IBK412: ENVIRONMENTAL BIOPROCESS TECHNOLOGY

ASSIGNMENT 2 (RECOVERY OF USEFUL COMPOUND IN WASTEWATER)

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Simplify the given source following these criteria:

1. **Introduction on why need to recover the metal in wastewater? Justify.**

   Water that contains metal can be toxic to human beings and environment. Metals are generally not able to be degraded biologically, can be absorbed through the organism circulatory system and stay in the tissue networks leading to multiple illness. Next, recovery of the metals from wastewater which has a high value in the market can help the wastewater treatment process to be advantageous in terms of the overall cost while still being environmentally friendly and feasible.

2. **State at least 10 common metals that being recovered (include their concentration (mg/L) and source of the wastewater). *<u>put in table</u>**

   Refer Table 1.0

Table 1.0: Concentration of different types of metals in common wastewaters (mg/L)

Name	**Symbol**	**Price (USD/kg)**	**MTP (Concentration, mg/L)**	**Road wash (Concentration, mg/L)**	**Tannery (Concentration, mg/L)**	**Mining (Concentration, mg/L)**	**Battery factory (Concentration, mg/L)**	**Copper smelting (Concentration, mg/L)**	**Acid mine drainage (Concentration, mg/L)**	**Electroplating industry (Concentration, mg/L)**	**Metal finishing industry (Concentration, mg/L)**	**An acidic industrial effluent (Concentration, mg/L)**
Aluminum	Al	1.85		0.467-26.1		0.161	0.2-7.3		115.2			
Cadmium	Cd	1.87	0-0.0033		0.056	0.004	0.02-0.12	76.05	1.9			
Calcium	Ca	110			255	548	83-255					50
Chromium	Cr	8.8	0.04-0.56	0.004-0.107	391		<0.0044-0.08	2.3	0.2	0.71	<0.05	<5
Copper	Cu	6.72	0.079-0.58	0.0111-0.177		0.244	<0.033-0.38	164.48	168	0.97	2.53-6.97	<5
Iron	Fe	0.2	0.48-3.9	2.59-26.8	4.4	0.033	0.02-20	88	2830	618		8000
Lead	Pb	2.09	0-0.039	<0.018-0.053	0.872		4.0-13	4.6		0.46		
Magnesium	Mg	5.84			268	29.52	15-26		56			800
Zinc	Zn	2.14	0.026-0.75	0.105-1.56	0.684	0.023	0.6-17	7.33	2.33	1.40	0.08	16.84
Manganese	Mn	2.2	0.067-1.16		0.396		0.04-0.6					

3. **How much Water Environment Research foundation (WERF) recorded the amount they could obtain in dolar, $/ year? (How much the basis per day of the wastewater volume?)**

   The Water Environment Research Foundation (WERF) stated that the amount they could obtain is estimated to be $8849-$3,904,664 per year from a 10 MGD or roughly 37,854 m^3/day flow of waste production.

4. **There are three categories (physical, chemical, biological) for the metal recovery. State their common methods used. *<u>put in table.</u>**

Table 2.0: Categories of metal recovery methods

Category	Example of methods
Physical	• Membrane filtration (microfiltration, ultrafiltration, nanofiltration, reverse osmosis) • Electrodialysis • Ion exchange • Adsorption
Chemical	• Chemical precipitation (sulfide precipitation, chelation precipitation) • Electrocoagulation • Electroflotation
Biological	• Bisorption • Bioremediation (phytoremediation)

5. **The new technology to recovery metal is using bioelectrochemical system (BESs). What is the definition of this technique?**

   A technique that is used the concept of oxidation and reduction reactions in a reactor with the aid of microorganisms. Wastewater is oxidized by microbes that are presented in the anode chamber, producing a current that is detected by the cathode chamber and is then used for production of electricity. Other than that, the electrons can be used for reduction of water or oxidization of chemical compounds.

