Bioresource Technology 160 (2014) 203–212

Contents lists available at ScienceDirect

Bioresource Technology

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

Biosorbents for recovery of precious metals

Sung Wook Won[a], Pratap Kotte[b], Wei Wei[b], Areum Lim[c], Yeoung-Sang Yun[b,c,*]

[a] *Department of Marine Environmental Engineering and Institute of Marine Industry, Gyeongsang National University, 38 Cheondaegukchi-gil, Tongyeong, Gyeongnam 650-160, Republic of Korea*
[b] *School of Chemical Engineering, Chonbuk National University, Jeonju, Jeonbuk 561-756, Republic of Korea*
[c] *Department of Bioprocess Engineering, Chonbuk National University, Jeonju, Jeonbuk 561-756, Republic of Korea*

HIGHLIGHTS

- Biosorbents for the recovery of PMs were introduced.
- The sources, existing media and recovery methods of PMs were summarized.
- The required specifications of biosorbents for the recovery of PMs were presented.
- Various strategies for powerful biosorbents were suggested and highlighted.

ARTICLE INFO

Article history:
Available online 8 February 2014

Keywords:
Biosorbent
Biosorption
Precious metal
Recovery
Strategy

ABSTRACT

Biosorption is a promising technology not only for the removal of heavy metals and dyes but also for the recovery of precious metals (PMs) from solution phases. The biosorptive recovery of PMs from waste solutions and secondary resources is recently getting paid attractive attention because their price is increasing or fluctuating, their available deposit is limited and maldistributed, and high-tech industries need more consumption of PMs. The biosorbents for recovery of PMs require specifications which differ from those for the treatment of wastewaters containing heavy metals and dyes. In this review, the previous works on biosorbents and biosorption for recovery of PMs were summarized. Especially, we discuss and suggest the required specifications of biosorbents for recovery of PMs and strategies to give the required properties to the biosorbents. We believe this review will provide useful information to scientists and engineers and hope to give insights into this research frontier.

1. Introduction

In today's world, the rapid development of industries generates a huge amount of toxic pollutants such as heavy metals, dyes, and precious metals (PMs) into the environment. In order to achieve effective removal of these environmental contaminants, several traditional methods including chemical precipitation, chemical coagulation, ion-exchange, electrochemical technology, membrane process and ultrafiltration were employed (Das, 2010). However, the materials applied in the above methods generally need a high cost. In contrast, biosorption has been considered as a promising technology to remove heavy metals or anionic/cationic dyes or to recover PMs from aqueous solutions and wastewaters. This is because of the its advantages including low cost, high efficiency, the minimal generation of chemical or biological sludge, regenerability, and possible recovery of metals by desorption (Vijayaraghavan and Yun, 2008). Over the last few decades, biosorption has been widely and successfully studied for removal of heavy metals and ionic dyes by using various types of biomasses such as bacteria, fungi, algae, agricultural and industrial byproducts, and other biomaterials (Vijayaraghavan and Yun, 2008; Park et al., 2010a).

PMs including platinum group metals (PGMs) such as Ru, Rh, Pd, Os, Ir, and Pt are widely used in a variety of industries due to their unique physical and chemical properties. An increasing demand but a limited availability of PMs has led to great rises or fluctuations in their price. Thus it is urgent but attractive to recover PMs from secondary resources.

In recent years, some researchers have tried to utilize biomasses in order to recover PMs, in particular Au, Pt, Pd and Ru. Table 1 summarizes the various types of biosorbents used for PMs biosorption. Generally, the raw biomasses showed low sorption capacities for PMs compared to commercial sorbents like activated carbons

---

* Corresponding author at: School of Chemical Engineering, Chonbuk National University, Jeonju, Jeonbuk 561-756, Republic of Korea. Tel.: +82 63 270 2308; fax: +82 63 270 2306.

E-mail address: ysyun@jbnu.ac.kr (Y.-S. Yun).

http://dx.doi.org/10.1016/j.biortech.2014.01.121

Table 1
Biosorption of precious metals using different biosorbents.

