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Review

Bioelectrochemical metal recovery from wastewater: A review

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ABSTRACT

Metal contaminated wastewater posts great health and environmental concerns, but it also provides opportunities for precious metal recovery, which may potentially make treatment processes more cost-effective and sustainable. Conventional metal recovery technologies include physical, chemical and biological methods, but they are generally energy and chemical intensive. The recent development of bioelectrochemical technology provides a new approach for efficient metal recovery, because it offers a flexible platform for both oxidation and reduction reaction oriented processes. While dozens of recent studies demonstrated the feasibility of the bioelectrochemical metal recovery concept, the mechanisms have been different and confusing. This study provides a review that summarizes and discusses the different fundamental mechanisms of metal conversion, with the aim of facilitating the scientific understanding and technology development. While the general approach of bioelectrochemical metal recovery is using metals as the electron acceptor in the cathode chamber and organic waste as the electron donor in the anode chamber, there are so far four mechanisms that have been reported: (1) direct metal recovery using abiotic cathodes; (2) metal recovery using abiotic cathodes supplemented by external power sources; (3) metal conversion using bio-cathodes; and (4) metal conversion using bio-cathodes supplemented by external power sources.

Contents

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1. Introduction

Rapid industrialization and human activities generate large amount of metal-laden wastewater. The metal contaminated water posts great health and environmental concerns, because most metals are not biodegradable and can be accumulated in living tissues of plants, animals, and human bodies, causing diseases and disorders (Olojo and Awoniran, 2012; Raskin et al., 1994). Physical, chemical, and biological technologies have been developed to remove metals from wastewater, and more and more efforts have been made to possibly recover precious metals, so the treatment process can be cost-effective and sustainable (Barakat, 2011; Fu and Wang, 2011; Veglio and Beolchini, 1997). Table 1 shows the concentrations of the main metals in different wastewaters, and it can be seen that industrial wastewaters contain much more metals than municipal wastewater, including those with higher market values, such as silver, gold, copper, zinc,

Table 1 – Metal concentration in common wastewaters (mg/L).

Name	Symbol	Price (USD/kg)	Municipal treatment plant	Road wash water	Tannery	Mining	Battery factory
Aluminum	Al	1.85[a]		0.467–26.1		0.161	0.2–7.3
Antimony	Sb	9.75[b]					
Arsenic	As	1.43[c]	0–0.0019				
Barium	Ba	100[c]					
Bismuth	Bi	23.4[d]					
Cadmium	Cd	1.87[e]	0–0.0033		0.056	0.004	0.02–0.12
Calcium	Ca	110[f]			255	548	83–255
Chromium	Cr	8.8[c]	0.04–0.56	0.004–0.107	391		<0.0044–0.08
Cobalt	Co	30.2[a]			1.55	0.0126	
Copper	Cu	6.72[a]	0.079–0.58	0.0111–0.177		0.244	<0.0033–0.38
Gold	Au	46378.6[a]					
Iron	Fe	0.2[g]	0.48–3.9	2.59–26.8	4.4	0.033	0.02–20
Lead	Pb	2.09[a]	0–0.039	<0.018–0.053	0.872		4.0–13
Magnesium	Mg	5.84[a]			268	29.52	15–26
Manganese	Mn	2.2[a]	0.067–1.16		0.396		0.04–0.6
Mercury	Hg	2.9[h]	0–0.0002				
Molybdenum	Mo	33.0[a]		0.0154–0.021			
Nickel	Ni	18.45[a]	0.0067–0.77	<0.006–0.0525	0.179	0.142	0.07–0.38
Potassium	K	22[i]			183	34.9	
Silver	Ag	735.8[a]	0–0.0014				
Sodium	Na	3.3[j]			25519	100.05	
Strontium	Sr	1000[c]					
Tin	Sn	22.6[a]	0–0.028				
Vanadium	V	26.5[a]					
Zinc	Zn	2.14[a]	0.26–0.75	0.105–1.56	0.684	0.023	0.6–17
Estimated monetary value (USD)[k]			0.02	0.06	121.35	61.56	28.29
Ref.			(Karvelas et al., 2003; Lipczynska-Kochany and Kochany, 2009; Varga et al., 2013)	(Paruch and Roseth, 2008)	(Tariq et al., 2005)	(Chakraborty and Chakrabarti, 2006)	(Yabe and Oliverira, 2003)

[a] http://www.infomine.com/investment/metal-prices/ (accessed on 6/21/2014).
[b] http://www.metalprices.com/p/AntimonyFreeChart?weight=KG&size=M&theme=1011 (accessed on 6/6/2014).
[c] http://en.wikipedia.org/wiki/Prices_of_elements_and_their_compounds.
[d] http://www.metalprices.com/p/BismuthFreeChart?weight=KG&size=M&theme=1011 (accessed on 6/6/2014).
[e] http://www.metalprices.com/p/CadmiumFreeChart?weight=KG&size=M&theme=1011 (accessed on 6/6/2014).
[f] http://www.ask.com/question/cost-of-calcium.
[g] http://www.chemicool.com/elements/.
[h] http://www.recycleinme.com/scrapresources/us_metal_prices.aspx (accessed on 6/21/2014).
[i] http://en.wikipedia.org/wiki/Potassium.
[j] http://en.wikipedia.org/wiki/Sodium.
[k] Suppose recovering 1000 L wastewater with 100% recovery efficiency.