6. **State three (3) researchers' findings using these five (5) mechanisms involved in (*<u>put the photo of the system too):</u>**

Eg:

Method used	Findings	Ref
Without external energy using two-chambered MFC types BES	- 99.89 ± 0.00% gold Au (III) ions in the catholyte with a maximum power production of 6.58 W/m2 at 25 h - 99.91 ± 0.00% of Ag(I) was recovered after 8 h operation with a maximum power density 4.25 W/m2	Choi and Hu (2013)
	Ag(I) recovery (removal rate of Ag(I)) was more rapid than that of Ag(I) thiosulfate complex	Tao et al (2012)
BES aerobic or anaerobic	Cu(II) recovery, with initial concentrations ranged from 0 to as high as 6400 mg/L (recovery efficiencies: 60.1% to 99.9%)	Heijne et al (2010)

a. The bioelectrochemical platform for metal recovery

Table 3.0: Studies on bioelectrochemical platform for metal recovery (BES)

Method used	Findings	Reference
BES for wastewater treatment	Bioelectrochemically assisted metal recovery processes can be grouped into four; direct reduction of metals on an abiotic cathode, metal recovery using abiotic cathodes supplemented by external power sources; metal conversion using biocathodes, metal conversion using biocathodes supplemented by external power sources.	Wang and Ren (2014)
	BES proposes a suitable way for both oxidation and reduction reaction and is efficient for integrated waste treatment and energy and resource recovery.	Li et al (2014); Logan and Rabaey (2012); Wang and Ren (2013)
	BES is advantageous in terms of the savings of aeration energy and sludge disposal, owing to its lower energy densities compared to other anaerobic processes.	Huggins et al (2013); McCarty et al (2011); Zhang and He (2013)

b. Direct metal recovery using abiotic cathodes

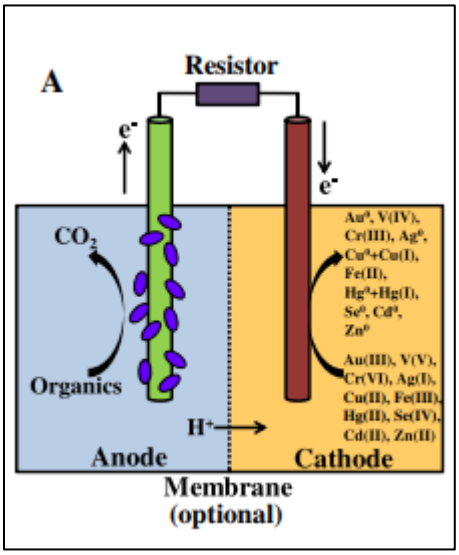

Figure 1.0: Direct metal recovery using abiotic cathodes diagram

Table 4.0: Studies on direct metal recovery using abiotic cathodes

Method used	**Findings**	**Reference**
Single-chamber reactors BESs or MFCs	Removal of Cd and Zn through biosorption and sulfide precipitation with a higher power output of 3.6 W/m^2 Maximum tolerable concentrations (MTCs) of Cd and Zn were 200 mM and 400 mM respectively.	Abouraches et al (2014)
	Electrons directly by Se(IV) from bacteria enhanced for electricity generation. 99% Se(IV) recovered as the bright red deposit of elemental Se. Power density is inversely proportional to the concentration of Se(IV) as it is affected by the increased toxicity to microbes.	Catal et al (2009)
Three-chamber system (two chamber MFC and a strip chamber adjacent the cathode chamber)	Zn(II) in the cathode chamber was extracted physically through supported liquid membrane and amassed in the strip chamber. No chemical reactions happened to affect Zn(II)	Fradler et al (2014)

c. Metal recovery using abiotic cathodes supplemented by external power sources

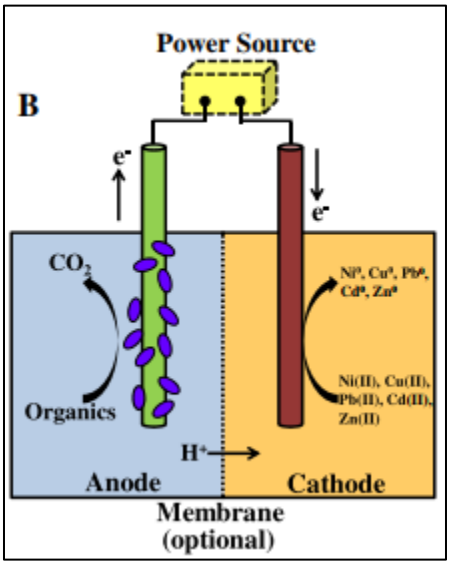

Figure 2.0: Metal recovery using abiotic cathodes supplemented by external power sources diagram

Table 4.0: Studies on metal recovery using abiotic cathodes supplemented by external power sources diagram

