Chemosphere 154 (2016) 628–639

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Review

A greener approach for resource recycling: Manganese bioleaching

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HIGHLIGHTS

- Microbial diversity involved in manganese bioleaching has been highlighted.
- Mechanism of manganese bioleaching have been described.
- Process parameters for efficient Mn recovery has been discussed.
- Recent development and future trends in manganese mining has been suggested.

ARTICLE INFO

Article history:
Received 8 February 2016
Received in revised form
5 April 2016
Accepted 8 April 2016
Available online 19 April 2016

Handling Editor: Shane Snyder

Keywords:
Manganese
Bioleaching
Resource
Recycling
Waste

ABSTRACT

In view of unremitting diminution of mineral resources, rising energy economics along with increasing global consumption of Manganese (Mn), development of environment friendly technologies for tapping alternate sources of Mn has gained importance lately. Mn recovery from mining residues using conventional approaches is extremely expensive due to high capital and energy costs involved. However lean grade ores present in millions of tons awaits the development of competent and cost effective extractive process. Mn recovery by biomining with diverse microbes is thereby recommended as a superior and green alternative to the current pyro metallurgical techniques. The synergistic effects of different factors are known to influence microbial leaching of mineral ores which includes microbiological, mineralogical, physicochemical and process parameters. Bacterial bioleaching is mostly due to enzymatic influence, however fungal bioleaching is non enzymatic. Genomic studies on microbial diversity and an insight of its metabolic pathways provides unique dimension to the mechanism of biomining microorganisms. The extraction of Mn has a massive future prospective and will play a remarkable role in altering the situation of ever-decreasing grades of ore. This review aims to encompass the different aspects of Mn bioleaching, the plethora of organisms involved, the mechanisms driving the process and the recent trends and future prospects of this green technology.

Contents

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http://dx.doi.org/10.1016/j.chemosphere.2016.04.028
0045-6535/

1. Introduction

Manganese (Mn) is mostly found in its oxide form and is available as a key constituent in around hundred naturally present minerals (Das et al., 2011). The major components are birnessite (δMnO_2), psilomelane [Ba, Mn^{2+} $(Mn^{4+})_8O_{16}$ $(OH)_4$], manganite (MnOOH), pyrolusite (MnO_2), vernadite (MnO_2), hausmannite (Mn_3O_4) and braunite (Mn,Si_2O_3). Mn mostly exists in the oxidation state ranging from +2, +3 and +4 and is hardly found in its elemental state (Ehrlich, 2002).

Mn reserves are predominant in many countries across the globe including India and the metal has imperative industrial applications in industries like steel, glass and batteries (Das et al., 2012a) (Fig. 1). Extensive industrial activities lead to the generation of huge amount of Mn wastes (Ghosh et al., 2015). During this process a considerable amount of Mn is lost as wastes which do not possess any market value (Venugopal, 2010). Unmonitored Mn wastes are known have several toxic effects on human health (Das et al., 2015a; Acharya et al., 2003; Das and Mishra, 2010, 2015b). Around 20% of the untreated mining wastes are discharged into the environment which leads to the contamination of both the terrestrial and aquatic ecosystems (Ge et al., 2004; Liu et al., 2004).

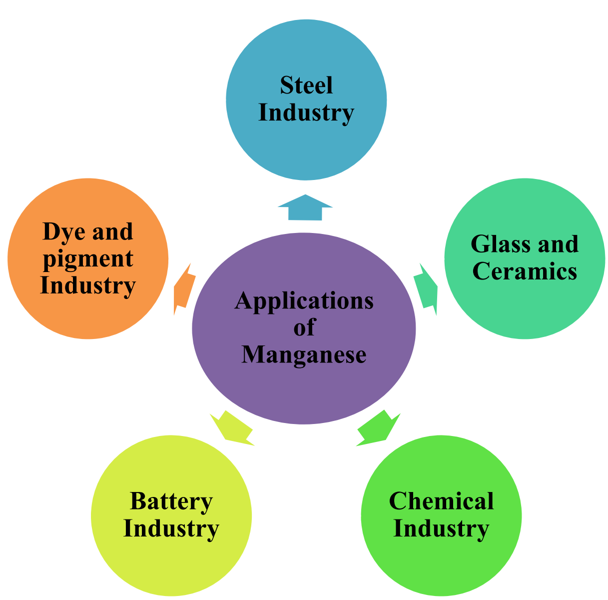

Fig. 1. Industrial applications of Mn compounds.

The environmental contamination and obligatory health implications due to conventional methods of metal extraction of are an important concern (Das and Singh, 2011, Akcil et al., 2015). There has been the establishment of several physical and electrochemical recovery processes for metal extraction from the mining sites; although they don't seem to be very beneficial in remediation of the wastes and effluents (Akcil and Agcasulu, 2015).

Bioleaching is the dissolution of metals from their mineral source by the activity of specific microorganisms. Bioleaching with Mn solubilising microorganisms is the most promising green technique applied in a large scale (Srichandan et al., 2013; Panda et al., 2015). Mn solubilizing microorganisms play a vital role in evaluating the significance of microbes in Mn biomining. Remediation of Mn and resource recycling can be implemented and enhanced by improving the efficiency of microorganisms. Manganese bioming activity has been investigated and reported in a diverse group of microorganisms including *Lysinibacillus* sp., *Acinetobacter* sp. (Ghosh et al., 2015); acidophiles like *Enterobacter* sp., *Bacillus cereus*, *Bacillus nealsonii* and *Staphylococcus hominis* (Sanket et al., 2016), *Fusarium* sp. (Bing et al., 2012) and *Penicillium* sp. (Acharya et al., 2004). Extensive bioleaching studies have been carried out from waste printed circuit boards (WPCBs) by *Acidithiobacillus ferrooxidans* (Chen et al., 2015), spent batteries with a Mn extraction efficiency of 60% (Xin et al., 2012a,b), solid industrial wastes (Mishra and Rhee, 2014), digested sewage sludge with an extraction percentage of 80 (Xiang et al., 2000), Mn oxides by fungal strains (Wei et al., 2012) and low grade Mn ores using native Mn solubilising bacterial strains (Ghosh et al., 2015).

"Biomining" is mostly concerned with large-scale microbial recovery of metal operations especially in mining industries for a cost effective metal recovery (Das et al., 2012b; Abhilash et al., 2015; Kim et al., 2015; Qua et al., 2015; Ishigaki et al., 2005). It is the amalgamation of all the three techniques namely bioleaching, biooxidation and biomineralization (Das et al., 2011). Today commercial biomining of precious rare earth metals has been widely employed in countries like found South America, Asia, Africa, Uganda, Canada and Australia (Abhilash, and Pandey, 2013; Das et al., 2011; Xin et al., 2012a). Uzbekistan currently boasts two large refractory gold projects. Bioleaching of copper from ores is carried out in many countries. Copper extraction from ores containing minerals, secondary copper sulphides is carried out in heap bioleaching plants located in different countries (Rohwerder et al., 2003; Ghassa et al., 2015).

In India a single electrolytic Mn dioxide plant, is situated at Dongri Buzurg Mine, Tumsar, Bhandara District Maharashtra This plant commissioned in 1991, is continuously producing Electrolytic