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Co-disposal of benign desulfurised tailings with sulfidic waste rock to mitigate ARD generation: Influence of flow and contact surface

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ABSTRACT

The co-disposal of desulfurised tailings, prepared from coal fines, with sulfidic coal interburden was investigated for the long-term prevention of ARD under extreme oxidative conditions. Benign tailings, comprising less than 0.78 wt% sulfur and classified as non-acid forming by standard acid-base accounting, were co-disposed with coal waste rock (1.58 wt% sulfur) in layered or blended configurations to minimise the infiltration of oxidants to the sulfide minerals exposed to the porous ore surface by minimizing flow through voids present in the bed. Reduction in ARD through co-disposal was demonstrated in a previous study in which columns were irrigated with water (Kotsiopoulos and Harrison, 2015). Here we use acidified conditions (pH 2) to aggravate the ARD generation while investigating co-disposal of desulfurized benign tailings and waste rock. The minimization of acid generation through introduction of desulfurized benign tailings to both neutralize acidity and minimise permeability was affected by the column packing, ore bed cross-sectional area and variation in permeate flow paths through the system. Rapid increase in flow, postulated to be due to a shift or segregation in fine desulfurised tailings, resulted in exposed active surface sites promoting the oxidation of the sulfide minerals. Where the integrity of the column packings were sustained over extended time periods, co-disposal resulted in ARD potential being minimised over longer periods maintaining near neutral pH conditions and low overall redox potentials.

1. Introduction

A major environmental concern associated with existing and abandoned mines is the generation of acid from the oxidation of disposed sulfide minerals when exposed to the natural elements, water and the oxygen in the air, especially in the presence of iron- and sulfur oxidising microorganisms. Over time, the liberated ferrous ions are oxidized to ferric ions in an increasingly acidic environment. Ferric iron, a more efficient oxidizer than oxygen at low pH, accelerates the leaching of exposed sulfide minerals, further compounding the potential for ARD (McGuire et al., 2001; Sengupta, 1993). Iron and sulfur oxidising microorganisms that prevail under these extreme acidic conditions accelerate the regeneration of the leach agents. Without effective preventative measures, treatment of these acidic runoffs using chemical neutralising agents is expensive and labour intensive (Erguler et al., 2014; Johnson and Hallberg, 2005). In the absence of treatment, environmental degradation occurs with potential for impact on human health. Prevention of these ARD producing reactions is preferred by removal of the sulfide fraction from finely disseminated waste rock (Kazadi Mbamba et al., 2012) or, where this is impractical owing to its lack of liberation in coarse waste rock, limiting access of oxidants to the sulfide mineral surface (Demers et al., 2008).

Several factors influence the rate of metal, sulfate and proton liberation and the initiation of the leaching of sulfide minerals present in mine wastes. These include the mineralogy and chemical composition of the disposed minerals as well as physical attributes such as the particle size distribution, and correspondingly the particle surface area (Erguler et al., 2014; Fall et al., 2009; Harrison et al., 2013; Robertson and Broughton, 1992; Strömberg and Banwart, 1999). Contacting of the oxidants with the mineral sulfide is essential for leaching; this implies that the rate of surface exposure influences the onset of leach reactions (García et al., 2005; Harrison et al., 2013). Diffusion of gaseous components and infiltration of liquid elements through waste rock beds are enhanced by the inherent available porosity of the dump, further increasing the available surface area for reaction (Fall et al., 2009; Lefebvre et al., 2001). Several studies have demonstrated the relationship of ore particle size distribution, shape and compactness of waste rocks with porosity and solution flow characteristics (Erguler and

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Erguler, 2015; Fall et al., 2009; Lefebvre et al., 2001; Parbhakar-Fox et al., 2013). These have been demonstrated in research investigating the feasibility of barrier materials used either as covers or in co-mingled configuration with potentially acid forming sulfide minerals (Bussière et al., 2004; Demers et al., 2008; Doye and Duchesne, 2003; Gautama et al., 2010; Hakkou et al., 2009; Lamontagne et al., 2000; Maddocks et al., 2009). These works clearly show that the compactness of the ore bed and its influence on hydraulic conductivity as well as the extended exposure of the minerals to the aqueous phase or hydrogeological effects influence the success of these preventative measures (Fall et al., 2009; Hakkou et al., 2009; Sáinz et al., 2002; Smith et al., 1995; Wilson et al., 2006). The presence of large channels and voids allow preferential flow paths to develop, exposing the sulfide minerals in these paths to aqueous oxidants. This further promotes microbial growth with eventual acceleration of oxidation reactions (Fagan-Endres et al., 2015; Fagan et al., 2013; Harrison et al., 2013; Smith et al., 1995). However, limited information regarding the influence of the cross-sectional area of the ore bed on the rate of oxidation is available in ARD investigations. The influence of column dimensions on the universal validity of kinetic ARD tests has recently been investigated (Erguler et al., 2014; García et al., 2005). These studies showed an inverse relationship between the onset of ARD inducing (and neutralising) reactions and the height, diameter and volume of the test columns (Erguler et al., 2014). It was clear from these investigations that the initiation of ARD generating reactions may be delayed or facilitated by changes in the exposure of bulk surface area of the ore bed to the oxidising agents. It is challenging to study these factors as well as solution holdup within the test columns independently.