Method used	**Findings**	**Reference**
Applying a higher voltage to reduce the metal ions under standard MFC/BES conditions	When an external voltage of 0.5-1.1 V applied, Ni(II) was reduced to a percentage 51 ± 4.6% and 67 ± 5.3% where the initial concentration is 500 mg/L.	Qin et al (2012)
	Cu(II), Pb(II), Cd(II) and Zn(II) that were presented in a mixed catholyte were successively recovered.	Modin et al (2012)
Successive removal of Cu^{2+}, Ni^{2+}, and Fe^{2+} from artificial acid mine drainage with simultaneous H_2 production as 1.0 V of power is added.	The value of energy recovery efficiency (calculated by dividing the ratio of energy content of the H_2 produced with the input electrical energy) obtained was approximately 100%, suggesting that produced H_2 gas was enough to offset the energy consumed during the metal recovery.	Luo et al (2013)

d. Metal conversion using bio-cathodes

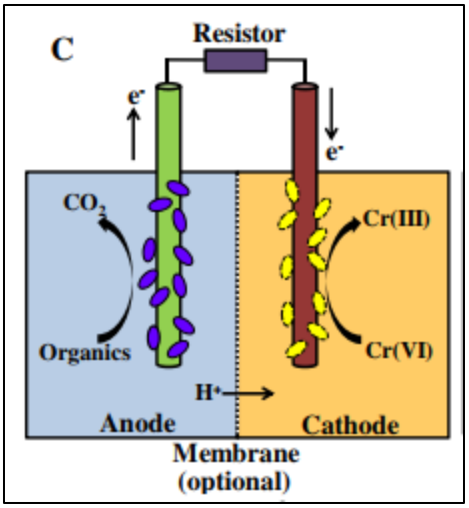

Figure 3.0: Metal conversion using bio-cathodes diagram

Table 5.0: Studies on metal conversion using bio-cathodes

Method used	**Findings**	**Reference**
Dissimilatory metal reducing bacteria species that use metal ions as terminal electron acceptors	Mobile and toxic Cr(VI) can be reduced to less mobile and less toxic Cr(III)	Daulton et al (2007); Rahman et al (2007); Shugaba et al (2012); Tandukar et al (2009); Viti et al (2003)
	Se(VI) and Se(IV) can be microbially remediated to Se(0) so that metal can be precipitated.	Combs et al (1996); Garbisu et al (1996); He and Yao (2011); Kashiwa et al (2000); Kessi et al (1999); Tomei et al (1995)
	Reduction of soluble Pd(II) to Pd(0) nanoparticles outside microbial cells with the use of *Geobacter sulfurreducens.*	Yates et al (2013)

e. Metal conversion using bio-cathodes supplemented by external power sources*

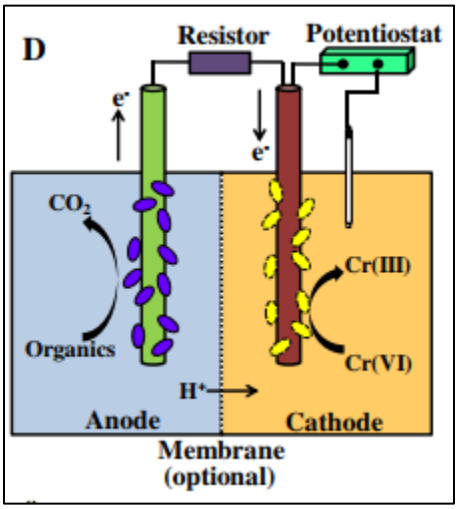

Figure 4.0: Metal conversion using bio-cathodes supplemented by external power sources diagram

Table 6.0: Studies on metal conversion using bio-cathodes supplemented by external power sources

Method used	**Findings**	**Reference**
Applying lower redox potential so that external power sources can be used on biocathode to facilitate reduction	U(VI) reduced to U(IV) by *Geobacter sulfurreducens* with a poised cathode potential of -500 mV, which is a lot lower than electrochemical reduction of U(VI) at -900 mV.	Gregory and Lovley (2005)
	Application of -300 mV potential leads to improvement in reduction rate of Cr(VI) and power production compared to condition where control reactors are presented without set potentials.	Huang et al (2011a)

7. **State two example for each technique (Question 6 on 5 mechanism) their type of metal, reactor, reaction, redox potential, electron donor and electron acceptor.*<u>put in table.</u>**

Table 7.0: Details on techniques of bioelectrical metal platform techniques

Technique	Example 1	Example 2
Direct metal recovery using abiotic cathodes	Type of metal: Au(III) Reactor: Two-chamber	Type of metal: V(V) Reactor: Two-chamber

