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Life cycle assessment of the desulfurisation flotation process to prevent acid rock drainage: A base metal case study

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ABSTRACT

The long-term generation of acid rock drainage (ARD) from sulfide-bearing mine waste is a major environmental liability for the mining sector. Previous studies have demonstrated that these ARD risks can be effectively avoided, and resource recovery simultaneously improved, through the pre-disposal removal of sulfide minerals, by means of flotation.

This study uses life cycle assessment to evaluate the broader environmental consequences of incorporating a desulfurisation flotation unit for the pre-disposal treatment of a base metal sulfide tailings wastestream. The desulfurisation flotation process is shown to result in a significant decrease in human toxicity, eco-toxicity, urban land occupation and natural land transformation impacts, but an increase in climate change, fossil fuel depletion and terrestrial acidification impacts. Desulfurisation flotation also offers the opportunity for improved recovery of valuable resources, such as water, residual metals and sulfur. An expanded system boundary would, however, be required to capture the environmental benefits of upstream and downstream utilisation of recovered resources. The study also highlighted the deficiencies of current life cycle impact assessment tools, in terms of their ability to adequately assess the environmental impacts associated with solid mineral wastes. These deficiencies and shortcomings will be the subject of further studies.

1. Introduction

The minerals industry is characterised by large tonnages of solid waste, with potential implications in terms of public health and safety, environmental degradation, as well as site rehabilitation and maintenance costs. Of particular concern are the waste rock and tailings arising from the extraction and processing of sulfide-bearing hard rock ores and coal deposits. These waste deposits can contain significant quantities of residual sulfide minerals, particularly pyrite, which are susceptible to oxidative dissolution in the presence of water and oxygen, giving rise to the formation of acid rock drainage (Broadhurst et al., 2013; Harrison et al., 2010; Lottermoser, 2007). Acid rock drainage (ARD) is typically characterised by low pH, high salinity and elevated metal concentrations, and frequently results in prolonged degradation and pollution of the local environment (see for example reports by Bell et al., 2001; Lottermoser, 2007; Rosner et al., 2001).

Traditionally the management of ARD from waste piles has relied on end-of-pipe treatment techniques which are aimed at preventing the dispersion of acidic drainage into the surrounding environment. Changes in legislation and global thinking has, however, prompted the development of more pro-active approaches which are aimed at minimising or preventing ARD generation. Whilst in practice such approaches are mainly concerned with avoiding exposure of waste to oxygen and water, discussions in the open literature (see for example Cilliers, 2006; Harrison et al., 2010; McCallum and Bruckard, 2009; Mitchell, 2000; Napier-Munn et al., 2008) indicate a growing trend towards the development of approaches that remove the ARD pollution risks over the long-term, through the generation of wastes that are benign in the first instance. One such approach entails the pre-disposal removal of sulfide sulfur from fine waste, using physical separation techniques such as froth flotation (Benzaazoua et al., 2000, 2008; Benzaazoua and Kongolo, 2003; Bois et al., 2004; Hesketh et al., 2010; Kazadi-Mbamba et al., 2012; Leppinen et al., 1997).

In the integrated approach proposed by Hesketh et al. (2010) and illustrated diagrammatically in Fig. 1, froth flotation is used to separate base metal sulfide tailings into two separate fractions; namely a benign, sulfide-lean tailings fraction, containing the bulk of the gangue minerals, and a smaller volume sulfide-rich fraction.

Harrison et al. (2013) provide an overview of potential management options for the down-stream management and processing of the separated tailings fractions, some of which are outlined in

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Fig. 1. These authors highlight the potential economic benefits of using separated tailings to generate valuable by-products whilst simultaneously avoiding the associated costs and environmental liability associated with land disposal. Although the technical feasibility of using desulfurisation flotation to reduce ARD pollution risks has been demonstrated in a number of case studies, little attention has been given to other potential environmental implications of this tailings management option, such as the potential toxicity of additional chemical use and disposal, enhanced resource recovery and utilisation, reduced waste burden and additional consumption of energy and materials.

