

Biomining – Biotechnological Systems (Bioleaching and Biosorption) for the Extraction and Recovery of Metals from Secondary Sources.

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Abstract: Biomining is the common term used to define processes that utilize biological systems to facilitate the extraction of metals from ores. Nowadays, a biomining concept can be defined as a two stage combined biological systems (1st stage bioleaching and 2nd stage biosorption) in order to perform the extraction and recovery of the metals from secondary sources such as industrial and mining waste, waste electrical and electronic equipment (WEEE), bottom ash and end of life vehicles. Overwhelming demand and limited sources of metals have resulted in searching new sources so that attentions have been shifted from mining process towards recycling of secondary resources for the recovery of metals. There are several metallurgical processes for metal recovery from the secondary sources such as pyrometallurgical processing, hydrometallurgical and bio/hydrometal-lurgical processing. Biomining processes are estimated to be relatively low-cost, environmentally friendly and suitable for both large scale as well as small scale applications under the bio/hydrometallurgical processing. Thus, the process involves physical separation (pre-treatment) and biomining (bioleaching and biosorption) and hydrometallurgical processes for recovery of base metals, rare earth elements (REEs) and precious metals from e-waste was evaluated.

Keywords: Biomining, Biosorption, Bioleaching, Critical Metals, WEEE

1. Introduction

The life cycle of electronic products has been reduced significantly in recent years (Oh *et al.*, 2003). Due to rapid growth of information technology around the world and paired with the arrival of new design and technology at regular intervals in the electronics sector, an early obsolescence of many electronic items used around the world today is taking place (Herat and Agamuthu, 2012; Gu *et al.*, 2016). Waste electrical and electronic equipment (WEEE or e-waste) is one of the fastest growing solid waste streams around the world which is growing at a rate of 3% to 5% per annum or approximately three times faster

than other waste streams in the solid waste sector (Schwarzer *et al.*, 2005). It is estimated that the total amount of WEEE was 41.8 million megagram (MMg) in 2014 (Baldé *et al.*, 2015). The composition of generated WEEE in 2014 is: lamps (1.0 MMg), screens (6.3 MMg), small IT (3.0 MMg), small household equipment (12.8 MMg), large household equipment (11.8 MMg) and of cooling and freezing equipment (7.0 MMg) (Baldé *et al.*, 2015). The EU was the largest WEEE generator with a total of 9.8 MMg, along with the United States (7.1 MMg) and China (6 MMg) in 2014 (Baldé *et al.*, 2015; Wang *et al.*, 2016). An overview of the WEEE generation in 2013 by selected countries is shown in Figure 1 (StEP, 2015; Eurostat, 2016). Therefore, the treatment of WEEE is a fundamental issue for not only developed countries but also developing countries such as India, South Africa, Ghana, Nigeria, Brazil, Turkey, China etc.

WEEE contains significant quantities of base metals, precious metals (PMs) and rare earth elements (REEs) with high economic potential. The critical elements such as rare earth elements (REEs) and precious metals are the essential materials of WEEE and have increasingly importance in the transition to a green, low-carbon economy. The extraction of critical metals, which often contributes extensively to the value of WEEE, is therefore crucially important (Tuncuk *et al.*, 2012). Several treatment options based on conventional mechanical, pyrometallurgical, hydrometallurgical and biometallurgical processes are proposed in previous studies for recovery of metals from WEEE (Tuncuk *et al.*, 2012). The most important factors affecting for selection or development of a WEEE treatment process can be listed: quantity of precious metals and REEs in wastes; metal losses; environmental impact and amount of WEEE/scale of operation Tuncuk *et al.*, 2012). The process should be designed according to these factors (Kucuker and Kuchta, 2012). The aim of the study is the development of a biomining concept for the recovery of valuable and critical metals from WEEE using bio/hydrometallurgical processes (bio/leaching and biosorption). It can be inferred that the search for efficient, low cost and environmentally friendly processes as well as the refining of the available

technologies for the leaching and recovery of base metals and, in particular, REEs and PMs is essential. Since the bulk of hydrometallurgical studies and bio/hydrometallurgical (bioleaching and biosorption) are essentially limited to lab-scale tests, further research should also focus on the development of a combined process with bio/hydrometallurgical aspect to generate operational and cost data with the ultimate aim of commercialization.

