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Dispersion of respirable particles from the workplace in opencast iron ore mines

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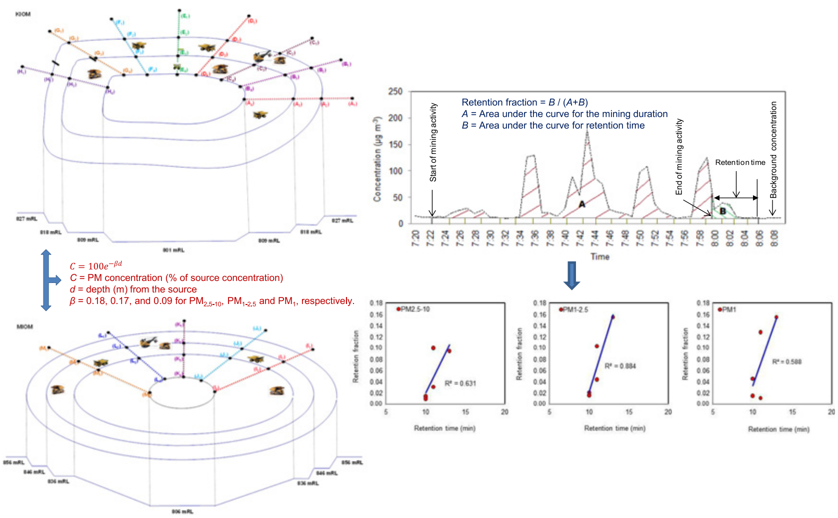
GRAPHICAL ABSTRACT



HIGHLIGHTS

- Up to 17 min of particle travel time is estimated for source up to 9–10 m.
- Up to 13 min of particle retention time is estimated.
- 7%–40% of the particle retained at the workplace during the retention time.
- Within a horizon of 18–20 m, up to 73% $PM_{2.5-10}$, 63% $PM_{1-2.5}$, and 15% PM_1 settle.
- Empirical equation for the downward movement of PM from the source is developed.

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ABSTRACT

Earlier studies on dispersion of Particulate Matter (PM) in opencast mines primarily focused on estimation of source strength of each mining operation and dispersion of the pollutants away from mines. No study has focused on estimation of particle travel from the workplace with respect to time since its emission, enhanced concentration at workplace during as well

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as after mining and contribution of workplace emission to concentration rise in other parts of the mine. However, this is important because particle generated at workplace travels to other places in the mine and therefore influences the PM exposure level and duration of mine workers. The paper presents the outcome of a study that involved measurements of PM concentration and local meteorology for a period of 24 days in two opencast iron ore mines to address the above in terms of (i) particle travel time, (ii) retention time and fraction at workplace, (iii) mass balance of particle generated at workplace and (iv) downward movement of the particle in mine. Results show that mining activity generates more coarse particles ($PM_{2.5-10}$) than fines ($PM_{1-2.5}$ and PM_1). Wind speed was significantly correlated with PM concentration when wind speed was high. Up to 17 min travel time was recorded for 9–10 m vertical movement of PM. Travel time is significantly correlated with wind direction. No relationship could be found between wind speed and travel time. Particle retention time at the workplace varied from 10 to 13 min. Retention fraction varied from 7% to 40% of the PM generated during the mining, indicating significant exposure after the mining activity stops. Retention fraction and retention time are strongly related. In the mine within a short vertical distance (18–20 m) from the source, $PM_{2.5-10}$, $PM_{1-2.5}$, and PM_1 settle in the ranges of 72–73%, 53–63%, and 7–15% respectively. The proportion of $PM_{2.5-10}$, $PM_{1-2.5}$, and PM_1 that escaped from the work place varied 27–28%, 37–47% and 85–93% respectively. An empirical relationship developed for downward movement of particle from the source was able to predict the PM concentration 73%–88% and 15%–80% of the measured value for depths of 10 m and 40 m respectively. The findings of this study enhance the understanding of workers' exposure to PM inside the mine.

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 (Cowherd, 1979; Ghose and Majee, 2001; Pless-Mulloli et al., 2001). Studies show that increased airborne concentration of PM has harmful effects on human health (Wilson and Suh, 1997; Gautam et al., 2012). Turner and Grace (1938) and Boyd et al. (1970) reported that large scale iron ore mines can have significant impact on health, specifically increased levels of lung cancer. Several other studies indicated that lung cancer is a very common disease among the workers exposed to iron ore dust (Chau et al., 1993; Chen et al., 1990; Kinlen and Willows, 1998). Size of PM determines the penetrability of it into deeper parts of the lungs and is therefore an important parameter that determines different disease or health hazards. Respirable coarse particles ($PM_{2.5–10}$) and fine PM ($PM_{1–2.5}$ or PM_1) penetrates to deeper parts of the lungs and cause several lung diseases (Finkelman et al., 2002; Hendryx and Ahern, 2008).

Tecer et al. (2008) 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 (2009) indicated that the generation of respirable coarse particles ($PM_{2.5–10}$) is very high during drilling operation as compared to other mining operations. Although the study provided the estimate of PM generated from different mining operations, it did not estimate increase in concentration with respect to size of PM. Several earlier studies have been conducted to estimate the source strength of individual mining activity (Ghose and Majee, 2001; Chaulya, 2004) as well as the amount of particulate pollutant that comes out of the mine (Chakraborty et al., 2002). Chakraborty et al. (2002) and Chaulya et al. (2002) determined emission rate and developed empirical formulae to calculate emission, both particulate and gaseous, from different opencast mine operations. Trivedi et al. (2009) studied generation of PM from different mining activities and its dispersion beyond the mine boundary. The study showed that the average concentration of total suspended particle (TSP) decreases from $\sim 700\ \mu g\ m^{-3}$ at the mine boundary to $\sim 150\ \mu g\ m^{-3}$ 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 (Winges, 1981; Fabrick, 1982). These studies were carried out three decades ago and it primarily focused on estimation of pit retention. Winges (1981) proposed an expression in terms of particle deposition velocity, vertical diffusivity and pit depth to estimate fractions of the total emissions that escape from the mine. Expression of pit retention by Fabrick (1982) included 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 (Winges, 1981) and 0.23–1.0 (Fabrick, 1982), respectively. The weighted average values of pit retention were 0.50 (Winges, 1981) and 0.84 (Fabrick, 1982). In recent times, Gautam and Patra (2015) carried out a dust dispersion study in a deep opencast copper mine in India; but it was limited to the estimation of the PM profile at different depths and escape time of the respirable particles from the pit bottom. They did not measure particle retention at the workplace or in the mine during and after the mining operations.

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 retention time of PM inside the mine, more importantly at the workplace, needs to be assessed. However,