Exploring an alternative approach to mine waste management in the South African gold sector of the article

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Abstract

The large volumes of waste generated during gold beneficiation are a major pollution concern in South Africa. To remove these potential pollution risks in perpetuity, non-conventional approaches to mine waste management are required which avoid land disposal of "unwanted" material. This paper explores the opportunities, drivers and barriers for the re-purposing of gold waste in the South African context. The findings identify numerous opportunities for reusing gold mine tailings and tailings dumps, and highlight the interrelated factors that constrain their uptake.

Keywords: gold tailings, mine waste management, mine waste reuse

Introduction

Despite the gold industry's contribution to the national economy, the industry has been plagued by labour disputes and is widely criticized for its negative impacts on the surrounding environment and local communities (Antin 2013). Many of these impacts are associated with the land disposal of the large-volume wastes generated by the industry, which include overburden, waste rock and tailings (Bellenfant et al. 2013). In South Africa, defunct gold tailings dumps occupy large areas of land, with more than 270 mine dumps covering an area of 400km^2 having been identified (Oelofse et al. 2010). Many of these tailings dumps are situated in close proximity to human settlements, and typically contain reactive minerals and toxic metals, such as uranium, thus representing a significant, and often irreversible, risk to the surrounding environment and local communities (Franks et al. 2011). Of particular concern in the Witwatersrand gold basin of South Africa, is the prolonged generation of salt-laden and metal-rich acid rock drainage (ARD), formed through the exposure of sulfide minerals to air and water (Oelofse et al. 2010). These dumps are also a source of wind-blown dust, which affects the health and quality of life of surrounding communities.

To address the potential long-term risks associated with these dumps, alternate approaches to the non-conventional management of large-volume mine waste streams are required (Yellishetty et al. 2008). One alternative approach to the land disposal of large-volume mine waste entails the re-allocation of these wastes as feedstock for other uses. Such an approach is aimed at simultaneously minimising the waste burden and maximising the efficient use of mined materials, and is consistent with the principles of resource efficiency and the circular economy (Pajunen 2015). This paper presents the findings of a study to explore the opportunities, drivers and barriers for the re-purposing of gold tailings in the South African context.

Methodology

This study is based on a comprehensive review and analysis of information and data in the public domain, complimented by semi-structured interviews with nine experts and practitioners in the field of mine waste management. The findings of the research are presented below by first providing a review and analysis of the opportunities for re-purposing gold tailings material and mine dumps in South Africa, and subsequently assessing the key factors influencing the development and implementation of these opportunities.

Opportunities for gold waste utilization

From the review of literature and interviews with various experts, numerous applications for gold tailings were identified, including using tailings for making bricks, ceramics, cement, mine backfill, stone paper and as aggregate material for construction. The findings also indicated that the discarded tailings dump themselves can be used for recreation, tourism and other alternative land uses, such as for the generation of clean energy. Each of the opportunities identified is discussed briefly in the sub-sections below:

Bricks

Studies by Roy et al. (2007), Zhang and Ahmari (2014), and Kiventerä et al. (2016) have indicated that gold tailings are a viable alternate aggregate for brick making. However, all these studies have indicated that additives need to be including in the tailings brick mixture to improve the compressive strengths of the bricks, with cement resulting in the highest compressive strength and thus being the preferred additive across all studies. In South Africa, a study by (Malatse and Ndlovu 2015) evaluated the viability of using Witwatersrand gold mine tailings for brickmaking, with positive results. In addition, the interviews with experts and industry representatives indicated that the use of gold tailings for the production of bricks has been both investigated and applied on a commercial scale in South Africa. However, attempts to obtain further information from two local organisations reportedly making bricks from tailings were unsuccessful. One of the research participants (participant 2) had been involved in a project which confirmed the feasibility of using gold tailings to produce brick specimens. Participants 4 and 5 both raised concerns on the the potential radioactive nature of tailings material and stated that this would pose a significant challenge to using tailings.

Ceramics

Liu et al. (2015) assessed the technical viability of using gold mine tailings as a resource in place of clay in the production of ceramic products. The research findings showed that blending gold tailings and clay resulted in optimum mineral composition, particle gradation, and shaping property. Similarly, a study by Yassine et al. (2016) determined that gold tailings are a feasible alternative material for producing ceramic products. Two interviewees (participants 2 and 8) indicated that they were aware of cases of gold tailings being used to produce ceramic products in the United States. However, no evidence could be found of any attempts to produce ceramics from gold tailings in South Africa.

