NOVEL TECHNIQUES FOR EVALUATION OF WIND EROSION POTENTIAL OVER SURFACES

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Abstract

Accurate characterisation of wind erosion potential is an essential component of particulate matter emission inventory development for any mining or extractive industry application. However, typically practitioners rely upon threshold friction velocities and control factors for exposed surfaces within literature. Such data sources are often historical, based on limited field measurements, and developed for different surface types, geographies and wind exposures. This paper compares three practical techniques to establish site-specific data that can be applied to derive scientifically robust data on wind erosion potential of multiple exposed surfaces, as well as estimates of control efficiency of different dust management techniques. Firstly, we present the learnings from portable wind tunnel testing across a variety of fugitive dust surfaces (e.g. mine tailings, construction sites or laboratory samples). The tunnel is placed directly over the test surface to generate controlled wind conditions over the sample area. Threshold friction velocity and erosion potential of the surface is measured under controlled and repeatable wind conditions. Threshold friction velocities are compared to the results of a US EPA sieving test method. This is complemented by an overview of a little used, but highly practical technique for the estimation of relative control efficiency of different surface stabilisation techniques; the Confined Air Burst Chamber (CABC). The use of these techniques, either on their own or in tandem, can deliver site-specific estimates of wind erosion potential of multiple media in situ, as well as the control efficiency of dust suppression activities such as water / dust suppression application, or natural crusting of undisturbed material.

Keywords: wind erosion, emission factors, particulate matter, dust control

1. INTRODUCTION

Atmospheric dispersion modelling executed for mining and extractive industries within Australasia has historically depended upon generic emission factors derived from historical international datasets. These datasets, compiled primarily under the United States Environmental Protection Agency (US EPA) AP-42 framework during the late 1970s and early 1980s, reflect environmental parameters, operational configurations, and equipment scales that diverge substantially from contemporary industrial practices. In an Australian context, regulatory bodies and industrial operators have identified a requirement to transition away from generic estimates toward site-specific, empirically validated data that accurately map localised dust mobilisation mechanisms. Fugitive dust emissions from exposed surfaces (such as stockpiles, active open-cuts, and tailings storage facilities) present a challenge in terms of accurate dust emission quantification. This paper provides a comprehensive evaluation of site-specific characterisation techniques utilised at active mine sites. As mining operations encroach upon other competing land uses, capturing the precise wind erosion potential and dust mitigation efficiencies of exposed surfaces becomes essential, both to

demonstrate compliance and prioritise operational dust management.
This study compares portable open-floor field wind tunnel testing, the Confined Air Burst Chamber (CABC) technique, and the US EPA AP-42 nested sieving protocol. These methods provide scientifically robust datasets to optimise predictive emission inventories and confirm control factors for industrial dust management.

2. METHODS AND SETUP

2.1 Open-Floor Field Wind Tunnel

Measurement of absolute wind erosion potential from surfaces can be completed using a portable open-floor wind tunnel. The apparatus is composed of a specialised boundary layer fetch section connected to a downwind sample collection section. The test section in this study possesses a 280 mm by 280 mm internal square cross-section and spans a longitudinal length of 3.6 metres. Crucially, the bottom of the test section is completely open to the ground interface, allowing the generated airflow to interact directly with the surface in-situ.
Four centrifugal fans draw ambient air through the tunnel assembly to achieve cross-sectional flow velocities of up to 16 m/s within the ductwork. A woven wire mesh screen (0.45 mm strand diameter, 2.0 mm internal aperture) separates the open test floor from the sampling section to ensure comprehensive mixing and establish a uniform dust profile across the extraction zone.

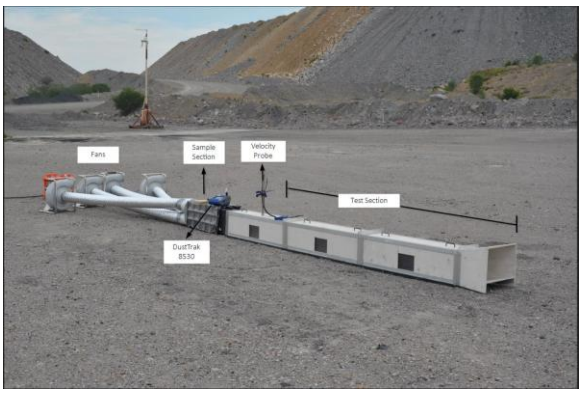


Figure 1. Overview of open floor wind tunnel configuration.

