Environmental Technology & Innovation 5 (2016) 233–249

Contents lists available at ScienceDirect

Environmental Technology & Innovation

journal homepage: www.elsevier.com/locate/eti

Emissions and human health impact of particulate matter from surface mining operation—A review

Aditya Kumar Patra [a], Sneha Gautam [b,*], Prashant Kumar [c,d]

[a] Department of Mining Engineering, Indian Institute of Technology Kharagpur, Kharagpur-721302, India

[b] The INCLEN Trust International, Okhla Industrial Area, Phase-I, New Delhi-110020, India

[c] Department of Civil and Environmental Engineering, Faculty of Engineering and Physical Sciences (FEPS), University of Surrey, Guildford GU2 7XH, United Kingdom

[d] Environmental Flow (EnFlo) Research Centre, FEPS, University of Surrey, Guildford GU2 7XH, United Kingdom

HIGHLIGHTS

- Strong medical evidences of PM emitted from surface mine on health exist.
- Particle size, especially the ultrafine particles ($<1\ \mu m$), analysis are limited.
- Empirical equations are inadequate for PM emission estimates from surface mine.
- Studies on particle size analysis and PM inhalation model are emphasized.
- Need of in-pit wind field modeling and vertical transport of PM is emphasized.

ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 1 March 2016
Accepted 27 April 2016
Available online 30 April 2016

Keywords:
Air quality
Emission rate
Mining
Particulate matter
Surface mine

ABSTRACT

Particulate matter (PM) is one of the primary pollutants produced from surface mining operations. Health related studies indicate a strong association of airborne PM with adverse impacts such as restricted airways, reduced lung capacity, reduced lung function, increased cardiovascular disease, pneumoconiosis, cancer, and neurotoxic effects. A review of the existing studies to estimate the emission of PM from surface mining indicates empirical relationships among a wide range of parameters including silt content and moisture content of the PM, vehicle speed, drop height, weight of the vehicle, size of loader, area of the exposed surface, frequency of loading and unloading, number of dry days. Mitigation strategies are needed to determine the PM exposure level to human health inside opencast mines where production based operations take place. Synthesis of available studies suggests that while the empirical relationships explain the emission estimates, there is yet no established theoretical basis to explain the movement of fine particles inside the mine. A few recent studies on modeling PM concentration profile across the benches are reviewed. It is felt that there is a need of detailed studies for assessment of fate of the PM from mining operations for better understanding of its health impact on miners and people around the mining sites and to improve the local air quality. To this effect, need of studies focusing on wind field modeling and vertical transport of PM in surface mines is emphasized. Particle size analysis and PM inhalation model can help in better understanding the health impact of PM emitted from different surface mining activities.

* Corresponding author. Tel.: +91 9996636538.
E-mail address: gautamsneha@gmail.com (S. Gautam).

http://dx.doi.org/10.1016/j.eti.2016.04.002
2352-1864/

Contents

1. Introduction

The financial progress of several countries depends on the production and consumption of minerals, including fuel minerals, and thus leads to the expansion of mining activities (Kan et al., 2012). Depending on the mode of extraction of minerals, mines can be surface mines, underground mines or a combination of both. When mineral deposits are too thin and shallow, or the topography too steep for deep mines, surface mining is the most feasible extraction process. Surface mining involves removal of overburden (soil and rock materials lying below the surface and above the deposit) to access the minerals of interest.

