harmful effects on human health [2, 3]. Inhalable coarse particle ($PM_{2.5\text{-}10}$) and fine particle ($PM_{1\text{-}2.5}$ or PM_1) penetrate to deeper parts of the lungs and cause several lung diseases [4, 5].

Tecer et al. [6] reported that the concentration of coarse PM has been always higher than fine particles in opencast mines in all climatic conditions. Study by Onder and Yigit [7] indicated that the generation of inhalable coarse particles ($PM_{2.5\text{-}10}$) is very high during drilling operation as compared to other mining operations. Chaulya et al. [8] determined emission rate and developed empirical formulae to calculate emission, both particulate and gaseous, from different opencast mine operations. Trivedi et al. [9] reported that the concentration of total suspended particle (TSPM) decreases from 698 $\mu g\ m^{-3}$ at the mine boundary to 125 $\mu g\ m^{-3}$ at a distance 500 m from the mine boundary. However, they have not assessed dust dispersion inside the mines, in terms of PM concentration at different parts in the mine during and after the mining activity.

Only a few studies have been conducted to assess the dispersion pattern of PM inside the mine [10, 11]. These studies were carried out three decades ago and it primarily focused on estimation of pit retention. Wings [10] proposed an expression in terms of particle deposition velocity, vertical diffusivity and pit depth to estimate fractions of the total emissions that escape the mine. Expression of pit retention by Fabrick [11] included parameters like wind speed at the top of the pit, pit width and particle deposition velocity. Retention fractions of PM from 10 to 95 µm varied from 0.14 to 0.73 [11] and 0.23 to 1.0 [10], respectively. The

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weighted average values of pit retention were 0.50 [11] and 0.84 [10]. No recent studies on pit retention could be found.

The adverse effect on health depends on concentration of the PM as well as the time for which the worker is exposed to it. Therefore residual time of PM inside the pit, more importantly at the workplace, needs to be assessed. However, no study could be found on estimation of the residual time of the PM.

The paper presents the findings of a study that was aimed at the estimation of contribution of mining operations to PM concentration ($PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1) inside the mines, time taken by particle generated at workplace to travel to higher benches, time and fraction of PM that remains at the workplace after mining activity stops (residual time and residual fraction, respectively) and interrelationships among them.

2. Methodology

The field study was conducted in two mines, namely Kiriburu Iron Ore Mine (KIOM) and Meghahatuburu Iron Ore Mine (MIOM), located in the eastern part of India. At KIOM experiment site, surface RL is 827 m. It has 3 benches with first and second bench 9 m high and the bottom third bench is 8 m high. The pit bottom RL is 801 m. At MIOM, surface and pit bottom RLs are 856 m and 806 m respectively, and the bench height is 10 m (Figures 1a&b). PM concentration was measured at 1 min interval using Grimm aerosol spectrometer (Model 1.108). Meteorological data were recorded at 1 min interval using WatchDog 2000 series portable weather stations.

At KIOM the source was located at the first bench and PM concentration was measured at surface level, at the pit boundary (Figure 1a). At MIOM the source was located at second bench and concentration was measured at the first bench (Figure 1b). Sampling point X is located on the surface at the pit boundary at 827 mRL (mRL is Reduced Level with respect to datum/mean sea level, expressed in m) and at 856 mRL at KIOM and MIOM respectively. At X, a Grimm aerosol spectrometer measured PM concentration and a portable weather station recorded local meteorology. The source comprised of a shovel and a number of dumpers transporting iron ore from the mines. The experiment was conducted during the day shift (6:00 to 14:00) that consisted of two phases with a tea-break of about 30 min in between. The experiment was repeated for 3 consecutive days on 21, 22 and 23 May 2013 at KIOM and on 4, 5 and 6 June 2013 at MIOM.

