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Development of an electrical conductivity screening test for mine waste assessments

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HIGHLIGHTS

- Leaching characteristics of a waste stream from a coal processing plant were evaluated.
- The key factors impacting electrical conductivity of leachate were evaluated using statistical analyses.
- Leachant volume to particles surface area ratio and oxidant were the most significant parameters.
- A conductivity screening test was developed for assessing environmental impacts of waste streams.

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ABSTRACT

An environmental concern at mining operations is the potential leaching of trace elements from overburden and byproduct streams of processing plants. To provide a timely assessment of this concern, electrical conductivity of the leachate emanating from the plant waste streams can be measured as an indicator of the trace element content levels using the USGS Field Leach Test (FLT). However, the research reported in this publication revealed the need to modify the FLT procedure to improve the precision of the test results. The primary issue involved the importance of leachant volume-to-particle surface area ratio in the assessment of the leaching potential for a given source. To determine the key factors impacting leachability of a given material, a statistically-designed parametric study was performed. The experimental program evaluated the effects of particle surface area, the leachant volume-to-surface area ratio, and the amount of oxidant used to expedite the leaching rate during the test. The results revealed that the significant parameters are leachant volume-to-solid surface area ratio and the amount of oxidant. The findings were used to recommend a modification to the conductivity screening test.

1. Introduction

The leaching of major and trace elements into streams and their potential environmental impacts are of environmental concerns especially for mine overburden, coal and mineral processing waste materials, naturally mineralized soil, industrial waste, construction sites, natural and amended soils, ash material from coal combustor units, dust, dried sludge and sediments, etc. (Daniels et al., 2013; Ghosh et al., 2014; Gluskoter et al., 2009; Hageman, 2007; Huggins et al., 2016; Plumlee et al., 2005; Van Gosen et al., 2000; Yager et al., 2004).

In processing plants, gangue minerals are separated from valuable minerals using low-cost separation technologies which improves the quality of raw material to a level that meets product quality requirements (Amini et al., 2016a,b; Gluskoter et al., 2009). The gangue minerals may oxidize in the waste piles or impoundments and dissolute into the water. Oxidation and/or dissolution reactions of different types of minerals such as sulfide, carbonate and clay minerals have been extensively researched (Bibi et al., 2011; Chandra and Gerson, 2010; Evangelou and Zhang, 1995; Huertas et al., 1998; Köhler et al., 2003; Moses et al., 1987; Pokrovsky et al., 2005). The dissolution of minerals in aqueous streams may result in pH variations and an elevation in total dissolved solids (TDS) in the supernatant water. The relative level of TDS concentration can be indirectly measured by the electrical conductivity (EC) of the liquid with higher values indicating an elevated TDS level.

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Specific conductance values of water exceeding 500 μS/cm in headwater streams has been reported as one of the causes for the loss of certain groups of bugs, e.g. myflies, and the disturbance of aquatic life in certain areas like Appalachia, USA (Cormier et al., 2011; Agouridis et al., 2012). To minimize the TDS and conductivity levels of the discharged water from the waste streams, identifying potentially high conductivity producing components followed by isolation or encapsulation have been suggested to be promising operational methods (Rezaee et al., 2013; Yeheyis et al., 2009). Given the vast number of mineral sources contained within typical mine wastes, a quick and inexpensive method for providing an initial ranking of the potential leachability is needed. The measurement of the water conductivity resulting from the contact with the solid waste meets the requirements assuming acceptable accuracy and precision. Using the conductivity test as a screening mechanism, the waste materials that have the greatest potential for environmental harm can be identified for isolation and the remaining material can be tested in more detail using established static and kinetic leaching tests to assure they meet environmental requirements (Chotpantarat, 2011; Kleinmann, 2000; O'Shay et al., 1990; Parbhakar-Fox and Lottermoser, 2015; Sobek et al., 1978).

To quickly assess and compare leachate geochemistry from historical metal mine dumps, Hageman (2007) developed the USGS Field Leach Test (FLT). In this test, 1000 mL of deionized water is slowly added to 50 g of prepared sample (20:1 water/solid ratio) in a wide-mouth plastic bottle. The capped bottle is vigorously hand shaken for 5 min and the contents allowed to settle for 10 min. The leachate is extracted from the bottle and analyzed for pH, specific conductance, alkalinity or other water quality characteristics. This test was later modified by Monday and Warner (2013) for screening-level specific conductivity of drill core strata in the field or laboratory. Modifications included a reduction from 1000 mL to 450 mL of either distilled or deionized (alternative methods) water with or without the addition of 50 mL hydrogen peroxide added to a 25 mg of sample (20:1 liquid/solid ratio) in a 1 L wide-mouth plastic bottle. Hydrogen peroxide and other oxidants increase the oxidation rate of minerals especially pyrite followed by dissolution of the elements. As a result, an expedited assessment of the leaching potential for mineral types and individual fractions of the mine waste can be achieved through the measurement of specific conductivity, and visual observation of effervescences (Holmes and Crundwell, 2000; Lara et al., 2015; Schoonen et al., 2010).

