NURUL NAJWA BINTI ADAM MALIK (137656)

ASSIGNMENT 2 (RECOVERY OF USEFUL COMPOUND IN WASTEWATER)

Simplify the given source following these criteria:

1. Introduction on why need to recover the metal in wastewater? Justify.
2. State at least 10 common metals that being recovered (include their concentration (mg/L) and source of the wastewater). *put in table

Eg:

Name	**Symbol**	**Price**	**MTP**	**Roadwash**	**Tannery**	**Mining**	**Battery factory**
nickel	Ni	18.45	0.0067-0.77	<0.006-0.0525	0.179	0.142	0.038

3. How much Water Environment Research foundation (WERF) recorded the amount they could obtain in dollar, $/ year? (How much the basis per day of the wastewater volume?)
4. There are three categories (physical, chemical, biological) for the metal recovery. State their common methods used. *put in table.
5. The new technology to recovery metal is using bioelectrochemical system (BESs). What is the definition of this technique?
6. State three (3) researchers' findings using these five (5) mechanisms involved in (*put the photo of the system too):
    a. The bioelectrochemical platform for metal recovery

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)

    b. Direct metal recovery using abiotic cathodes
    c. Metal recovery using abiotic cathodes supplemented by external power sources
    d. Metal conversion using bio-cathodes
    e. Metal conversion using bio-cathodes supplemented by external power sources*

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

Eg

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

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

ANSWERS

1. As a result of rapid industrialisation and the anthrogenic activities that comes with the ever-increasing world population, a great number of wastewaters are now heavily contaminated with metals. These metal-saturated wastewaters bring about various health and environmental concerns particularly on the human population especially from wastewater containing high lead concentration. These metals are often introduced into the wastewater through discharge via several routes including effluent, leachates, runoffs and industrialisation. It is required of these toxic metals to be removed from wastewater or water system as they can also accumulate within organisms in the water such as in the living tissues of plants or animals over a span of time. Alongside that, these unwanted metals can also be accumulated in the human bodies through the consumption of metal-laden animals such as fish. This accumulation of metals in the tissues of plants, animals, and human alike has been known to have caused diseases and disorders. It is also of a benefit to recover the metals in wastewater as it provides the opportunities for precious metal recovery. Alongside that, the removal also reduces the need for a thorough treatment or purification processes in removing the metals. This would result in a greater cost-effective and sustainable treatment processes.

2.

Metal	**Symbol**	**Price (USD/kg)**	**Municipal treatment plant**	**Road wash water**	**Tannery**	**Mining**	**Battery factory**
Zinc	Zn	2.14	0.26-0.75	0.105-1.56	0.684	0.023	0.6-17
Aluminium	Al	1.85	-	0.467-26.1	-	0.161	0.2-7.3
Cadmium	Cd	1.87	0-0.0033	-	0.056	0.004	0.02-0.12
Calcium	Ca	110	-	-	255	548	83-225
Chromium	Cr	8.8	0.04-0.56	0.004-0.107	-	0.244	<0.0033-0.38
Iron	Fe	0.2	0.48-3.9	2.59-26.8	4.4	0.033	0.02-20
Lead	Pb	2.09	0-0.039	<0.018-0.053	0.872	-	4-13
Magnesium	Mg	5.84	-	-	268	29.52	15-26
Manganese	Mn	2.2	0.067-1.16	-	0.396	-	0.04-0.6
Nickel	Ni	18.45	0.0067-0.77	<0.006-0.0525	0.179	0.142	0.07-0.38

3. The recovered precious metals can be further exploited for commercial purposes such as the selling of silver. This commercial sector has been deemed as a great potential wherein it has been mentioned by Water Environment Research Foundation to have a potential of $ 8849 - $3, 904, 664 of silver-related revenue per year. This value was estimated based on a 10 million gallon per day which is approximately equivalent to 37, 854 m^3/d of wastewater.

