Spectroscopic Investigations of Mining Residues Drying Kinetics to Predict and Prevent Fugitive Dust Emission

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Abstract

Aluminium oxide extraction from bauxite generates over 3000 tonnes of filtered bauxite residue daily at Rio Tinto's Vaudreuil Plant. Managing these mine tailings includes addressing the risks of fugitive dust scattering from their surface while they are momentarily stored in the open without dust suppressant at the disposal site in Jonquière, Quebec. To mitigate the risks, continuous monitoring of the drying process is imperative. A real-time quantification of their surface moisture content (SMC) is necessary to predict and prevent fugitive dust scattering, thereby reducing managing and mitigating costs. Albedo measurements in the near infrared (λ = 1200–1550 nm) will be shown to be a precise, sensitive and selective optical method for characterizing the mine tailings' SMC and monitoring their drying rate. A portable device has been designed for continuous SMC measurement, with high temporal and spatial resolution allowing their drying rate to be monitored *in situ* and in real time, under adverse environmental and operational conditions. This device also facilitates laboratory investigations into the dependencies of the mine tailings' drying rates on ambient air temperature and relative humidity, revealing how atmospheric boundary conditions influence water transport mechanisms within their interconnected porous network, namely capillary pumping and gaseous diffusion. The drying rates accelerate with increasing temperatures and decreasing relative humidity, while surface drying is more rapid in frozen tailings because capillary pumping is significantly inhibited. A comprehensive and quantitative knowledge of the impact of these key parameters, along with that of meteorological conditions such as wind speed and solar irradiance, and their recent history, should improve our description of water transport mechanisms and kinetics within mine tailing. The quantification of their drying rates should also improve our prediction of the evolution of their SMC and promote the development and implementation of models and tools necessary for the forecasting and prevention of fugitive dust scattering events thereby contributing to the reduction of the environmental impact of the mine tailings disposal site.

Keywords: Fugitive dust, Remote sensing, Surface water content, In situ monitoring, Water transport mechanisms.

1. Introduction

The rapid population growth since the early 20th century has driven a notable increase in global economic activity, with the mining sector experiencing a 58 % rise in demand between 2000 and 2021 [1]. This industrial growth has significantly increased the environmental footprint of the mining sector requiring improved waste and emissions management strategies [2, 3]. For instance, in Canada in 2021, the production of 3.2 million tonnes of aluminium generated approximately 6 million tons of waste [1]. The extraction of aluminium oxide via the Bayer process continues to present a significant challenge for the mining industry, particularly concerning the disposal and storage of bauxite residues, the primary byproduct [4]. Given their large quantities, these residues must often be momentarily stored outside without protection from the elements [4], as they require to prolong drying times before potential revalorization or revegetation strategies can be implemented [5]. When weather conditions favour the drying of the superficial layers of bauxite residues, these materials become highly susceptible to fugitive dust emissions [6]. This issue is especially critical during winter in boreal regions that harbour seasonal snow covers, as dust deposition on snow can alter its albedo, accelerating melting thus affecting local hydraulic budget management due to snow melt [7, 8]. Fugitive dust emissions from tailings disposal sites could represent environmental and health risks to nearby communities. Exposure to fine particulate matter, such as basic iron oxide particles from bauxite residues, can lead to respiratory complications upon inhalation [6, 9]. This highlights the importance of effective management and mitigation strategies for dust emissions to reduce the environmental footprint and health hazards associated with mining activities.

Several costly and labour-intensive methods are currently employed to control and suppress fugitive dust emissions. These include the use of liquid dust suppressants and the application of sand or wood chip overlayers. However, these methods have significant drawbacks. They not only incur high costs and require substantial labour but also reduce the storage capacity of tailings disposal areas, thereby shortening their lifespan. Additionally, dust suppressants can inhibit bulk evaporation, which is undesirable since slurries need to dry until they reach solid fractions suitable for subsequent on-site geotechnical applications. Excessive use of dust suppressants can hamper evaporation, delaying the revalorization and restoration of disposal sites [5]. In turn, free evaporation from tailings can lead to premature drying of the superficial layers, favouring dust emissions when capillary forces release their grip on dust particles [6, 10]. A delicate balance must thus be struck between the requirements of efficiently attaining sufficiently high drying fractions to allow for proper manipulation and geo-technical compaction on the disposal site, while preventing surface layers from reaching elevated drying states which increases risks of fugitive dust emissions. Predicting the drying state of slurry surfaces is challenging due to the limited understanding of how environmental conditions such as temperature, relative humidity, solar irradiance, and precipitation affect evaporation kinetics. Therefore, there is a need for improved continuous and surface-sensitive monitoring methods to assess tailings moisture content (TMC) for better risk management and dust emission prevention.

To address this challenge, a bauxite residue storage area (BRSA) was selected as a case study for developing remote sensing and on-site monitoring tools. The study involved collecting bauxite residue samples and characterizing their physico-chemical properties, including moisture content [10]. Surface drying states and evaporation kinetics were analysed using surface-specific optical techniques, such as albedo measurements with a field spectroradiometer at short-wave infrared (SWIR) wavelengths, and thermal imaging using an infrared camera. These optical methods need to be validated for their reliability and robustness under the harsh conditions of BRSA operations. They must provide sufficient precision, accuracy, surface sensitivity, and selectivity for remote sensing applications. Ideally, these methods should not rely on the highly variable solar irradiance flux as a light source to ensure consistent TMC measurements throughout the complete diurnal cycle and be immune to fluctuations in the nebulosity. In situ methods for estimating soil moisture content, such as gravimetric and dielectric measurements, are limited in several ways. Gravimetric methods, while accurate, are labour-intensive and not feasible for continuous monitoring in the field. Dielectric measurements, which include capacitance and time-domain reflectometry, can be influenced by soil salinity and composition, making them less reliable for heterogeneous materials like bauxite residues [11]. Neutron probes, though effective for volumetric water content measurements, are expensive, require specialized training, and pose safety concerns due to the radioactive source involved [12]. Gamma-ray attenuation methods also provide good volumetric data but suffer from similar drawbacks regarding cost, safety, and complexity [12]. Other remote sensing techniques, such as those using thermal infrared imagery, can provide valuable data but are often limited by atmospheric conditions, which affect the accuracy and reliability of the measurements. These methods are typically not suitable for the for robust and sensitive measurement techniques to predict drying behaviour accurately and, thus, surface moisture content. Future research will focus on enhancing this predictive aspect of the IRDI device in the field while also exploring water transport mechanisms in greater detail in the laboratory, more specifically in terms of the impact of the structural and morphological characteristics of the tailings interconnected pore network on the drying kinetics.

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6. References

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