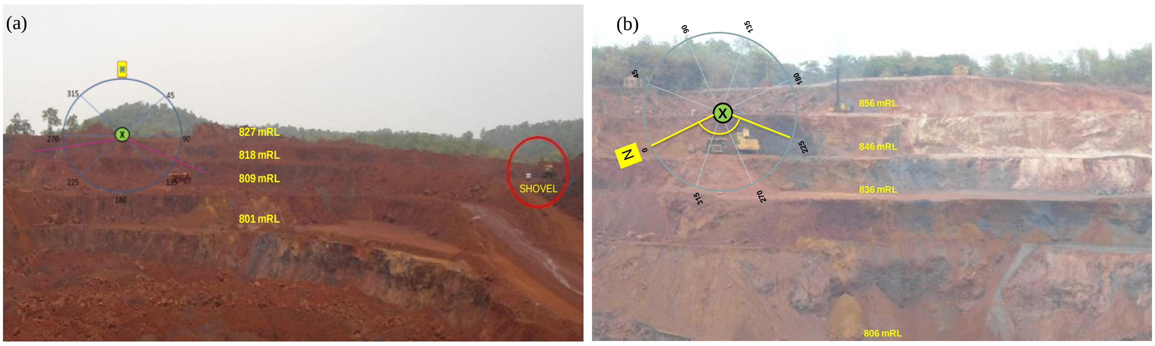

Fig. 1: Experiment site (a) KIOM and (b) MIOM

3. Results and Discussion

3.1. Wind speed and wind direction

Average as well as the highest wind speed at KIOM was higher than corresponding values at MIOM. Most of the time calm conditions prevailed in both the mines (wind speed < 1 m s^{-1}). In MIOM calm condition prevailed as high as 75% of the time on 05 June 2013. Wind direction at both mines varied widely.

3.2. PM concentration

Result of 12 cases (2 mines, 3 days in each mine and 2 mining events in each day) shows that PM concentration due to mining increased to several times that of the background concentration. The increase of coarse particle concentration remained higher than the increase of fine particle concentration. Concentrations of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 increased by 6-52 times, 3-14 times and 1.5-3 times of the background concentration (Table 1).

Table 1. PM concentration

Study site	Date of study	Background concentration ($\mu g\ m^{-3}$)			Average concentration during mining ($\mu g\ m^{-3}$)		
		$PM_{2.5-10}$	$PM_{1-2.5}$	PM_1	$PM_{2.5-10}$	$PM_{1-2.5}$	PM_1
KIOM	21/05/13	5	10	15	94.14	63.18	29.12
	22/05/13	5	11	15	32.44	31.54	20.03
	23/05/13	8	16	12	49.40	41.6	31.57
MIOM	4/6/2013	2	5	7	5.88	7.37	11.52
	5/6/2013	1	5	8	13.26	10.08	14.34
	6/6/2013	2	3	5	103.48	41.48	15.46

This shows that while the background concentration is dominated by fine particles (PM_1), mining activity contributes PM primarily in coarse size ranges ($PM_{2.5-10}$ and $PM_{1-2.5}$). Several earlier studies have also demonstrated that mining activity generates more coarse particles than fines [1, 7].

3.3. Particle travel time

While some particle matter generated due to mining gets settled inside the mine (settled particles may further get re-suspended due to machine or wind induced turbulence), the majority of it leaves the mine boundary due to dispersion effected by meteorological condition. The quicker the particles move from the place of generation, the earlier the workplace concentration returns to the pre-mining level [12]. Therefore, short travel time of particles indicates earlier cleaning of the mine environment.

Table 2. Travel time estimates

Mine	Travel Time (min)						
	Date	$PM_{2.5\_10}$		$PM_{1\_2.5}$		PM_1	
KIOM	21/05/13	4	4	4	4	4	4
	22/05/13	5	4	5	4	5	4
	23/05/13	2	7	2	7	2	7
MIOM	4/6/2013	5	17	5	17	5	17
	5/6/2013	4	1	4	1	4	1
	6/6/2013	2	2	2	2	2	2

Table 2 shows that travel time of particles vary in the range of 1-17 min.

3.4. Particle residual time

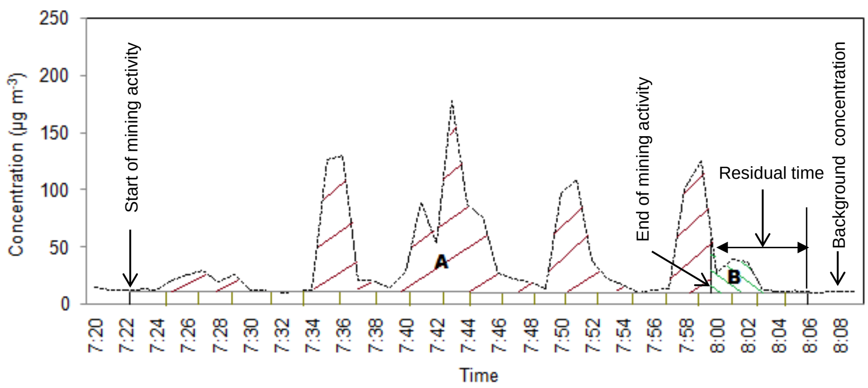

Fig. 2: Residual time

In both the mines the time interval between the end of mining and the PM level reaching the background level gives the time during which enhanced concentration due to mining was prevailing at the workplace after the mining activities stopped. This gives a measure of the duration for which a mining activity has an impact, in terms of enhanced PM concentration, at a workplace inside the mine after mining activities stop. This is referred to as residual time (Figure 2). Long residual time indicates more exposure of mine workers to enhanced PM concentration at the workplace.

