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Wind tunnel simulation of environmental controls on fugitive dust emissions from mine tailings

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ABSTRACT

The development of techniques for determining fugitive dust emissions presents numerous challenges and remains the subject of much investigation. Past approaches have included field based monitoring stations and wind tunnel studies, while more recently, highly portable field units (e.g., PI-SWERL) have been added to our toolkit of instruments and methodologies. In the case of the investigation reported herein, a laboratory wind tunnel study was designed to systematically simulate PM_{10} emissions from mine tailings for a range of surface treatments. Unique challenges were associated with the project in the sense that the proposed mine and tailings did not exist at the time of the investigation, so that it was impossible to work on-site. Only a small amount of slurry from a milled drill core was available to work with, and there were no established test protocols and few experimental precedents to work from. The slurry formed highly cohesive bricks when dried, similar to crusted playas investigated in field experiments. The PM_{10} emissions demonstrated strong temporal variation with particle supply limitation. A small amount of vertical dust dispersion was observed, with PM_{10} concentrations decaying exponentially away from the source. The emission rates obtained are similar in magnitude to those obtained in field analogues. The highly controlled experiment allowed for separation and analysis of several physical controls on PM_{10} emissions from tailings; namely, the study addressed the degree of disturbance, shrinkage and cracking, and the effects of spigotting, particle settling and re-wetting.

1. Introduction

1.1. Overview of the research problem

Mining operations and aggregate extraction sites are significant sources of fugitive dust emissions. Numerical models provide an important tool for assessing the dispersion and deposition of dust sized particles in boundary layer flows, as well as in the design of dust mitigation strategies. However, the accuracy of such model predictions relies a great deal upon the input of dust emission data; that is, the total mass of dust sized particles emitted directly from a unit area of surface in a unit length of time ($\mu g\ m^{-2}\ s^{-1}$). In industrial applications, emissions estimates are usually obtained from standardized tables such as those found in the US EPA's AP 42 Compilation of Air Pollutant Emission Factors. These tables incorporate a small number of field measurements at sites that may bear little to no resemblance to the physical properties of the specific material under consideration. Predicted atmospheric concentrations and deposition rates can therefore be either over- or underestimated by several orders of magnitude. Inadequate consideration is often given to temporal and spatial variation in factors that govern the release of dust sized particles; as for example, bulk pore water and humidity, texture, mineralogy and cohesion. At most industrial sites, heavy vehicle movement and material handling also can cause intermittent releases of significant quantities of dust.

Fugitive dust emissions can be managed by a range of strategies inclusive of: chemical stabilization using surfactants, planting of vegetation cover, construction of wind breaks, and finally, watering. Chemical applications provide longer periods of dust suppression than watering, but can be costly, adversely affect plant and animal life, and contaminate the treated material. Watering is the most common and, generally, least expensive method. Unfortunately, there are few guidelines concerning the amount and frequency of watering needed to either reduce or prevent the emission of dust.

This paper reports on wind tunnel simulations undertaken to quantify potential fugitive dust emissions from a tailings impound at a proposed mine at the southern boundary of the Gobi desert steppe. The site lies at the boundary of the South Mongolian and the South Gobi tectonic units, and includes Paleozoic volcanic, sedimentary and intrusive rocks. Rock cores from the proposed mine site were extracted, and milled into tailings at an existing mine in Australia in order to replicate as closely as possible the expected

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waste product. Samples then were shipped to the Trent Environmental Wind Tunnel lab for dust emissions testing. Once operational, the tailings area is anticipated to comprise a series of parallel 2 km long cells or ‘beaches’. The tailings will be discharged to each cell as a slurry of ground rock and water from a number of spigot points along a header line. This technique is referred to in the mining industry as ‘spigotting’. It is anticipated that with time the ground rock flour will segregate from the slurry and dry, and that this waste product will remain uncovered. Periodic irrigation is under consideration as the principal method for managing dust emissions.

Four specific objectives were identified at the outset of the project:

(a) Determine the relationship between fugitive dust emissions, wind velocity and water content of the mine tailings, inclusive of dry pulverized tailings that represent a ‘worst case’ scenario.
(b) Assess the effect of crusting and crust rupture on dust emissions.
(c) Quantify the reduction in dust emissions associated with decanting the finest particles from the slurry, replicating particle segregation upon spigotting.
(d) Quantify the increase in the dust emission rate caused by the impact of saltating particles, as inter-related with objectives (a)–(c).

While the original scope of the project was mission oriented, the results obtained contribute appreciably to our understanding of the fundamental physical controls on dust emissions, complimenting and extending earlier experimental and theoretical work concerning the role of saltation bombardment (e.g., Gillette, 1977, 1978; Gillette and Passi, 1988; Gomes et al., 1990; Shao et al., 1993; Cahill et al., 1996; Alfaro et al., 2004; Roney and White, 2006), moisture (e.g., Gillette, 1978; Fecan et al., 1999) and crusting (e.g., Houser and Nickling, 2001a,b).