2. Biomining concept for metal recovery

Biomining is considered as the technologies that utilize biological systems to facilitate the extraction and recovery of metals from ores (Brierley and Brierley, 2013; Johnson, 2014; Johnson, 2015; Kucuker *et al.*, 2016). In recent years, there has been growing interest in the recovery of metals through biomining among researchers (Figure 2). However, limited research has been carried out on the metal recovery from secondary sources using biomining approach. Nowadays, biomining can be defined as a two stage combined biological processes (1st stage bioleaching

and 2nd stage biosorption) in order to extract and recover the metals from primary and secondary sources such as ore, industrial and mining waste, WEEE, bottom ash and end of life vehicles.

A new approach of leaching metals from secondary sources such as WEEE and bottom ash by acidophilic bacteria was occurred. In the past two decades, researchers' attention has been focused on the development of techniques for WEEE recycling (Kucuker and Kuchta, 2012; Gurung *et al.*, 2013). In this context, bio/hydrometallurgical techniques which are reportedly more environment friendly, predictable, and easily controlled due to mild working conditions can be investigated for recovery of valuable metals from WEEE (Kucuker and Kuchta, 2012; Gurung *et al.*, 2013). Recovery of critical metals from aqueous solution is the second essential step in bio/hydrometallurgical operations. Biosorption studies generally focus on the removal of heavy metal ions from industrial effluents, where the detoxification of these solutions prior to disposal as the primary goal (Schiewer and Volesky, 2000; Vieira and Volesky, 2000; Diniz and Volesky, 2005; Kucuker and

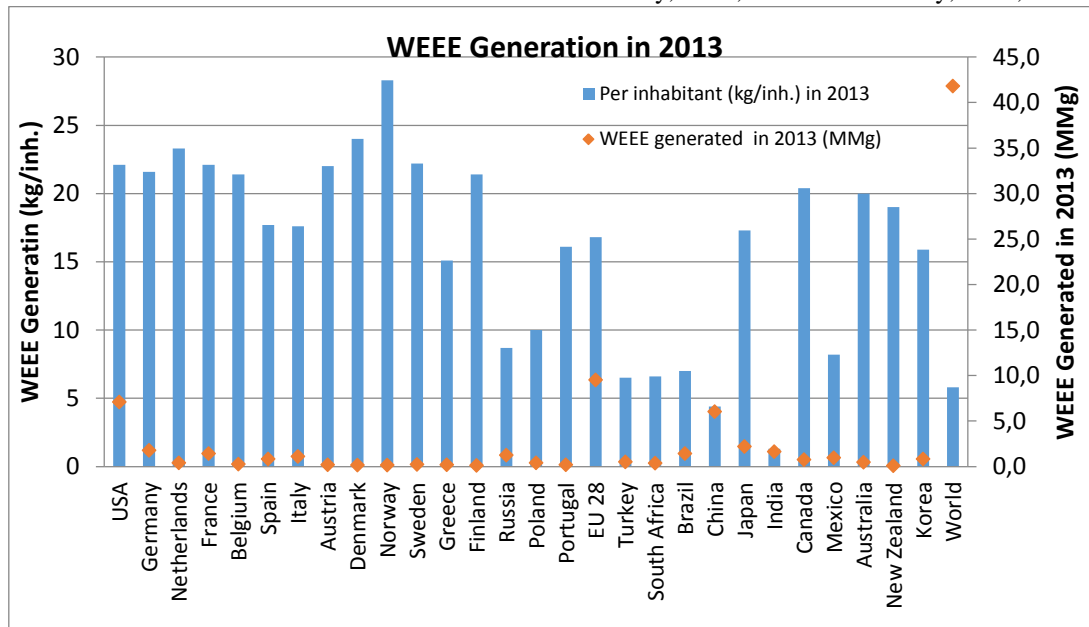


Figure 1. E-waste generated per selected country in 2013 (StEP, 2015; Eurostat, 2016).

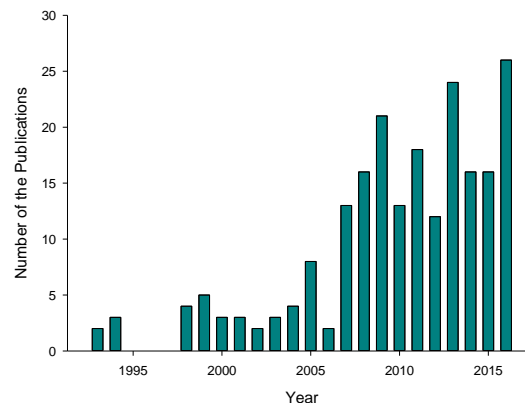


Figure 2. Numbers of papers appearing with 'biomining' in the topic as listed in the ISI Web of Science database for years between 1945–2017 (out of a total of 216 articles appearing: database searched 16.01.2017).

