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Application of aerial image analysis for assessing particle size segregation in dump leaching

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ABSTRACT

Understanding the behaviour of fluid flow through packed ore/rock beds is essential for estimating metal extraction from low-grade ores via dump leaching as well as the release of toxic elements from mine waste rocks. One fundamental factor that determines the flow behaviour in ore/rock beds is particle size distribution. Given the limitations presented by the traditional sieve analysis, we applied aerial imagery to investigate the particle size distribution in ore piles. Using dump leaching as an example, we analyzed the aerial images of a dump leach pad acquired by a camera installed on a drone while the leach pad was under construction. The image analysis results showed that the dump leach pad contained an extremely wide range of particle sizes. A spatial segregation of fine and coarse particles was observed. The widely used P_{80} was deemed to be questionable to represent particle size distribution in dump leach pads. The Sauter mean diameter (d_{32}) and the dump permeability were found to increase with depth. The technical method described in this study provides a more convenient and reliable tool for particle size distribution analysis, thereby facilitating future studies that will enhance understanding of metal extraction from low grade ores in leaching operations as well as the potential release of pollutants from waste rock piles.

1. Introduction

The movement of fluids (water and air) through packed beds of ore/rock particles plays an essential role in the extraction of valuable metals from low-grade ores via heap/dump leaching as well as the release of potentially harmful substances from mine waste rocks (Bouffard and Dixon, 2001; Stockwell et al., 2006; Wu et al., 2007). Understanding the mechanisms of fluid flow through such porous matrix is greatly assisted by the knowledge gained in the area of unsaturated soil mechanics (Fredlund and Rahardio, 1993). The two major mechanisms of unsaturated flow through porous media are uniform flow and preferential flow, which often occur simultaneously but have distinct effects on wetting of the materials and chemical leaching (Hendrickx and Flury, 2001). In uniform flow water percolates through the packed materials evenly and slowly, leading to a stable wetting front that is parallel to the porous matrix. In contrast, preferential flow comprises all phenomena where water moves unevenly and often rapidly along the least resistant pathways (Hendrickx and Flury, 2001). Preferential flow and the resulting bypass of a considerable fraction of the porous media by moving fluids is a common phenomenon in dump leaching and in heterogeneous waste rock piles (Eriksson and Destouni, 1997; Stockwell et al., 2006). The ratio of uniform to preferential flow is crucial for determination of the amounts of solutes leached from solid matrix and transported by moving fluids (Dykhuizen, 1987; Jarvis, 2007).

Fluid flow in unsaturated porous media is described by such bulk parameters as the fluid properties (density and viscosity), the intrinsic permeability of the porous media, and the degree of saturation (Bear, 1972; van Genuchten, 1980). Quantification of the intrinsic permeability at the pore scale can be extremely challenging due to the highly heterogeneous nature of the pore structure (Stewart et al., 2006). The intrinsic permeability has been estimated by using empirical relationships of various degrees of complexity. Examples are the Hazen formula that predicts permeability using only one characteristic particle size and the Kozeny-Carmen formula that is based on the entire particle size distribution, the particle shape and the void ratio (Carrier, 2003; Chapuis, 2004). Hydrogeoscientists are commonly required to estimate permeability with knowledge only of a characteristic grain size or a grain size distribution (Alyamani and Şen, 1993; Masch and Denny, 1966; Shepherd, 1989). Similarly, in the field of heap/dump leaching, particle size distribution acts as one fundamental parameter for the ultimate estimation of metal extraction efficiency (Ghorbani et al., 2011). In the case of run-of-mine (ROM) ore, the particles range in size from less than 0.01 cm to greater than 100 cm in diameter. The

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tendency for finer materials to remain near the top and coarse materials to roll down towards the toe of the dump during end dumping may result in spatial heterogeneity in particle size and therefore create pathways for preferential flow to occur (Allaire-Leung et al., 2000; David, 1993; Wu et al., 2007). This can be aggravated by a top layer of low permeability resulting from the compaction by the heavy equipment traffic.

To understand fluid flow through rock piles, we investigated the particle size distribution of a dump leach pad and estimated its permeability based on the particle size distribution. Particle size distribution is typically derived from sieve analysis, where the size of a particle, typically not spherical or of any regular shape, is based on the aperture of a screen. However, the existence of particles as large as 100 to 200 cm in dump leaching renders it impractical to use sieves of such large size. The limiting sieve size may lead to the collection of unrepresentative samples, which can produce results that do not reflect the particle size distribution of the whole leach pad. Another problem with sieve analysis is the impossibly large sample size required for adequate representation of very large particles, even when sufficiently large screens are available. In this study, image analysis technique was chosen as the method for obtaining particle size distribution. The technique has been used to analyze particle size distribution in rock piles that comprise particles of a wide range of sizes (Amos et al., 2015; Chi, 2011). The originality of this study lay in the way that these images were acquired: aerial images of the leach pad were taken using a camera installed on a drone while the leach pad was under construction. This enabled a complete view of various dump faces formed during construction, thus improving the chance of obtaining representative measurements of the particle size distribution. The findings of this study can provide insights into the behaviour of fluid flow and solute transport in dump leach pads as well as in waste rock piles.