The flow rate through the tunnel is managed using adjustable throttling holes located at the inlet to the fan assembly. Particulate concentrations are measured isokinetically through variable-sized sample inlets using a continuous photometer equipped with a PM_{10} size-selective impactor according to AS 4323.2 - 1995. Flow velocity parameters are captured simultaneously using a digital manometer configured for vertical boundary-layer profiling.

2.2 Confined Air Burst Chamber (CABC)

MRIGlobal has developed a test method known as the Confined Air Burst Chamber (CABC) test (Cowherd, 2012). The CABC represents a highly practical, semi-quantitative method developed to measure the relative dust emissions potential of wind-erodible media and evaluate the specific effectiveness of surface stabilisation treatments. The CABC is not an absolute method, as it does not quantify emissions. Rather, it is used to estimate the relative emissivity of two or more surfaces. In this capacity, the results of CABC testing are of use
in modifying the default emission predictions, to reflect surface conditions, or emission controls that have been implemented. The test is designed to produce a localised dust cloud within a small, open-floored sampling chamber (volume = 9.4 litres; diameter = 200 mm, height = 300 mm) placed directly over the target substrate.
To execute a test cycle, a vertical injection tube inside the chamber directs a compressed air jet onto the test surface. The air burst system utilises a standardised electric pump to pressurise a compressed air cylinder to a fixed pressure of 50 psi. Once this pressure level is achieved, a high-speed valve is opened to release the air burst onto the sample media. Open orifices in the chamber top prevent internal pressure build-up by venting excess air during the immediate injection pulse. A battery-operated laser photometer records the PM_{10} concentration in the chamber at high-frequency log intervals beginning at the exact release of the air burst. The maximum concentration recorded serves as a reliable surrogate for the erodibility of the target surface.

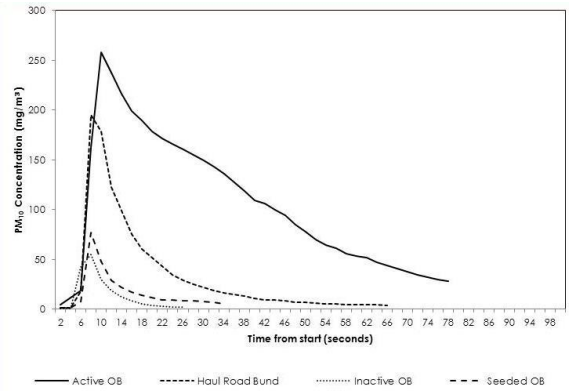


Figure 2. Example of PM10 concentration profiles in CABC test.

The fundamental layout and instrument configuration of the standard field CABC testing kit are presented schematically and photographically in Figure 2.

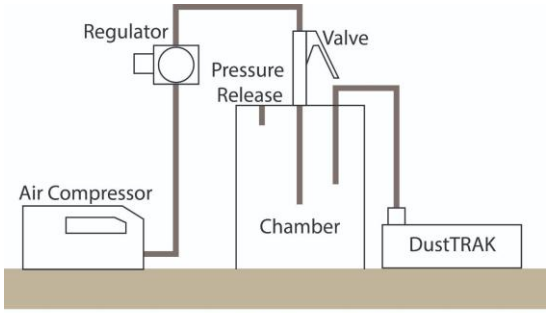




Figure 3. Confined air burst chamber test equipment and schematic.

2.3 US EPA Sieving Method

In accordance with Section 13.2.5 of the US EPA AP-42 Compilation of Air Pollutant Emission Factors, a site-specific nested sieving test was integrated to define threshold parameters based on aggregate size distribution. The procedure requires gathering a representative bulk sample from the undisturbed upper surface profile and passing it through a stacked set of five Tyler sieves (opening sizes: 4.0 mm, 2.0 mm, 1.0 mm, 0.5 mm, and 0.25 mm) resting on a base collector plate. By inspecting the dry mass distribution across the nested sieves, practitioners identify the "sieve mode"—defined as the specific sieve screen layer retaining the greatest dry mass fraction of the sample. This modal size parameter corresponds directly to an empirical surface threshold friction velocity and an implied lift-off wind speed threshold at a standard 10-metre regulatory monitoring height.