In many such applications, a portable wind tunnel, ideally one that is very large, is set up on site to simulate and quantify dust emission events. However, in the case of remote and relatively inaccessible areas, and especially for proposed tailings sites that do not as yet exist, this experimental set-up is not feasible. In comparison, simulations determining fugitive dust emission rates using an environmental boundary layer wind tunnel situated in a laboratory are relatively uncommon and present significant methodological challenges. Roney and White (2006) recently described a “novel methodology” for such experiments in their case study of Owens (dry) Lake soils. A somewhat similar methodology was developed independently for the present case study. The shortcomings and advantages of such laboratory simulations are discussed in the sections below.

2. Methods

2.1. Test surface preparation

Samples of slurry from four selected drill cores were dried, and then crushed with a mortar and pestle in order to break up all aggregates. The mean diameter (d) shown in the distributions in Fig. 1 was relatively uniform for samples Y1 (41 μm), Y4 (47 μm) and H1 (37 μm). A sub-fraction of the pulverized sediment was set aside, while the remainder was rewetted to 64% gravimetric water content, or 54% water content by volume. The intention was to replicate the physical properties of the slurry as it will be deposited at the tailings impound once it is operational. Small 16 cm × 26.5 cm, 2.5 cm deep aluminum trays were then lined with aluminum tape so that each could be overfilled without spilling, thereby allowing for shrinkage during drying. The trays were loaded with the slurry (Fig. 2), and allowed to settle. To address objective (c), samples Y1 and Y4 were decanted after 30 min and the segregated fines were discarded. All test samples then were dried in an oven at 50 °C over a period of several days until they reached 10% gravimetric water content. The water content (w_c) was determined from small cores that were extracted to obtain a vertically integrated measurement. After wind tunnel testing, some trays were returned to the oven and further dried to ≤2% water content. The 10% w_c runs eventually were eliminated as being non-emitting, so that all subsequent trays were dried to very low water contents.

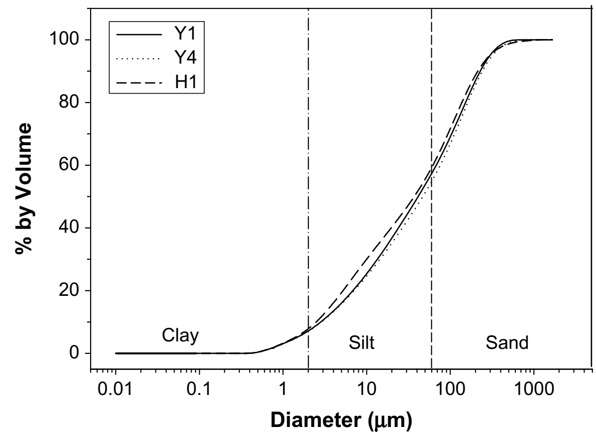

Fig. 1. Particle size distributions.

The very small amount of sample material provided for testing prohibited the use of large trays, with the exception of two experiments for which tailings samples Y1, Y23 and Y4 were combined in slurry, and poured into a 2 m × 0.35 m tray. This tray was too large to fit into an oven and therefore, was slowly dried over a period of 5 days under heat lamps (Fig. 2G,H).

In drying, all tailings formed cohesive blocks of sediment that were reduced in volume by approximately 25%. Tension cracks formed along the edges of the samples, and to varying degrees, through the center (Fig. 2A,C,H). By design, the final elevation of the shrunken surface aligned with the top edge of the aluminum tray. The excess tape was folded over and pressed down onto the surface of the tunnel bed in order to cover the gap along the tray edge.

2.2. Wind tunnel

Laboratory simulations for this project were conducted at the Trent University Environmental Wind Tunnel (TEWT). This facility and its instrumentation are fully described in previous studies, including McKenna Neuman (2003, 2004). The tunnel is a straight line suction design with a working section length of 13.8 m and a cross-sectional area of 0.54 m^2. The length to height ratio of 18.2 well exceeds the minimum value of 5 suggested by White and Mounla (1991) for the natural development of a boundary layer, which in this facility extends to about 0.30 m above a smooth bed surface. Large scale turbulent eddies generated by objects in the surrounding room are eliminated by flow-straightening tubes at the inlet to the compression bell. Air exiting the fan unit can be expelled, along with dust and sand, either to the outside atmosphere or re-circulated within the lab, depending on the test design and room configuration. For all tests described in the present paper, the dust laden air was exhausted outside through doors to the rear of the fan unit.

Within the tunnel test section, the airflow in the freestream is regulated by a programmable AC variable motor drive. Wind velocity is sampled using a micro-pitot tube (1 mm ID) that