2. Methodology

2.1. Image acquisition

The case study site was the Quebrada Blanca (QB) copper mine located in northern Chile. The operation produces copper cathodes using heap and dump leaching, solvent extraction, and electrowinning. This study aimed at investigating the particle size distribution of the dump leach pad, which was constructed via end dumping of the run-of-mine ore using haulage trucks without further crushing of the ore. During dump construction, a new dump face was formed after a truck load of ore was deposited over the previous dump face. Images of various dump faces were taken using a camera installed on a drone operated by San Lorenzo S.A. (Iquique, Chile). The angle of repose was between 30° and 40°. The camera was adjusted roughly in parallel with the dump faces at an angle of 35°. Four PVC pipes of 1-m length and 1-inch diameter painted in orange that provided high visibility were placed on the leach pad in the shape of a square as the reference size for the subsequent image calibration. Fig. 1 (left) shows a schematic of the dump construction via end dumping and the setup for the image acquisition. Fig. 1 (right) shows an actual photo of the drone in the process of acquiring images at the case study mine. The image resolution achieved was 4000 × 3000 pixels.

2.2. Image processing

Ten images in total, each representing a distinct dump face, were selected for the image analysis using ImageJ software, an open source platform designed for scientific image analysis (https://imagej.net). The image analysis procedure has been explained elsewhere (Zhang and Liu, 2016). The original RGB color images were imported to the software and converted to 8-bit grayscale images. The image calibration provided a pixel-to-real-distance conversion factor of 1.734 cm, i.e., each pixel was converted to a real world distance of 1.734 cm. Therefore, the height of the dump from the top to the toe in the images was calibrated to be 34 m and the horizontal distance from the left to the right in the images was calibrated to be 65 m. The software assigned each pixel a single number that represented the brightness of the pixel, the so-called “pixel intensity value”. The range of pixel intensity values in a grayscale image is between 0 and 255, with zero being black, 255 being white, and the values in between making up different shades of gray. Ore grain sizes can be obtained from image analysis on the basis that the boundaries of rock particles are generally darker than the interior, meaning that there are sharp changes in the intensity value from boundaries to the interior (Chi, 2011). After the image calibration, the boundaries of the ore particles were detected and emphasized by applying “Find Edges”. This was done through a Sobel filter, an image processing algorithm for edge detection in images by using two 3 × 3 convolution kernels to calculate vertical and horizontal derivatives of the image intensity function. Image thresholding was then applied to convert the image to a binary image, i.e., partition the image into ore particles (foreground) and background. Finally, the surface area of each ore grain was analyzed and the results were exported to a Microsoft Excel spreadsheet, where the surface area was converted to the equivalent sphere diameter. The cumulative volume of all spherical particles in one image was estimated to be about 467 m^3, which gave a total volume of 4670 m^3 of ore from the ten images studied by the image analysis technique.

2.3. Statistical interpretation of results

Even though efforts were made to obtain a perfect view of the entire dump face, imperfections were still found in six of the ten images due to the large dimension of the leach pad. The imperfections were on the part of the images that represented the top 2 m and the toe of the dump. Among the ten images selected for the study, four images with a satisfactory view from the very top to the toe of the dump were chosen for the analysis of the particle size distribution of the entire dump. Each chosen image was processed individually to extract data of the particle size distribution of the dump face formed. The data from the individual

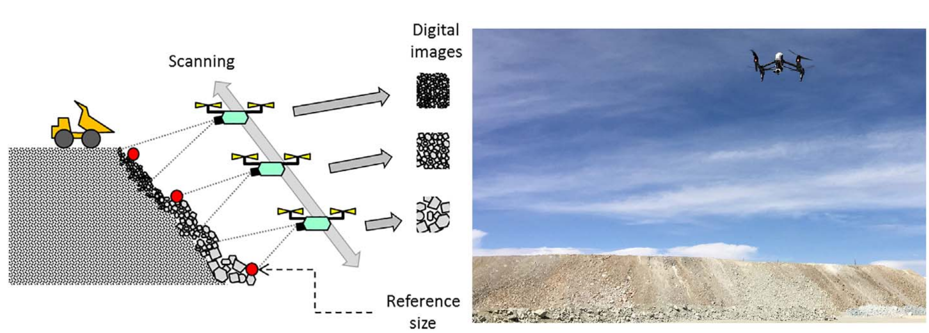

Fig. 1. (Left) a schematic for dump construction via truck end dumping and the setup for the image acquisition; (Right) a drone in the process of acquiring images of the leach pad at the case study mine.

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