2.4 Bulk Sampling Techniques

Key metrics that influence the wind erosion potential of exposed surfaces can be gathered using bulk sampling techniques.

Section 13.2.5 of (USEPA, 2006) AP-42 Compilation of Air Pollutant Emission Factors Appendix C.1 provides the methodology for material sampling to establish moisture and silt content. At a high level the method involves the following:

Define a sample area of at least 0.3 m by 0.3 m that is representative of the surface to be tested.

- The depth of the sample should be 2.5 cm or the diameter of the largest particle, whichever is less.
- Do not deliberately avoid collecting larger pieces of aggregate present on the surface.
- Collect a minimum of 400 g for laboratory analysis.

3. INTER-COMPARISON TESTING AND RESULTS ANALYSIS

3.1 Threshold friction velocity measurement and velocity profile characterisation

Field inter-comparison trials were performed across two distinct overburden emplacement storage facilities (designated as Overburden Zone 1 and Overburden Zone 2). Testing

examined both un-trafficked weathered profiles and freshly disturbed surfaces prepared by standard mechanical raking to disrupt natural surface bonding. For the first part of the method the wind tunnel was run at progressively increasing speeds by turning on the fans one at a time. At this point the Pitot tube is in the centre of the tunnel.
This approach was used to estimate the velocity within the tunnel at which significant wind erosion emissions were observed to commence (the threshold friction velocity, u^*_t), as well the rate of decay in surface emissions. A velocity profile was measured and used to estimate u^* and the surface roughness parameter (z_0). In this case,
the Pitot tube was firstly located near ground level and then progressively moved upwards up to the middle section of the wind tunnel. For this part of the test all four fans were continuously running. A total of 15 velocity points were measured as part of this test.
Applying log-linear regression matching to the lower boundary layer datasets allowed calculation of the surface roughness parameter (z_0). The surface roughness value is a measure of the roughness of the ground surface.

Velocity profile parameters derived from the log-linear boundary layer regressions are summarised across the tested surface regimes below at the threshold frictional velocity:

Table 1. Boundary layer parameters derived from wind tunnel velocity profiles at the threshold frictional velocity

Tested Surface Regime	Calculated Surface Roughness (z_0) (mm)	Friction Velocity (u^*) (m/s)	Threshold Friction Velocity (u_t^*) (m/s)
Overburden 1 – Weathered	1.7	0.89	0.58
Overburden 1 – Disturbed	2.8	0.74	0.49
Overburden 2 – Weathered	0.6	0.52	0.4
Overburden 2 – Disturbed	1.7	0.69	0.39

An example of the derivation of surface roughness using the log-law / linear regression method is shown in Figure 4, for the Overburden 1 - Weathered source.

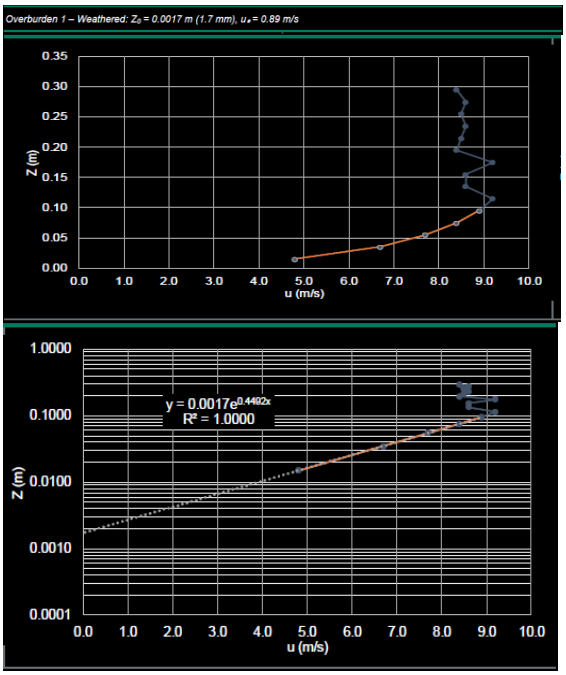


Figure 4. Open floor wind tunnel velocity profiles and derivation of surface roughness

3.2 Wind Erosion Erodibility Metrics and Core Relations

To enable a direct comparison between the wind tunnel and CABC datasets, raw concentration metrics from the wind tunnel erosion runs were normalised to a standard reference velocity of 12 m/s using the Shao et al. wind erosion velocity function. This allows direct benchmarking of the absolute mass concentrations (C_{corr}) generated by the wind tunnel against the peak localised metrics (C_{peak}) logged during corresponding CABC air burst cycles.
To enable a comparison between techniques, the average concentration obtained over the four Overburden cases of Table 1 was normalised to the peak concentration (Overburden case 2 Disturbed) observed using each technique. Figure 5 presents a comparison of these normalised (relative) emissivity derived by the open floor wind tunnel and CABC methods.