Cement additive

Globally, investigations on alternative binders and the production of blended cements using either industrial by-products and/or mineral additives have gained momentum (Sobolev 2003). Çelik et al. (2006) used different ratios of cement, tailings, fly ash and silica fumes for the production of Portland cement. The results revealed that gold tailings are a viable additive in the production of Portland cement, and that samples with up to 25% gold tailings within the clinker mix produced cement of the required standard in terms of comprehensive strength (Çelik et al. 2006). Although fly ash is commonly used as a cement additive within the South African construction sector, no evidence of the local use of gold tailings as a cement additive could be found.

Backfill

The use of backfill is common practice worldwide in mining operations. Research studies by Amaratunga and Yaschyshyn (1997), Benzaazoua et al. (2008) and Yilmaz (2011) have demonstrated the potential viability of using gold tailings as backfill, and the research findings suggest that tailings are a viable option. Whilst no such academic studies have been documented in South Africa, some mines make use backfill for structural stability and alleviating problems such as rock falls and rock bursts in mines (Squelch 1994). One such example of backfill operations is at the Gold Fields' South Deep Mine. The mine has a cemented tailings plant onsite and uses its own gold tailings produce backfill. This backfill is then used mainly to fill mining voids (Gold Fields 2012). Another example is at the Harmony's Target Mine which makes backfill

from a mix of cyclone tailings, cement and additives (Le Roux and du Plooy 2007).

Stone Paper

Stone paper, also referred to as mineral paper, is a novel paper type which is a blend of crushed stones and/or tailings as a substrate (80%), with polymers (20%) as a binding agent (Pauli 2012). An economic feasibility study conducted by the ZERI foundation indicated that the use of tailings is more cost-effective than crushed rock, whilst the capital costs of stone paper production are approximately 40% less than those for conventional pulp-based paper production (Pauli 2014). In South Africa, media reports suggest that the City of Johannesburg is exploring the establishment of a stone paper factory which will make use of gold railings and rubble from illegal dump sites for making stone paper (Knopjes 2015). Although participants 1 and 8 identified stone paper as a potential opportunity for gold tailings, no further information could be accessed on the development of this opportunity in the South African context.

Aggregate for road base and or construction material

The use of mining and metallurgical waste as aggregates for embankments of roadways, railways, rivers and dams has been on the rise over the past three decades (Yellishetty et al. 2008). According to Yellishetty et al. (2008), tailings as a replacement aggregate reduces the demand for natural aggregates and presents a practical solution to the environmental liabilities of tailing dams. Participants 1, 2 and 6 indicated that they were aware of cases where tailings have been used as a natural aggregate replacement in South Africa, but were unable to provide specific examples. In addition to using tailings as an aggregate for road base and construction materials, participants 2 and 6 mentioned that gold tailings are compatible for making plaster sand and paving material.

Alternative uses of defunct gold tailings dumps

Across the globe, mine sites have been repurposed for different uses such as manufacturing, industrial and residential redevelopments, heritage attractions, and tourism (O'Neill 2015). Other uses that were identified include using the sites as wildlife habitats, educational, leisure and sport facilities (Pearman 2009). In South Africa, very few of these initiatives are documented, although four of the interviewees (participants 1, 4, 7 and 8) indicated that defunct tailings facilities were being used for a number of (mostly informal and unregulated) activities, including agriculture, educational tours, recreation (quad biking, skate-boarding, off-roading), as well as photo and music video shoots.

Mine waste dumps also provide large, flat areas without significant vegetation that can be used for clean energy generation. In the United States of America, a project titled "Re-Powering America's Land" assessed the feasibility of generating wind power, solar, and hydroelectric systems on abandoned mines and contaminated land (Environmental Protection Agency 2013). As part of the project, renewable energy projects have been successfully implemented and are operating across the United States. The largest of these projects occurs in New Mexico, and generates 1 megawatt of electricity (peak output) from a total of 173 solar panels covering 21 acres. Numerous sites in Canada, Germany and the United States of America have used defunct mine land and dumps to generate clean energy (Choi and Song 2016). However, whilst participants 5 and 7 noted that generating renewable energy, specifically wind and solar energy, is a viable option and should be explored further, no energy generation on abandoned mines and tailings facility has been recorded in South Africa.

Drivers and Barriers to gold waste reuse

This section explores the key factors that both constrain and drive the uptake of the identified opportunities, namely material properties, technology, economics, corporate culture and values, and legislation.