4. Metal recovery technologies are essentially the methods and systems employed in the extraction of metals. These technologies can generally be categorised into physical, chemical, and biological processes. The common methods for each of the mentioned processes are as below in Table 2.

Category	Methods
Physical	• Membrane filtrations which include ultrafiltration, nanofiltration, reverse osmosis and electrodialysis. • Ion exchange • Ion flotation • Adsorption
Chemical	• Precipitation • Cementation • Electroextraction • Electrocoagulation • Photocatalysis • Membrane electrolysis
Biological	• Biosorption • Bioremediation

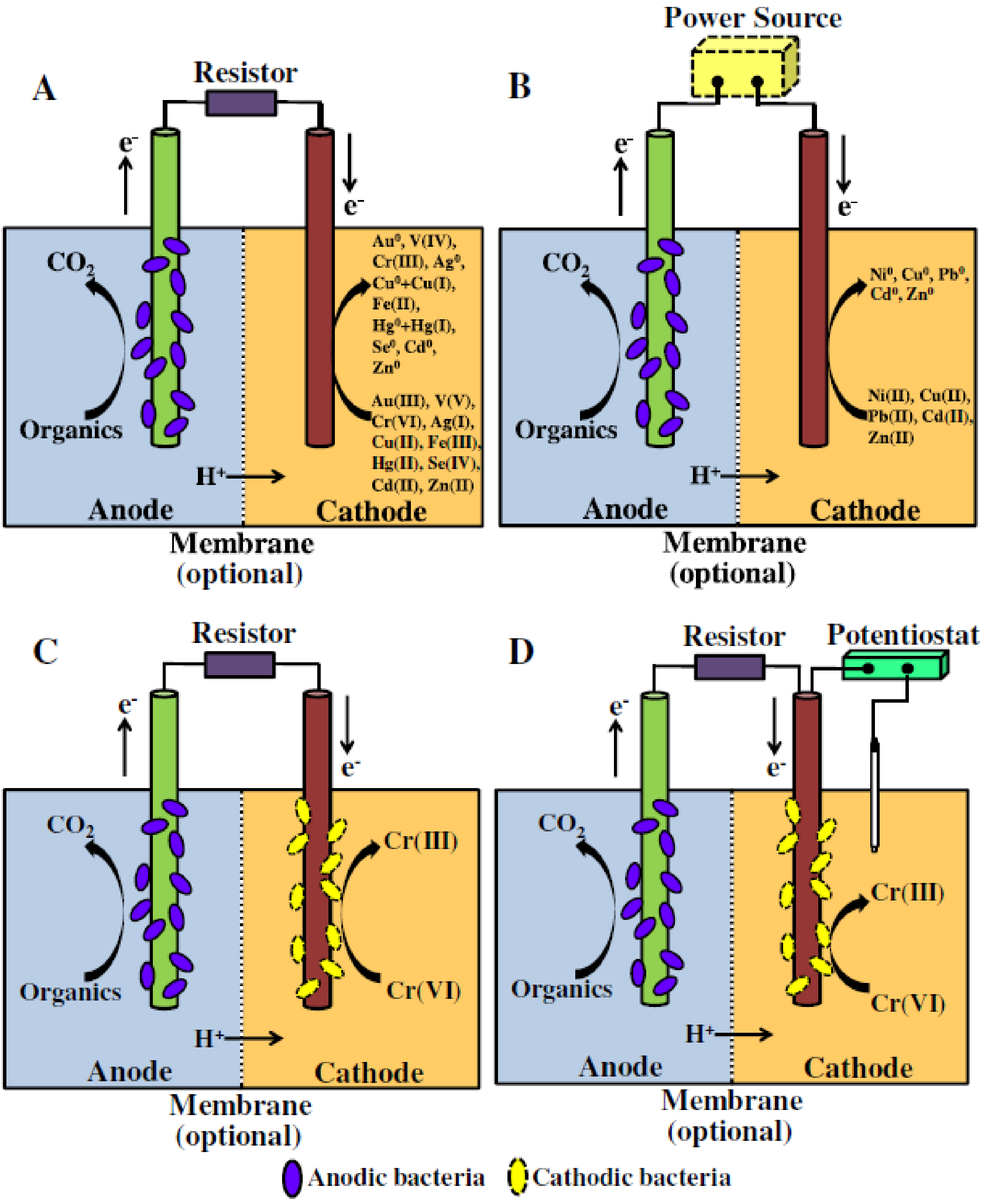
5. Bioelectrochemical system (BES) is essentially a technological system or a platform technology that exploits microorganisms as biocatalysts in oxidizing both organic and inorganic matter to generate electrical energy. In other words, the system transforms the