Previous researchers have found that parameters such as particle size and volume along with leachant volume are impactful parameters in assessing leachability using kinetic leaching experiments (Bradham and Caruccio, 1990, 1995; Brady and Weil, 2007; Kleinmann 2000; Sasaki, 1994). These parameters are directly linked to the exposure of the leachant to particle surface area (Lollar, 2005). However, the FLT and the modified FLT do not specify a particle size distribution. As such, the ratio of exposed surface area (SA) to the liquid volume is not held constant and, in fact, reaches values greater than 25:1. The impact is dilution of the ionic concentration which limits the ability to provide an initial leaching potential assessment using electrical conductivity measurements. Furthermore, the amount of oxidant (H_2O_2) added to the solution was not specified based on the mineralogical composition.

To develop a more meaningful standard test for rapidly performing conductivity screening assessments, the effects of three parameters and parameter interactions were evaluated using a statistically-designed test program. The parameters include: 1) surface area (as quantified by material particle size, density, and mineralogy of the sample), 2) volume-to-surface area ratio (VSAR) and 3) the amount of oxidant. The parametric evaluation identified the appropriate test procedural modifications and quantities of solids, liquids and oxidants needed to ensure a precise and accurate evaluation.

2. Materials and methods

2.1. Sample collection and characterization

A representative sample of a coarse refuse stream from a coal processing plant treating Indiana 5-B central coal seam was collected. Coal from this source is characterized as high-volatile 'C' bituminous coal with high concentrations of organic and pyritic sulfur. Upon receiving the sample, the material was crushed using a laboratory jaw crusher to achieve a top size of 6.35 mm, which was selected based on the leaching test standard described by the D-5744 ASTM procedure. After crushing, the sample was split into 1 kg sample lots using a Jones riffler. The samples were placed into plastic containers and stored until needed in the test program.

Characterization of the coarse refuse was conducted on a representative 1 kg sample lot. As shown in Table 1, proximate, ultimate and sulfur form analyses found that the sample contained 54.5% ash-bearing material and the sulfur was primarily in the form of pyritic sulfur from which the oxidization product generates acidic runoff. The minerals present within the ash-forming material were identified and their content quantified using X-ray Diffraction (XRD) by the Rietveld method. The mineral was mostly pyrite which comprised 43% of the total material followed by nearly equal amounts of quartz, illite and kaolinite. A minor amount of calcite was also present which has value as a neutralizing component to counter acid generation. These findings were confirmed by results obtained from X-ray fluorescence (XRF) analysis of the ash produced by combusting the coarse refuse sample at 500 °C. The ash was primarily comprised of iron oxide which mostly resulted from the combustion of pyrite. Significant quantities of aluminum and silica oxides were found which was in agreement with the XRD results. A low CaO concentration indicated limited natural buffering capacity.

Prior to performing a modified conductivity screening test, a 1 kg sample was screened using sieves having 1 mm and 0.15 mm apertures which resulted in three particle size fractions: i.e., coarse (6.35 × 1 mm), fine (1 × 0.15 mm) and ultrafine (minus 0.15 mm). The ultrafine fraction was not used in the screening test and thus was discarded. The coarse and fine size fractions were subjected to density fractionation at a specific gravity of 2.95 using a lithium metatungstate (LMT) solution. In this process, the particle size fraction was submerged into an LMT medium contained in a 2-L beaker followed by removal of the float fraction using a screening tool which allowed the excess medium to drain. The remaining medium was filtered to recover the particles that settled to the bottom of the beaker. Both the float and sink fractions were rinsed and dried. As a result, four particle size and density fractionated samples were produced as shown in Table 2 which were used for the modified FLT parametric study.

Leaching characteristics of the bulk coal sample were studied by a static leaching test and a long-term dynamic column leaching test, which was performed according to standard ASTM method D-5744. The two long-term leaching tests were utilized to simulate various storage conditions associated with typical coal waste disposal practices. The static test was designed to simulate the stable storage of coarse waste materials submerged under water that are used for embankment construction of impoundments. The dynamic test was designed to model storage under more variable conditions similar to those of coarse refuse piles that provide intermittent exposure to air and variations in humidity.