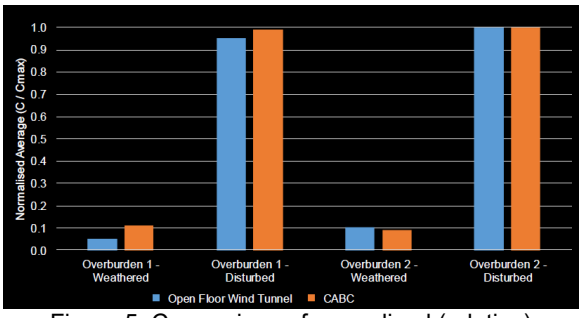


Figure 5. Comparison of normalised (relative) emissivity - open floor wind tunnel and CABC methods

The inter-comparison results demonstrate a good correlation between the small-scale CABC device and the large-scale open-floor field wind tunnel. Plotting the normalised emissivity values from both instruments yields a highly linear relationship. This relationship confirms that the vertical air burst mechanism of the CABC successfully evaluates relative dust emitting potentials and control efficiencies as effectively as a traditional horizontal boundary-layer wind tunnel.

Significant differences in emission potential were observed between weathered and freshly disturbed surfaces, with a factor-of-10 reduction in emissivity provided by natural crusting across both evaluation frameworks.

However, the study identified variances between the measured surface threshold friction velocities and those estimated by the generic US EPA AP-42 nested sieving protocol. This variance underscores the benefit of utilising field wind tunnels or CABC testing to obtain accurate, site-specific aerodynamic data rather than relying on sieve distributions alone.

4. PRACTICAL APPLICATION IN AN INDUSTRIAL SETTING

The empirical validation of these testing methodologies supports their practical implementation within site-specific dust management protocols. For example, data derived from site-specific field investigations can be directly integrated into operational air quality trigger systems to manage dust risks proactively.

In one industrial application, wind tunnel analysis identified a critical wind speed threshold of 10.9 m/s (at a 10 m standard height) for dry fine particles, which has been established as an initial alert level. A secondary critical wind velocity of 14.3 m/s (at a 10 m standard height) indicates the lift-off threshold for dry coarser tailings, serving as an absolute alarm level. When adverse meteorological conditions or elevated particulate concentrations are forecast or recorded, the automated control system pre-emptively activates a comprehensive ring-main sprinkler array surrounding the tailings storage facility (TSF).

Furthermore, CABC field testing has provided a reliable method for evaluating the relative performance of chemical dust suppressants over extended tracking periods. For example, testing performed on un-trafficked mine profiles demonstrated that an application of a polymer-based crusting agent maintained an erosion control efficiency of 98.9% five months after application. This highlights the utility of the CABC technique for verifying the long-term performance and durability of chemical binders under realistic weathering cycles. These verified control factors support the selective deployment of specialised suppressants through the site's automated dosing infrastructure during extended dry periods or water supply constraints, ensuring continuous compliance with regulatory impact criteria.

5. CONCLUSIONS

This investigation establishes a technically validated framework for evaluating wind erosion potential and dust control factors using site-specific empirical methods. The field inter-comparison program demonstrated a strong linear correlation between the portable open-floor wind tunnel and the Confined Air Burst Chamber (CABC) results. This confirms that the compact CABC device accurately evaluates relative fine particle emissivity and surface stabilisation efficiencies compared to larger less portable systems.

The application of these techniques highlights the limitations of relying solely on generic literature values or dry sieve size distributions, which were shown to overstate actual mobilisation thresholds. Implementing site-specific wind velocity and particulate triggers within a predictive telemetry framework enables operators to deploy dust mitigation measures proactively. Ultimately, utilising wind tunnel and CABC testing provides rigorous approaches to quantifying suspended emissions from exposed

fugitive dust surfaces, verifying the performance of chemical binders, and ensuring that operational dust management is optimised where it matters most.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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