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Windblown fugitive dust emissions from smelter slag

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ABSTRACT

The waste products of mining and smelter operations contain fine particles that, when stored in stockpiles and tailings ponds, are subject to aerodynamic forces that may result in their suspension and transport within boundary layer air flows. The accuracy of atmospheric dispersion models such as AERMOD depends strongly upon suitable inputs for the emission rate that generally must be either measured or estimated from suitable analogues. Measurements of the emission rate of PM_{10} from smelter slag, based on wind tunnel experiments using the control volume method, are reported in this study and compared with vertical flux values obtained using a finite difference approximation. As compared to natural soils, the dust coatings on slag fragments are rapidly depleted during wind events so that the temporal aspect is important to capture in any consideration of the emission rate. At low wind speeds, vertical flux measurements underestimate the emission rate, but otherwise the agreement is excellent. Comparison with field measurements obtained at the smelter site reveals a degree of overlap with the laboratory data. As a general rule, PM_{10} emission from smelter slag by aerodynamic entrainment alone is several orders of magnitude lower than published fluxes of total suspended particulate (TSP) emitted from natural soil surfaces for which saltation bombardment is recognized to play a key role in the ejection of dust.

1. Introduction

Mining and smelting operations introduce fugitive dust into the surrounding environment from varied sources, inclusive of roadways, material handling sites, stockpiles and tailings. At a majority of sites worldwide, companies are required to monitor and limit the amount of airborne particulate matter (PM) that escapes from their operations, as well as to maintain inventories of dust emission sources on site. While the measurement and modelling of emission rates from continuous point sources (e.g. smokestacks) is well established, the physics of wind-driven dust emission from large source areas are complex and difficult to model with a high degree of accuracy. Dispersion models such as AERMOD can be indispensable tools in the prediction of offsite concentrations of fugitive dust originating from both point and area sources when coupled with suitable meteorological data. However, the accuracy of such models is crucially dependent on the availability of realistic input values for the emission rate of particulate matter from the source into the near-surface airflow.

Given that every source of fugitive dust is unique, whether it is natural or anthropogenic in origin, it is rare for the particulates corresponding to emission rate values provided in AP 42 (US EPA, 2006), for example, to adequately represent the physical properties of any given material in question. Previous studies have shown that emission rates often vary by several orders of magnitude from site to site and time to time (e.g. Gillette, 1978; Fairchild and Tillery, 1982; Gillette and Passi, 1988; Nickling and Gillies, 1989; Shao et al., 1993; Loosmore and Hunt, 2000; Roney and White, 2006; McKenna Neuman et al., 2009), and therefore, the need for accurate, site specific emission rates for use in dispersion modelling is quite apparent.

The present study examines the emission of fugitive dust from nickel slag produced at a large nickel smelter in Sudbury, Ontario, Canada. Since the early 20th century, the facility has accumulated approximately 1.95 km^2 of slag (Fig. 1a) which is stored in flat topped stockpiles rising as much as 50 m above the surrounding terrain (Fig. 1b).

Freshly poured and cooled slag is similar to an extrusive igneous formation such as basalt or obsidian. It is devoid of fine particles, and bears a notable lustre (Fig. 2a). Once cooled, the slag is granulated or “ripped” *in situ* using specialized heavy machinery, and is then transported to intermediate and final storage locations via dozers, dump trucks and front-end loaders. The material is also rather friable so that when ripped and stockpiled, processes of abrasion and spalling produce particles that span a very wide range