stored chemical energy in the biodegradable materials into electric currents and chemicals through the employment of microorganisms.

6.

Method used	Findings	Reference
a) BES (MFC)	Concept- The system converts the chemical energy into electrical energy through the usage of microorganisms.	
b) Double chamber MFC without the use of any energy	• 67.9 % +- 3.1 % Vanadium (V) ions in the electrolyte with a maximum power density of 970.2 +- 20.6 % mW/m^2 at 240h operation.	(Zhang et al. 2012)
b) Double chamber MFC built in cylindrical geometry equipped with an exchange membrane	• 25.3 +-1.1 % of Vanadium (V) reduced into its ions with a max power output of 572.4 +- 18.2 mW/m^2 at the 72nd hour. • 84.7 +- 2.8 % of sulphide removal and a total organic removal of 20.7 +- 2.1 %.	(Zhang et al. 2009)
b) Membrane-less baffled MFC	• 70 % of Cu (II) reduction with columbic efficiency of 5.3 % with an initial concentration of 6400 mg/L.	(Tao et al. 2011)
c) Microbial electrolysis cell with applied voltage of 0.5V to 1.1V	• Nickel (Ni^{2+}) removal of 99 +- 0.6 % to 33 +- 4.2 % with initial nickel concentration of 50 to 1000 mg/L respectively at 19.8 h.	(Qin et al. 2012)
c) Two-chambered BES with an ion exchange membrane	• 51 +- 4.6 % to 67 +- 5.3 % of nickel were reduced from an initial concentration of 500 mg/L	(Qin et al. 2012)
c) A cubicle single-chambered MFC	• Obtained maximum power density of 70.40 mW/m^2. Recovery of Cu^{2+} with 99.95 %	(Luo et al. 2014)

	0.09 and 99.86 +- 0.04 % at the 140th hour.	
d) Single MFC	- Conversion of Cr (VI) to Cr $(OH)_3$ with a maximum power production of 55.5 mW/m^2 at initial concentration of 63 mg/L	(Tandukar et al. 2009)
d) DMRB	- Toxic metals can be conducted into its respective less toxic metals through the utilisation of dissimilatory metal reducing bacteria species that employs metal ions as the terminal electron acceptor.	(Tandukar et al. 2009)
d) MFC	- Interaction of cyanobacteria with aqueous $AgNO_3$ promoted the precipitation of spherical silver nanoparticles and octahedral silver platelets (of up to 200 nm) in solutions.	(Lengke, Fleet, and Southam 2007)
e) BES (MFC)	- U (VI) is converted into U (IV) by Geobacter sulfurreducens with a poised cathode potential of -500 mV, which is much lower than the electrochemical reduction of U(VI) at -900 mV	(Gregory and Lovley 2005)
e) Tubular two-chambered (MFC)	- Conversion of Cr (VI) into Cr (III) with simultaneous energy generation	(Gregory and Lovley 2005)