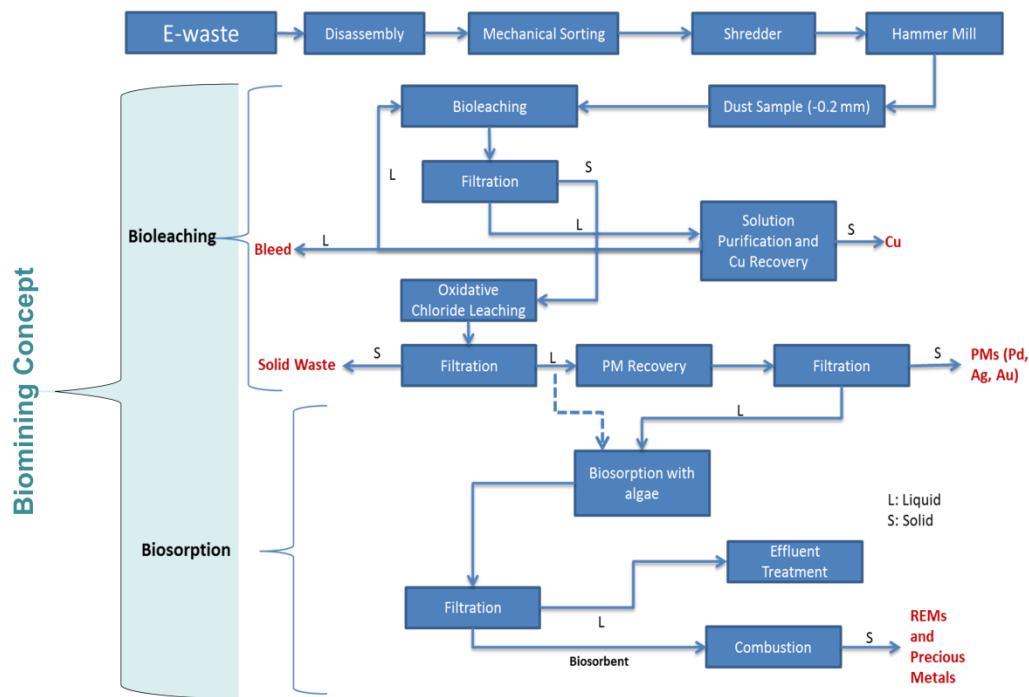


Figure 3. The process flow sheet proposed for the recycling system linking bio/hydrometallurgical and biosorption processes for recovery of REEs and precious metals from WEEE

Kuchta, 2012). Biosorption is a metabolism independent process that takes place in the cell wall of microorganisms e.g. algae, fungi, yeast, bacteria, biowaste (wood and garden waste) (Mao *et al.*, 2009). Since biosorption often employs dead biomass, this can enable the researchers to work on biosorption with extreme conditions such as high temperature and low pH (Das, 2010).

Some recent developments focus on the treatment of WEEE using biomining technologies. Since it has been observed that the WEEE is substantially appreciable quantities of base metals, precious metals and rare earth elements (REEs) with potentially high economic values. A major challenge is how to recover these metals from WEEE or other domestic and industrial metallic waste materials separately, for example using selective biomineralization or biosorption technologies (Kucuker and Kuchta, 2012; Johnson, 2014). On the other hand, motivation factors for biomining application for metal recovery from WEEE can be given as follows: to avoid costs associated with smelting and refining; an innovative and cost effective approach.

2.1. An integrated bio/hydrometallurgical process design under biomining concept

Various treatment options based on conventional mechanical, physical, pyrometallurgical, hydrometallurgical and bio/hydrometallurgical processes are proposed in order to recover the metals from WEEE, (Cui and Zhang, 2008; Akcil *et al.*, 2009; Yazıcı and Deveci, 2009; Tuncuk *et al.*, 2012). Biological recovery of metals from several post-consumer wastes through a process known as “bioleaching and biosorption” offers attractive advantages compared to conventional metal

processing technologies. The technological readiness level of bio-based processes for secondary sources, such as WEEE, is however low. Bioprocessing of waste for metal recovery attracts interest to meet the twin objectives of resource recovery and pollution mitigation (Lee and Pandey, 2012). Several researchers experimented several novel eco-innovative strategies using biomaterials to recover valuable metals from electronic waste (Bharadwaj and Ting, 2011). According to literature survey, a schematic flowsheet was illustrated with available processes for recovery of metals from WEEE (Figure 3). Thus, the process includes physical separation (pre-treatment) and bio/hydrometallurgical (bioleaching and biosorption) process for the recovery of REEs and precious metals from PCBs under a biomining concept.

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