In this paper, the bench-scale study seeks to investigate the co-disposal of fine tailings with waste rock to decrease bulk surface exposure, leachate contacting and resultant ARD. Further, it aims to decouple these parameters in column sets by using different aspect ratios and to describe the significance of ore bed compactness in the mitigating efficiency of imposed strategies. The study seeks to both shed light on the design and interpretation of column tests for characterisation of ARD potential as well as highlighting parameters of importance for the mitigation of ARD formation through co-disposal of sulfidic waste rock or interburden with desulfurised, acid consuming tailings.

2. Materials and methods

2.1. Waste rock and tailings fractions

Coal waste rock obtained from the Waterberg Coalfields in South Africa was utilised. The interburden was collected as a drill core sample and had not been subjected to intensive weathering. The crushed interburden waste rock sample was representatively split to give a topsize of 70 wt% passing 20 mm. X-ray Diffraction (XRD) of the interburden sample indicated that the only sulfide mineral present was pyrite constituting 1.37 wt% of the total composition with the remainder composed mainly of gangue materials kaolinite (62.33 wt%) and quartz (30.51 wt%) (Fig. 1a). From BET analysis, the coal waste rock had an average specific pore volume of 0.035 cm^3/g. Due to the high concentration of kaolinite in the interburden, a crude absorption test was conducted to obtain an indication of the porosity and hence degree of saturation of the waste rock particles under extreme conditions. After submerging a sample of interburden particles in water for 24 h, less than 0.05 wt% of water was absorbed by the particles on average. As the test columns in this study were operated in unsaturated mode, the porosity or water uptake and swelling of the interburden were deemed insignificant and therefore these hydrogeological aspects were considered not to hinder the hydrodynamics of the system.

Elemental analysis of the acid digested interburden was conducted using inductively coupled plasma techniques incorporating optical emission spectroscopy (ICP-OES). The elements in the digestate were found to be predominantly Fe, Al and Si with trace (<0.01%) Ca, K, Mg, P, S, Ti, Cr, Mn, Co, Ni, Cu, Zn, Ga, Rb, Sr and Pb.

Desulfurised tailings (d_{90} = 104 μm; d_{50} = 11.4 μm, Fig. 2), used as neutralising agent in the ARD prevention strategies, were obtained from the two-stage flotation of ultrafine bituminous coal waste samples. These samples were obtained from the Middleburg regions in South Africa and floated according the procedures outlined by Kazadi Mbamba et al. (2012). The resultant desulfurised tailings contained less than 0.78% of total sulfur as determined

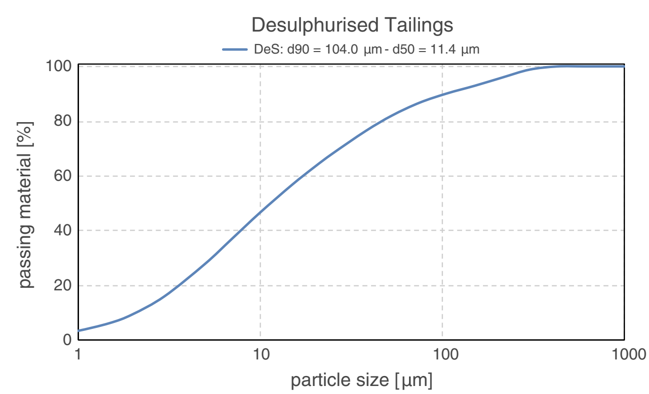

Fig. 2. Particle size distribution of desulfurised coal tailings obtained from the two-stage flotation of ultrafine coal waste. Samples were obtained from the Middleburg region in South Africa.

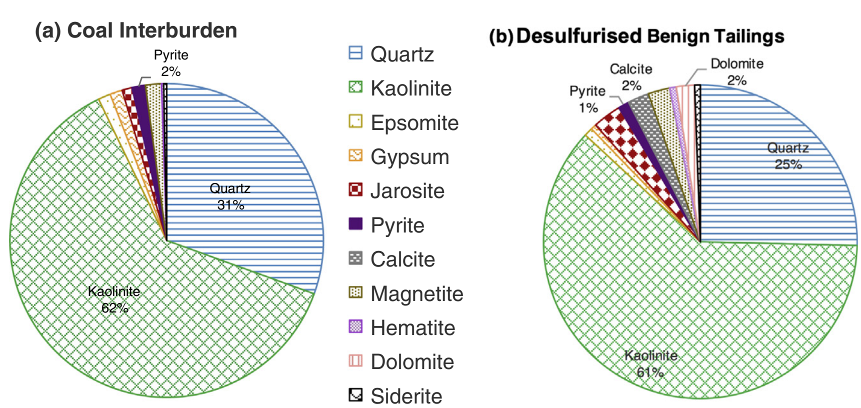

Fig. 1. XRD Mineralogical analysis of coal interburden and desulfurised tailings sourced from the Waterberg Coalfields and Middleberg regions in South Africa, respectively.