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Research article

Biotechnology in the management and resource recovery from metal bearing solid wastes: Recent advances

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ABSTRACT

Solid metalliferous wastes (sludges, dusts, residues, slags, red mud and tailing wastes) originating from ferrous and non-ferrous metallurgical industries are a serious environmental threat, when waste management practices are not properly followed. Metalliferous wastes generated by metallurgical industries are promising resources for biotechnological extraction of metals. These wastes still contain significant amounts of valuable non-ferrous metals, sometimes precious metals and also rare earth elements. Elemental composition and mineralogy of the metallurgical wastes is dependent on the nature of mining site and composition of primary ores mined. Most of the metalliferous wastes are oxidized in nature and contain less/no reduced sulfidic minerals (which can be quite well processed by biohydrometallurgy). However, application of biohydrometallurgy is more challenging while extracting metals from metallurgical wastes that contain oxide minerals. In this review, origin, elemental composition and mineralogy of the metallurgical solid wastes are presented. Various bio-hydrometallurgical processes that can be considered for the extraction of non-ferrous metals from metal bearing solid wastes are reviewed.

1. Introduction

Of late, demand for non-ferrous metals such as Al, Cu and Zn has been increasing significantly. The metals are produced by metallurgical industries from naturally occurring primary ores. However, the metallurgical industries generate considerable quantities of different types of solid wastes at each and every step of metallurgical unit operation (Lottermoser, 2010). According to EU estimates, the wastes generated from mining and quarrying industries play a big contribution (>50%) to the total wastes generated in Europe (European Union statistics, 2012).

These metal bearing wastes are either stock piled in specially built storage dams or disposed in the environment without proper containment (Fig. 1). Storage of metallurgical wastes in the storage dams is a common practice. However, failure of the dams and release of metals to the environment is a serious threat. There have been instances of leakage and accidental collapses of several dams (Ajka (Hungary), 2010; Bento Rodrigues (Brazil), 2015) in the recent past (Ruyters et al., 2011; Segura et al., 2016). Such release of metals was linked to harmful adverse effects on the environment (Clemente et al., 2003; Hilson and Monhemius, 2006) (Fig. 1). In the environment, metals can be mobilized from wastes by biological agents and by natural processes like erosion aided by wind and water is referred as weathering. Natural weathering enhances the release of toxic metals into the environment, thus can contaminate the water resources (Keith et al., 2001; Gieré et al., 2003; Kachur et al., 2003; Kierczak et al., 2009; Johnson, 2009) (Fig. 1). Gradual depletion of high grade metal reserves is another important issue to be addressed (Anjum et al., 2012). Designing economic and eco-friendly ways to remediate, recover and recycle metals from metal bearing wastes would not only help in environmental protection but also allow sustainable resource management. One way to combat environmental pollution is to implement sustainable resource management. Though, these are considered as wastes but they still contain significant quantities of metals. Wastes that contain significant metal concentration needs to be considered as secondary resources. Green and environmental friendly processes