Table 3. Residual time estimates

Mine	Residual Time (min)			
	Date	$PM_{2.5\_10}$	$PM_{1\_2.5}$	PM_1
KIOM	21/05/13	10	10	10
	22/05/13	10	10	10
	23/05/13	11	11	11
MIOM	4/6/2013	13	13	13
	5/6/2013	11	11	11
	6/6/2013	10	10	10

Results show that residual time of PM generated on the first bench at KIOM lies in the range of ~ 10 min. At MIOM the residual time varies between 10 to 13 min (Table 3). Residual times for different size of particles were same, indicating no dependence of residual time on particle size. However, more data on residual time for particles generated at deeper benches are required to establish the dependence/independence of residual time with particle size.

3.5. Residual fraction

The ratio of the amount of PM generated due to a mining activity that remained at the workplace after stoppage of mining activity to the amount generated during the mining activity is defined as residual fraction and is expressed in percentage. Using area under the concentration curve (Figure 2), residual fraction has been calculated as follows:

$$\text{Residual fraction} = B/(A+B)$$

Where,

A= Area under the curve for the mining duration

B = Area under the curve for residual time

Table 4. Residual fraction estimates

Mine	Date	Residual fraction (%)		
		$PM_{2.5-10}$	$PM_{1-2.5}$	PM_1
KIOM	21/05/13	1.40	1.57	4.50
	22/05/13	1.40	1.57	4.50
	23/05/13	9.99	10.32	12.79
MIOM	4/6/2013	9.45	15.49	15.50
	5/6/2013	3.06	4.36	1.04
	6/6/2013	0.90	2.08	1.48

The estimates indicate that residual fraction is higher for fine particles than coarse particle (Table 4). After mining stops, further generation of PM from mining activity ends. Coarse fractions generated during the mining activity settles comparatively faster than fine fractions. As a result, fine fractions dominate mine atmosphere, and this increases the residual fraction of fine particles.

Residual fraction for PM_{10} varied from 7.47% to 33.10% for KIOM and 4.46% to 40.44% for MIOM. Therefore, a worker at the workplace in the mine is likely to be exposed to as high as ~ 40% of the PM generated during mining for a period of 10-13 min (residual time) after the mining activity stops.

3.6. Relationship between residual time and residual fraction

Residual fraction depends on residual time as well as concentration of PM during residual time. During six days of the study, both residual time and concentration of particles of different sizes varied.

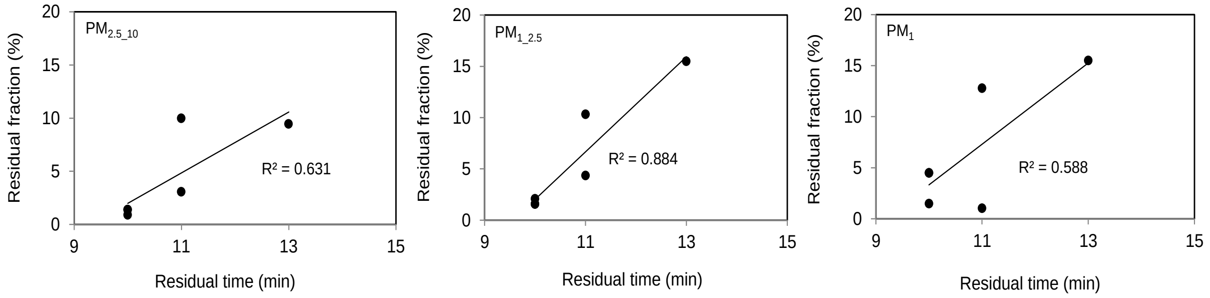

Fig.3: Residual time vs. residual fraction

Figure 3 shows a strong relationship between residual time and residual fraction for particles of all sizes.

4. Conclusions

The article presents an overview of occupational exposures of workers to airborne PM in two opencast mines. This is important for assessment of health risk to the workers; however very limited study has been carried out on this. The study showed that particle travel time across a bench of 9-10 m high varied between 1 and 17 min. Particle residual time at the workplace varied from 10 to 13 min. Residual fraction varied between 7.47% and 40.44% and it has an inverse relationship with PM size. Therefore, workers are exposed to elevated particulate pollution, as high as ~ 40%, for 10-13 min, when no mining activity is in progress. The role of meteorological parameters on PM travel time, residual time and residual fraction are presently investigated. The findings presented in this paper are based on the studies carried out in shallow mines (KIOM is 26 m and MIOM is 50 m deep). The authors propose more studies in deeper opencast mines for estimation of these parameters.

5. References

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