Life cycle assessment (LCA) offers a potentially suitable tool for a more holistic evaluation of the environmental performance benefits and burdens of this process, as it is considers a range of environmental impacts over an extended system boundary, which encompasses both downstream and upstream linkages in the value chain of a particular product or activity (ISO 14040, 2006). Whilst LCA has been applied in the context of minerals processing and primary metals production by a number of authors (Durucan et al., 2006; Giurco et al., 2000; Mangena and Brent, 2006; Norgate and Rankin, 2000; Norgate, 2001; Tan and Khoo, 2005; Swart and Dewulf, 2013), little attention appears to have been given to the management of large-volume mineral wastes. Solid waste disposal is generally addressed in a very simplistic manner (if at all), and the impacts of solid waste on abiotic resource depletion, particularly in terms of unused minerals and entrained water, as well as the quality of soils and water as a result of seepage from tailings impoundments, are largely ignored (Stewart, 2001; Stewart et al., 2004). Deficiencies of LCA tools in terms of addressing impacts relating to the disposal and management of solid mineral wastes include the absence of factors to characterise the toxicity impacts of relevant water-related emissions (i.e. metals, acid and salts), and the general lack of inventory data to adequately describe the impacts associated with relevant background processes, particularly the production of raw materials used in waste treatment. These deficiencies are highlighted by Reid et al. (2009), in the only other study known to have specifically applied LCA in a comparison of tailings waste management options.

This study evaluates the environmental consequences of incorporating a desulfurisation flotation unit for the pre-disposal removal of sulfur from a base metals sulfide wastestream, using state-of-the-art LCA tools and currently available datasets. Specific focus is placed on the evaluation of the eco-toxicity and human toxicity impacts associated with seepage from the tailings impoundment, as well as the background impacts associated with the production of electricity and xanthate salt, used as a collector in the desulfurisation flotation process.

2. Methodology

2.1. Case study scenarios

This study developed two scenarios for the treatment of a tailings slurry stream generated during the milling and flotation of a run-of-mine base metal sulfide ore (Fig. 2). The first treatment option (termed the base case scenario) entails conventional dewatering of the tailings in a cylindrical continuous thickener, to produce an underflow stream which is discharged to a tailings impoundment. After solids settling, the decant water is recycled, together with the thickener overflow, to the main processing plant. Dissipative water loss occurs through evaporation (typically 5–40% of tailings water), seepage (typically in the order of 5% of tailings water) and entrainment (30–50% of tailing water) (Bleiwas, 2012). Seepage contains residual flotation chemicals, as well as acid, salts and metals mobilised through the reaction of residual sulfides and acid neutralising carbonate minerals in the tailings during disposal. In this way, the deposit is considered as a unit operation generating its own emissions to air (water vapour) and water (seepage) and having a land requirement (unreacted tailings), as well as a product output in the form of recovered water.

In the second scenario (termed the desulfurisation flotation scenario), the tailings slurry is treated by means of desulfurisation flotation, using a xanthate collector, and the desulfurised tailings fraction subsequently subjected to dewatering and disposal as in the base case scenario. The flotation concentrate stream is dewatered by means of filtration to produce a sulfide-rich by-product which can be recycled to the primary metal extraction circuit for further processing to produce acid and/or recover base metal values.

2.2. Life cycle inventory (LCI)

The overall system boundary, which includes both the background and foreground sub-systems selected for this study, is presented in Fig. 3. Life cycle inventory modelling for each of these systems was conducted with the Simapro Software version 7.3.3 (PRé Consultants, 2012) at a reference flowrate of 100 tons of dry tailings per day.

The system boundary specifically included electricity and xanthate production as background processes. Background data for electricity production was derived from the ecoinvent database (version 2.2). In the case of the desulfurisation flotation case study, background data for xanthate production was derived from a recent in-house LCA study of the local production of liquid ethyl xanthate at Senmin® International's production facility in Sasolburg, South Africa (Kunene, 2014). Downstream treatment of the

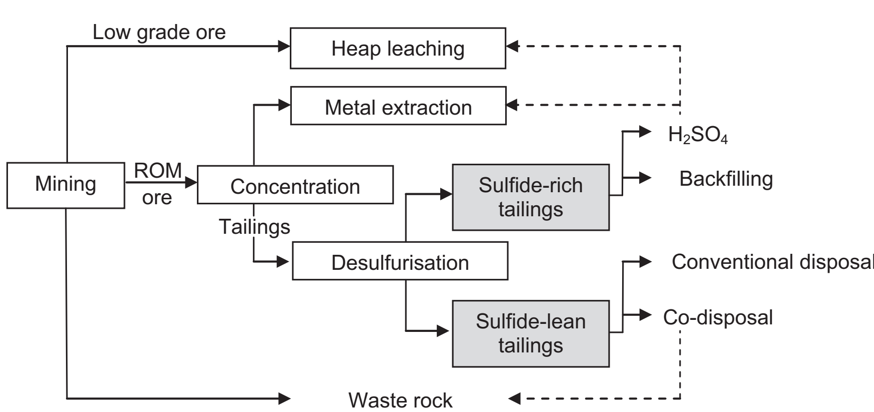

Fig. 1. Conceptual approach to sulfide tailings management (Hesketh et al., 2010).