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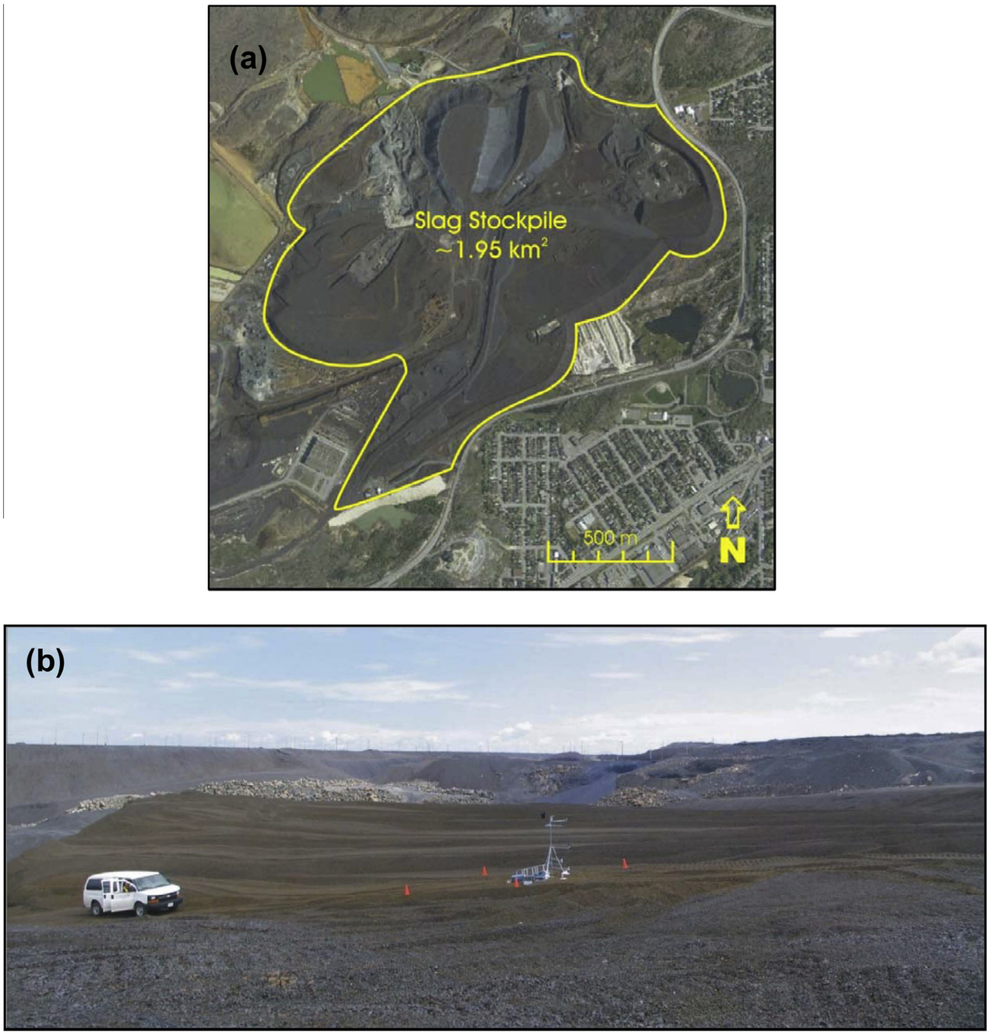

Fig. 1. (a) Aerial view of slag stockpiles. (b) View of stockpile surface and field instrumentation.

in diameter. The larger fragments usually become coated with silt and clay-sized particles having a red or yellow-brown hue (Fig. 2b). Although this waste rock is a man-made material, it remains subject to the same weathering processes that act on sediments in natural geophysical systems. Percolation of rain and melt water from the winter snow pack transports small particles deep into the pore spaces of the coarse slag where they accumulate over time. An unknown amount of fine sized particles may also be winnowed from the surface through wind erosion. The net result is a clean, lustrous surface of gravel-sized fragments that appears similar to desert pavement. Upon mechanical disturbance, however, large amounts of fine material are revealed immediately below this (Fig. 2c).

Saltation involves the ballistic transport of sand sized particles across a given surface, and through impact and particle ejection, is known to be the primary mechanism for dust emission from playas and natural soils in arid and semi-arid regions. In comparison, the entrainment of fugitive dust from stockpiles of slag occurs entirely by fluid drag, and is supported by wind pumping of the fine sized particles from deep interconnected voids (Sanderson, 2013). The formation of a saltation cloud is prevented through trapping of sand-sized particles within the aerodynamically rough surface (Chepil, 1950). As noted above, natural soils that are armoured with gravel are perhaps the closest analogue to slag. They are generally regarded to be far less emissive than cultivated fields, and as a consequence, have received less attention in the wind erosion literature.

In this paper, we present wind tunnel measurements of the emission rate of PM_{10} (particles with diameters <10 μm) from smelter slag at varied wind speeds, calibrate the power-law flux model for this waste product, and compare our results with those from published work for other surface types. A secondary objective of this study is aimed at validating the experimental procedure in which measurements of the dust flux obtained using a control volume approach in a wind tunnel are compared with those derived from the finite difference method for both field and laboratory settings. The effect of a restricted fetch length is also considered.

2. Context

2.1. Emission factors

Given the large expenditure of time and resources required to monitor fugitive dust emissions, consultants and engineers often estimate these amounts using a relatively simple algorithm such as that provided in AP 42 (US EPA, 1995):

$$E = A \cdot EF \cdot \left(\frac{1 - ER}{100}\right) \quad (1)$$

where A is the activity rate, EF is an emission factor quantifying the amount of dust released during a given event or activity, and ER is