A
Resistor
e⁻
e⁻
CO2
Organics
Au0, V(IV),
Cr(III), Ag0,
Cu0+Cu(I),
Fe(II),
Hg0+Hg(I),
Se0, Cd0,
Zn0
Au(III), V(V),
Cr(VI), Ag(I),
Cu(II), Fe(III),
Hg(II), Se(IV),
Cd(II), Zn(II)
H+
Anode
Cathode
Membrane
(optional)
B
Power Source
e⁻
e⁻
CO2
Organics
Ni0, Cu0, Pb0,
Cd0, Zn0
Ni(II), Cu(II),
Pb(II), Cd(II),
Zn(II)
H+
Anode
Cathode
Membrane
(optional)
C
Resistor
e⁻
e⁻
CO2
Organics
Cr(III)
Cr(VI)
H+
Anode
Cathode
Membrane
(optional)
D
Resistor
Potentiostat
e⁻
e⁻
CO2
Organics
Cr(III)
Cr(VI)
H+
Anode
Cathode
Membrane
(optional)
Anodic bacteria
Cathodic bacteria

7.

Metal	Reactor	Reaction	Redox Potential	Electron Donor	Electron acceptor
b) Se (VI)	Single chamber	$SeO^{2-}{}_3 + 4e^- = Se\ (s)$	NA	Sodium acetate or glucose	Oxygen, Se (IV)
b) V (V)	Two-chamber	$VO^{+2} + 2H^+ + e^- = VO^{2+} + H_2O$	0.991	Glucose and sulphide	V^{5+}
c) Ni (II)	Two-chamber	$Ni^{2+} + 2e^- = Ni$	-0.25	Acetate	Ni^{2+}
c) Fe (II)	Two-chamber	$Fe^{2+} + 2e^- = Fe(OH)_2$	NA	Acetate	Fe^{2+}
d) Cr (VI)	Two-chamber	$Cr_2O_2^{-7} + 14H^+ + 6e^- = 2Cr^{3+} + 7H_2O$	0.365	Excess acetate	Cr^{6+}
d) Pd (II)	Two-chamber			Hydrogen	
e) Cr (VI)	Two-chamber	$Cr^{6+} + 3e^- = Cr^{3+} + Cr(OH)_3$	NA	Acetate	Cr^{6+}
f) U (VI)					

8.

Metal ion	**Species**
Cr (VI)	*Trichococcus pasteurii*
Se (VI)	*Bacillus sp.*
Au (III)	*Verticillium luteoalbum*
Pd (VI)	*Escherichia coli*
U (VI)	*Clostridium spp.*
V (V)	*Shewanella oneidensis*

9.

Advantage	Disadvantage
Membrane-based project	
Due to its capacity of being able to have its pores modified to selectively filter the desired metal ions, it is a relatively flexible technology with a high selectively of separation with a lower foot-print.	Due to accumulation of retained materials there is fouling issues which levels to high operational cost
Ion-exchange	
Has fast kinetics and a high removal efficiency	Does not perform well for higher concentration wastewater due to its unsuitability.
Activated carbon	
High effectiveness in metal removal from	Can be considered as expensive when

wastewater due to high surface area of activated carbon.	compound to other alternatives
Chemical precipitation	
Has a low capital cost and single operation	Requires additional processing for disposal due to large amount of toxic stage generated
Electrocoagulation	
Does not require chemical coagulating agents in carrying out its process	Generates hazardous sludge as well as its anode replacement process
Bioremediation	
An environmentally-friendly method due its utilisation of microbes, enzymes or living organisms as in remediating the metals or pollutants.	Disposal issue of the contaminated plants which leads to the limiting factor of their range of applications

10.

Much data and studies on the feasibility of BES's capability in the extraction of metals has been acquired, however, BES's real life performances do not reflect these acquired data.

Biocathodes have shown good performances in removing and recovering metals, however, high concentration metal solutions generally inhibit microbial activities.

There has been limited informations on how electrostatic interactions between the cathode and metal ions affect metal recovery efficiency. Quantitive characterisations are needed to fully understand the effects.

Newer configurations of BES or MFC's needs to be developed in catering to current issues relating to the current's MFC configurations.

More studies are required to be looked further on economic and possible life cycle analyses in order to understand the costs and benefits of specific BES metal recovery processes.

Reference

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