	Reaction: $AuCl_4^- + 3e^- = Ai + 4Cl^-$ Redox potential: 1.002 Electron donor: Acetate (1000 mg/L) Electron acceptor: Au^{3+} (100-2000 mg/L), pH = 2	Reaction: $VO_2^+ + 2H + e^- = VO^{2+} + H_2O$ Redox potential: 0.991 Electron donor: Glucose (812 mg/L, pH = 7) and sulfide (100 mg/L, pH = 7) Electron acceptor: V^{5+} (500 mg/L) pH = 2
Metal recovery using abiotic cathodes supplemented by external power sources	Type of metal: Ni(II) Reactor: Two chamber Reaction: $Ni^{2+} + 2e^- = Ni$ Redox potential: -0.25 Electron donor: Acetate (1000 mg/L) Electron acceptor: Ni^{2+} (50,100,250, 500 or 1000 mg/L), pH = 3.0, 4.0, 5.0 or 6.0	Type of metal: Cu(II), Pb(II), Cd(II), Zn(II) Reactor: Two-chamber Reaction: $Cu^{2+} + 2e^- = Cu$ $Pb^{2+} + 2e^- = Pb$ $Cd^{2+} + 2e^- = Cd$ $Zn^{2+} + 2e^- = Zn$ Redox potential: 0.340, -0.13, -0.4, -0.762 Electron donor: Acetate (1640 mg/L), pH 7.2 Electron acceptor: Cu^{2+} (800 mg/L) Pb^{2+} (400 mg/L) Cd^{2+} (800 mg/L) Zn^{2+} (300 mg/L)
Metal conversion using bio-cathodes	Type of metal: Cr(VI) Reactor: Two-chamber Reaction: $Cr_2O_7^{2-} + 14H^+ + 6e^- = 2Cr^{3+} + 7H_2O$ $2Cr^{3+} + 7H_2O = 2Cr(OH)_3(s) + 6H^+ + H_2O$ (6.5 < pH <10) Redox potential: 0.365 Electron donor: Excess acetate	

	Electron acceptor: Cr^{6+} = 22,31,40 and 63 mg/L	
Metal conversion using bio-cathodes supplemented by external power sources	Type of metal: Cr(VI) Reactor: Two-chamber Reaction: $Cr^{6+} - Cr^{3+} + Cr(OH)_3$ Redox potential: NA Electron donor: Acetate (1000 mg/L) Electron acceptor: Cr^{6+} = 20 mg/L	

8. State five (5) microbial and precipitation of metal ions. *put in table.

Eg

Metal ions	Microbial Species	Reference
As(V)	*Chrysiogenes arsenates; Desulfotomaculum auripigmentum*	Macy et al. (1996)

Table 8.0: Microbial species involved in precipitation of some metal ions

Metal ions	Microbial Species	Reference
Se(VI)	*Desulfovibrio desulfuricans* and *Bacillus sp*	Kashiwa et al (2000); Tomei et al (1995)
Se(IV)	*Anaeromyxobacter dehalogenans, Bacillus subtilis, Microbacterium arborescens, Rhodospirillum rubrum, Pseudomonas fluorescens* and *Desulfovibrio desulfuricans*	Combs et al (1996); Garbisu et al (1996); He and Yao (2011); Kessi et al (1999); Tomei et al (1995)
Pd(II)	*Geobacter sulfurreducens, Cupriavidus necator, Cupriavidus metallidurans* and *Escherichia coli*	Deplanche et al (2012); Gauthier et al (2010); Yates et al (2013)
Au(III)	*Shewanella algae, Geobacillus sp., Cupriavidus metallidurans* and *Verticillium luteoalbum*	Correa-Llanten et al (2013); Gericke and Pinches (2006); Konishi et al (2006); Reith et al (2009).

9. **State one (1) advantage and disadvantage of the traditional metal recovery technologies (*put in table):**
    a. **Membrane-based project**

Eg

Technology	**Advantage**	**Disadvantage**
Membrane	High separation selectivity	High operational cost and fouling issue

b. Ion exchange
c. Activated carbon
d. Chemical precipitation
e. Electrocoagulant
f. Bioremediation

Table 9.0: Advantages and disadvantages of traditional metal recovery technology

Traditional metal recovery technology	**Advantage**	**Disadvantage**
Ion exchange	Has high removal efficiency and fast kinetics Good option for smaller scale industrial waste treatment processes	Not suitable for high concentration wastewater due to saturation of resins
Activated carbon	Effective in metal adsorption due to large surface area and biosorbents may be sourced from low-cost materials such as waste rice husk or fly ash.	Decent adsorption for certain metal ions only.
Chemical precipitation	Simple, relatively efficient and amongst popularly used method.	Generate large amount of toxic sludge therefore needing additional processing for disposal.
Electrocoagulant	Do not need chemical coagulating agents	Hazardous sludge disposal and anode replacement issues.
Bioremediation	Cost-effective and environmentally friendly.	Limitation on disposal of contaminated plants.