Metal	Biosorbent	$Q_{\max}$ (mg/g)	Sorption condition	References
Au(I)	Seaweed (*Sargassum fluitans*)	0.63	pH 2	Niu and Volesky (1999)
	Fungal (*Penicillium chrysogenum*)	1.42	pH 2	Niu and Volesky (1999)
	Bacterial (*Bacillus subtilis*)	1.58	pH 2	Niu and Volesky (1999)
	L-Cysteine-loaded *P. chrysogenum*	2.8	pH 2	Niu and Volesky (2000)
	L-Cysteine-loaded *S. fluitans*	0.92	pH 2	Niu and Volesky (2000)
	L-Cysteine-loaded *B. subtilis*	4.04	pH 2	Niu and Volesky (2000)
	Acid-washed *Ucides cordatus* (waste crab shells)	33.48	pH 3.4	Niu and Volesky (2003)
	Hen eggshell membrane	147	pH 3	Ishikawa et al. (2002)
	PEI-modified bacterial biosorbent fiber	421.1	pH 5.5	Park et al. (2012)
	PEI-modified chitosan fiber	251.7	pH 5.5	Park et al. (2012)
	PEI-modified *C. glutamicum* biomass	361.76	pH 3.0	Kwak and Yun (2010)
	Decarboxylated *C. glutamicum* biomass	86.16	pH 2.5	Kwak and Yun (2010)
Au(III)	*Cladosporium cladosporioides* Strain 1	94.2	pH 4.0	Pethkar et al. (2001)
	C. cladosporioides Strain 2	104.3	pH 4.0	Pethkar et al. (2001)
	Streptomyces erythraeus	6	pH 4.0	Savvaidis (1998)
	Spirulina platensis	5.55	pH 4.0	Savvaidis (1998)
	Sulfur derivative of chitosan	630.29	pH 3.2	Arrascue et al. (2003)
	Glutaraldehyde cross-linked chitosan	571.2	pH 1.6	Arrascue et al. (2003)
	Dealginated seaweed waste	78.79	pH 3.0	Romero-Gonzalez et al. (2003)
	Hen eggshell membrane	618	pH 3	Ishikawa et al. (2002)
	Ca-alginate beads	290	pH 2	Torres et al. (2005)
Pt(IV)	*Desulfovibrio desulfuricans*	62.5	pH 2.0	de Vargas et al. (2004)
	D. fructosivorans	32.3	pH 2.0	de Vargas et al. (2004)
	D. vulgaris	40.1	pH 2.0	de Vargas et al. (2004)
	Thiourea derivative of chitosan	386.9	pH 2.0	Guibal et al. (2000)
	Glutaraldehyde cross-linked chitosan	304.1	pH 2.0	Guibal et al. (2000)
	Poly(allylamine hydrochloride)-modified *E. coli*	348.8	pH 2.5	Mao et al. (2010)
	PEI-modified *E. coli*	108.8	Pt-containing ICP wastewater	Won et al. (2010)
Pd(II)	EN-lignin	22.7	0.5 M HCl	Parajuli et al. (2008)
	Bayberry tannin immobilized collagen fiber membrane	33.4	1 M HCl	Ma et al. (2006)
	Racomitrium lanuginosum	37.2	pH 5	Sari et al. (2009)
	L-lysine modified cross-linked chitosan resin	109.5	pH 2.0	Fujiwara et al. (2007)
	Glycine modified cross-linked chitosan resin	120.4	pH 2.0	Ramesh et al. (2008)
	Chitosan (glutaraldehyde cross-linked)	180	pH 2	Ruiz et al. (2000)
	Polyallylamine hydrochloride-modified *E. coli* biomass	265.3	pH 3	Park et al. (2010b)
	Chitosan (thiourea derivative)	277.5	pH 2	Guibal et al. (2002)
	Chitosan (glutaraldehyde cross-linked)	287.4	pH 2	Guibal et al. (2002)
	Chitosan (rubeanic acid derivative)	352	pH 2	Guibal et al. (2002)
	PEI-modified *C. glutamicum* biomass	176.8	0.1 M HCl	Won et al. (2011)
Ru	Decarboxylated PEI-modified *C. glutamicum* biomass	47.1	Ru-containing acetic acid wastewater	Song et al. (2013)
	PEI-modified *C. glutamicum*	34.4	Ru-containing acetic acid wastewater	Song et al. (2013)
	PEI-modified *C. glutamicum* biosorbent fiber	110.5	Ru-containing acetic acid wastewater	Kwak et al. (2013)
	C. glutamicum biomass	16	Ru-containing acetic acid wastewater	Kwak et al. (2013)

and ion-exchange resins. Thus research interest has been focused on enhancing the sorption capacity of a biomass using different surface modification methods. In this present review, previously reported papers on biosorptive recovery of PMs are analyzed. Especially required specifications of biosorbents for recovery of PMs are discussed in depth.

2. PMs occurring media and conventional recovery methods

2.1. PMs

The rare, naturally existing metallic chemical elements of high economic value are termed as PMs. The natural sources of these metals are seldom available and maldistributed. They include, but not limited to, Au, Pt, Pd and Ag which are internationally regarded as currency under the act of ISO 4217 and other PGMs (Ru, Rh, Os and Ir). The spectacular physical and chemical properties such as lustrous, ductile and non corrosive and high stability made them indispensable in high technology industries of the modern world. As a result of their increasing demand and lack of availability, acquired skyrocketing prices are never seemed to be come down. Hence the title ‘precious’ is given to them.

2.2. Sources of PMs

The content of the PMs in secondary sources (i.e., electronic and catalytic waste) was found to be far higher than their content in natural ores. The average concentration of the PMs found in actual and chief natural ores is about 1–30 ppm while secondary sources have higher concentrations around 1–2000 ppm. Hence the spent catalysts, electronic wastes and other secondary sources are also named as the urban mines of the PMs. Secondary sources of PMs are summarized in Table 2.

Although PMs are found even in the atmosphere (as a particulate matter) and street/road sides which are from the automotive exhausts, the sources contain extremely low concentration of PMs. Therefore the present review focuses on the feasible sources of PMs where biosorption can be applied.

2.2.1. Solid wastes

Different solid materials contain PMs. A huge quantity of solid materials containing PMs is generated and considered as wastes. The PMs contained in the solid wastes cannot be recovered directly by using biosorption. Leaching PMs from the solid matrices by using appropriate solvents should be prerequisite. Conventional