Material properties

The physical and chemical properties of the tailings can determine its suitability as feedstock for different applications, and also give rise to specific health and environmental risks

during processing and/or utilization. In certain cases, pre-treatment to remove impurities, as well as crushing and re-sizing may be required to render the tailings suitable (Godfrey et al. 2007). According to all the participants interviewed, the major constraint to reusing gold tailings in South Africa is their potentially toxic and radioactive nature. Gold tailings typically contain potentially hazardous metals, particularly uranium, and chemicals, such as cyanide, which pose significant contamination challenges (Durand 2012; Nengovhela et al. 2006).

Technology

In South Africa, improved technology has resulted in the recovery of gold (and other minerals) from both low-grade ores and waste tailings (Gericke 2014). Whilst this provides an ideal opportunity to simultaneously repurpose the bulk material, this has not been the case in practise and, with the exception of a few isolated cases, the gold-depleted re-processed tailings are being largely disposed of in engineered tailings dams. In line with this, participant 1 noted that whilst technological advancements have resulted in increased gold recovery from mine waste, the technology is not fully tried and tested in the case of most re-purposing options. Generally, new technology is characterized by a degree of uncertainty and there is a risk that unproven technology may not perform to the required standard and specifications, and/or be compatible to current technologies (Johnston 2012). Uncertainties and risks associated with unproven technology have been identified as a key technological barrier to mine waste utilization (Pajunen et al. 2012).

Economics

The findings of this study have revealed that economics is both an enabler and impediment to the uptake of reuse options. The escalating costs of complying with increasingly stringent legislation, particularly in terms of the land disposal of large-volume wastes, has the potential to provide financial incentives for companies to explore alternative uses (Godfrey et al. 2007). On the other hand, four participants (1, 6, 7 and 9) considered economics as a barrier to the uptake of reuse options. This was due to the fact that reuse options are considered financially non-viable on the basis of conventional financial indicators such as IRR, due to both the high direct costs entailed and the relatively low value of the products generated. Two of the interviewees (participants 1 & 6) emphasised that the uptake of the reuse options would only occur if it is deemed to be financially viable. In addition, the participants highlighted the high costs associated with transporting tailings. This, combined with the low price of virgin aggregate currently in use, renders the reuse of tailings uneconomic and provides no further incentives to reuse tailings.

Corporate culture and values

Corporate culture, leadership and overall company strategy influence how companies are run, the way tailings are classified, the uptake of waste reuse options, and the adoption of new technologies within the organization (Pajunen 2015; Pauli 2012). According to participant 3, companies can classify tailings as either a liability or an asset, and this determines the approach to tailings management. Participant 3 argued that organizations who viewed tailings as an asset are more willing to exploring reuse options and drive innovative solutions for dealing with waste; whereas organizations that view tailings as a liability or waste are often averse to the different waste reuse opportunities and likely to opt for conventional tailings disposal. Viewing tailings as an asset requires mining companies to look beyond the core business of extracting minerals from the ground (Pauli 2012). This, according to participant 3, requires businesses to create entrepreneurial linkages and strategic partnerships with organizations that are likely to utilize the mine waste.

Legislation

An in-depth review of literature on the legislation governing mineral waste, indicates that South Africa has robust legislation, policies and strategies which are on par with international legislation. Despite the robust legislative framework, the legislation governing mine waste is fragmented across different pieces of

legislation and there is no unifying policy outlining exactly how mining waste issues need to be addressed (Adler et al. 2007). Two of the participants (1 and 7) concurred with this thinking and stated that because there no clear legislative guidelines on the procedure and requirements for reuse of mine waste in South Africa, it posed a barrier to reuse of mine waste and created confusion on the appropriate measures to be taken for reusing waste. Participant 1 also cited the inconsistency in the definition of mine waste across different pieces of legislation, and the frequent changes to legislation as barriers to mine waste reuse, as it adds more complexity and makes it difficult to know what to comply with.

Concluding remarks

A number of potential uses for gold tailings and gold tailings dumps have been identified. However, despite existing opportunities, the re-purposing of gold tailings as feedstock for other purposes is currently constrained in South Africa. Uses of defunct gold mine dumps for recreational purposes, and tailings material for brick-making, appears to be largely informal and uncontrolled. The lack of formalised application of gold tailings and dumps can be attributed to a number of interrelated factors, such as inadequate technology development, lack of an enabling legislative framework, high short-term and direct costs, potential environmental risks associated with hazardous components in the waste, as well as a traditional corporate culture which views waste as unwanted material and focuses on conventional disposal as a waste management strategy. Given these constraints, it is unlikely that there will be a significant uptake of reuse options without concerted collaborative effort between different stakeholders, underpinned by a sustained programme of Research & Development.

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