The degradation of air quality is major problem in mining areas (Pandey et al., 2014; Zhang et al., 2013). It is of even more concern in case of surface mines where unit operations such as drilling, blasting, loading, transport, and unloading, produce particulate matter (PM) in diverse size ranges that are harmful for human health and surrounding environment (Bindhu and Tripathy, 2012; Heal et al., 2012; Kumar et al., 2014). PM generated during these activities is directly emitted to the atmosphere. Several studies have reported increased level of PM in and around the surface mines from emission during mining and processing of mined mineral near the mine (Trivedi et al., 2010; Singh et al., 2009; Ghose and Majee, 2007; Reddy and Ruj, 2003; Pless-Mulloli et al., 2000), with exception like oil sand mining in Canada where there is little evidence that the surface mining has contributed to higher PM level in the region surrounding the mine (Gosselin et al., 2010; Kindzierski et al., 2010), but black dust cloud during its processing is reported (NRDC, 2014). PM can be found in a wide range of sizes (Kumar et al., 2011a, 2010a), Particles larger than 500 μm (μm refers to micrometers, 10^{-6} m) in diameter fall down rather quickly due to gravitational settling (Greeley and Iversen, 1985; Shao and Lu, 2000). Those below <0.5 μm are small enough to remain in suspension and adhere onto the surface of other particles (Kumar et al., 2012a). Particles in between are distributed differently depending on the source minerals.

A few studies are available on particle size analysis of PM emitted from individual mining operations. Particles of 30 μm and above (also known as total suspended particulate matter), TSPM, are very coarse particles that settle very close to the point of emission. Particles with sizes between 30 and 10 μm remain suspended for a limited time in air and are not of concern from health point of view, as they become trapped in the nostrils or mouth and swallowed. Therefore, particles less than 10 μm (PM_{10}, PM_x, where x refers to median particle size in μm) are more likely to be inhaled through the respiratory tract. Particles smaller than 2.5 μm ($PM_{2.5}$) and fine particles up to 1 μm (PM_1) are inhaled deep into the lungs (Dockery and Pope, 1994; Dockery et al., 1993). Thus, PM_{10}, that includes $PM_{2.5}$ and PM_1, is responsible for the reduced air quality that results in adverse effects on human health (Tsiouri et al., 2015; Tiwari et al., 2012). Therefore, most of the studies focused on PM_{10} and $PM_{2.5}$ emissions from the mining operations that are also of regulatory interest, although some of it also looked into coarser PM up to 30–50 μm (Gautam et al., 2015; Chaulya, 2006; Reed, 2003; Chakraborty et al., 2002; USEPA, 1977, 1998). Reed (2003) sampled the PM emitted from the haul roads of a coal mine in Pennsylvania and a stone quarry in Virginia, both in US, in six size ranges using Cascade Impactor. The particle size distribution results are summarized in Table 1.

PM_{10} consists of only a small percentage of the dust, i.e., 12.72%–18.42% in coal mine and 6.39%–10.77% in stone quarry. The non-respirable particles in the range of 10–50 μm varied in the range 81.58%–87.28% in coal and 89.23%–93.61% in stone (Table 1). Therefore irrespective of the mineral, the particle size distribution shows that non-respirable particles dominate the PM emitted from haul roads. Gautam et al. (2015) analyzed the size distribution of respirable particle (PM_{10}) released from the entire surface mining operations in two large iron ore mines in eastern India. They used Grimm aerosol spectrometer for sampling that can measure particle mass concentration in different size ranges. The study showed that while background PM level was dominated by the fine fractions (PM_1 and $PM_{1-2.5}$) of the respirable particle, the emissions from the mining consisted mainly of the coarse fractions ($PM_{2.5-10}$) of the respirable particle (Fig. 1).

Several earlier studies have also reported generation of more coarse particles than fines from the surface mining operations (Aneja et al., 2012; Onder and Yigit, 2009; Ghose and Majee, 2001).

Earlier research on occupational exposure show association of increased level of PM concentration with the diseases such as asthma (Pless-Mulloli et al., 2000; Banks et al., 1998), black lung disease (Hendryx and Ahern, 2008; Finkelman et al., 2002; Coggon and Taylor, 1998), mesothelioma (Shah, 1998), cardiovascular diseases (Hendryx, 2009; Chen et al., 1990), Parkinson's disease and Alzheimer's disease (Buzea et al., 2007; Quintana et al., 2006). A summary of significant coal and non-coal mines based PM exposure studies are presented in Table 2.

There have been several reviews, covering air pollution management (Kumar et al., 2015) and particles exposure in cities (Kumar et al., 2013a), exposure at local scale such as in vehicle wakes (Carpentieri et al., 2011) and traffic intersections