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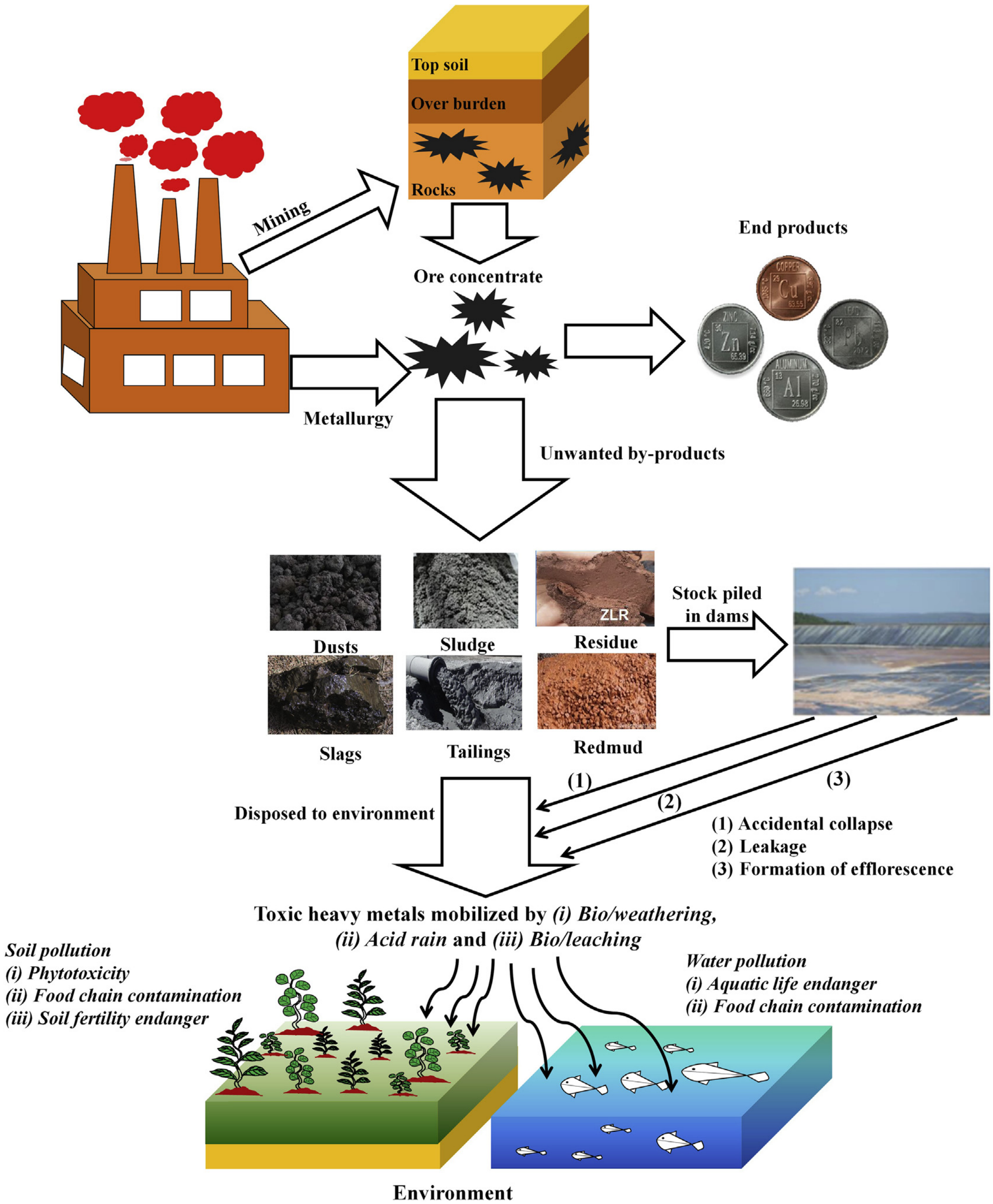

Fig. 1. Overview of mining and metallurgical operations, generation of metallurgical wastes and the problems associated with the disposal of metallurgical wastes.

must be developed to recover metals from these solid wastes. This approach not only decrease the amount of waste to be disposed of but also prevent release of metals into the environment.

1.1. Metallurgical wastes as secondary resource for metals

High grade primary ores have been depleting significantly in the last decades, which forces the metal industries to search for alternative feedstocks. There have been a handful of studies on the eco-friendly recovery of valuable metals from low grade ores (Anjum et al., 2012). Metal bearing wastes including solid wastes, slurry wastes and liquid wastes (such as mine water, fly ashes, spent liquors, spent catalysts, spent batteries, slags, shales and sludges) have been examined for extracting metals (Brombacher et al., 1997; Sethurajan et al., 2017a). Often these metallurgical wastes cannot be treated by commercial extractive metallurgy i.e. hydrometallurgy, pyrometallurgy or electrometallurgy. Hydrometallurgy is aimed at solubilisation of metals from their insoluble ores with the help of solvents. While, heat and electricity are used in pyrometallurgy and electrometallurgy, respectively, for extracting metals. Various hydro-metallurgical processes were proposed for the recovery of zinc from wastes both from ferrous and non-ferrous industries (Jha et al., 2001). Not only wastes from metallurgical industries such as slags and sludges but also household wastes like electronic waste (E-waste) could be seen as a secondary resource for the pyro/hydrometallurgical recovery of metals (Akcil et al., 2015; Tan et al., 2015; Lu and Xu, 2016).

Biohydrometallurgy can be defined as conversion of insoluble metal forms (e.g. metal sulfides) to soluble metals with the help of one or more microorganisms. Biohydrometallurgy could also be