10. Illustrate five (5) challenges for the metal removal and recovery from wastewater (put in a mind map method)

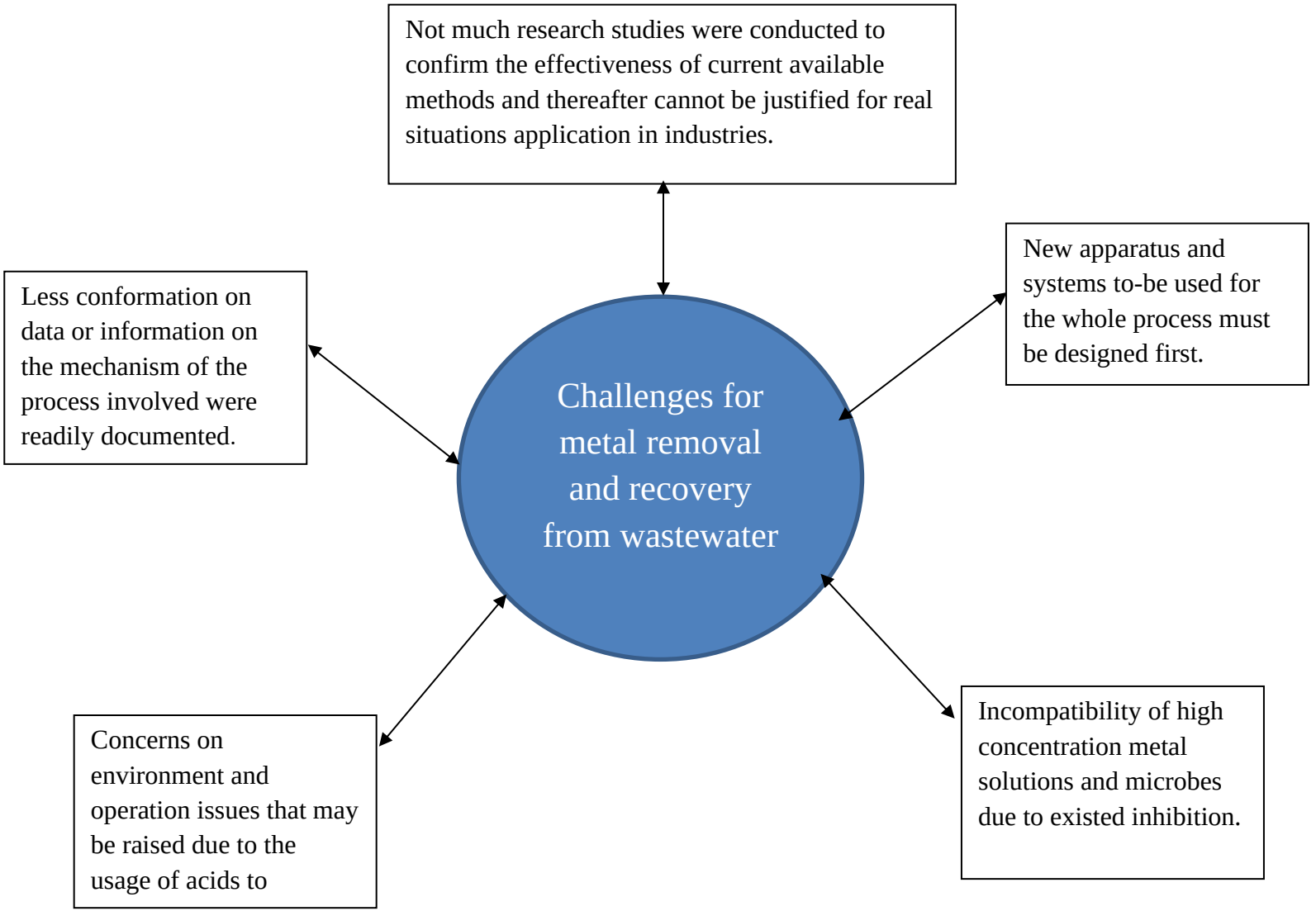

Figure 5.0: Challenges for metal removal and recovery from wastewater.