The Papua New Guinea University of Technology

DEPARTMENT OF MINING ENGINEERING

2021 FIRST SEMESTER EXAMINATION

Third Year Mineral Processing Engineering, Third Year Applied Chemistry and Fourth Year Applied Chemistry.

MP341 - HYDROMETALLURGY I

DATE: MONDAY, 7th JUNE 2021

TIME: 12:50 P.M.

TIME ALLOWED: 3 HOURS

INFORMATION FOR CANDIDATES:

1. You have ten minutes to read this question paper. You **SHOULD NOT** begin writing during this period.

2. There are **Four** questions altogether, read and understand instructions clearly. Answer all questions.

3. **ALL** answers must be provided on the answer book provided. No other written material will be accepted.

4. **ONLY** Rulers, Pen, Pencil and Calculators are allowed.

5. Write your **NAME** and **NUMBER** clearly on the **ANSWER BOOK**. Do this **NOW**.

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Principles of Leaching

Question 1: Leach Methods (15 Marks)

1. Name and discuss the two main sources of raw materials that are treated by leaching processes, give examples.
2. Discuss two Leach Methods practiced in the mining industry, (a high cost and low cost operations) and state their distinguishing characteristic features clearly.

Question 2: Thermodynamics of Leaching (25 Marks)

Construction of Eh –pH diagram.

All chemical reactions are either dependent on Redox potential (Eh) and pH or depend on Eh or pH alone.

With Oxidation and Reduction Reaction (only soluble species are included in the log term)

1. Derive the equation that define the boundary of the phase diagram.

   $$Cu^{2+} + e^{-} \rightarrow Cu^{+}.$$

2. Derive the equation that define the boundary of the phase diagram.

   $$HCu0_2^{-} + 3H^{+}. + e^{-} \rightarrow Cu^{2+} + 2H_20$$

Reactions involving two solids

3. Derive the equation that define the boundary of the phase diagram

   $$Cu_20(s) + 2H^{+} + 2e^{-} \rightarrow 2Cu_{(s)} + H_20$$

4. Derive the equation that define the boundary of the phase diagram

   $$Cu\ (0H)_2 + 2H^{+} + 2e^{-} \rightarrow Cu_{(s)} + 2H_20$$

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Electro Chemistry of Leaching (15 marks)

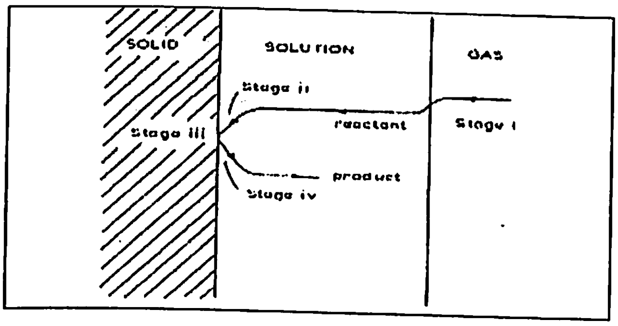
The standard half-cell reduction potentials of some selected metals are as follows:

$Fe^{2+} + S^o + 2e = FeS$	$Eo = +0.757$ v
$Zn^{2+} + S^o + 2e = ZnS$	$Eo = +0.174$ v
$Zn^{2+} + 2e = Zn$,	$E^o = -0.763$ v
$Fe^{2+} + 2e = Fe$,	$E^o = -0.440$ v
$Cd^{2+} + 2e = Cd$	$E^o = -0.403$ v
$Cu^{2+} + 2e = Cu$	$E^o = +0.337$ v
$Ag^{+} + e^{-} = Ag$	$E^o = +0.7991$v
$Au^{3+} + 3e = Au$	$E^o = +1.50$ v
$3/2O_{2(g)} + 2H^{+} + 2e- = O_{2(g)} + H_2O$	$E^o = 2.07$v
$H_2O_2 + 2H^{+} + 2e^{-} = 2 H_2O$	$E^o = 1.776$v

a. Write down three paired reactions that would lead to a metal leaching.
b. calculate the standard cell potential of the reaction pair and standard free energy change for the reactions
c. and state if the overall reactions are thermodynamically favorable.

Question 3: Kinetics of Leaching Reactions (25 Marks)

1. If the reaction of Cu silicate with H_2SO_4 is represented as follows: Cu silicate$_{(s)}$ + $H_2SO_{4\,(l)}$ → Cu $SO_{4\,(l)}$ + $SiO_{2\,(s)}$

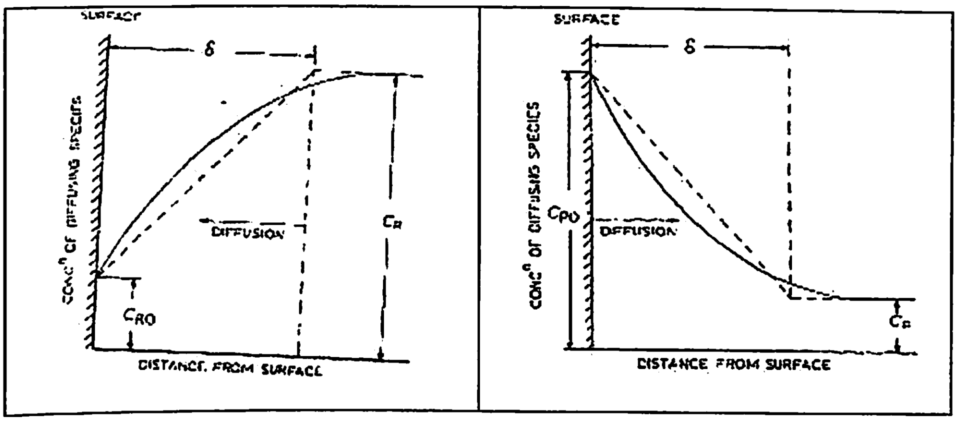


a. Discuss the various elements in the leach process that impedes on the rates of reaction in step (i) and the steps that must be taken to improve them.

b. Discuss the major hindrances in stage (ii) to the rates of reactions and the possible improvement steps that can be taken.

c. For stage (iii) Explain in your own words what causes the reagent concentration at the solid-solution interface to equal zero.

d. Discuss the major elements in the leach process step that impedes on the rates of reaction in step (iv) and the possible ways to improve them.



Question 4: **(20 Marks)**

Choose **only ONE** of the three questions below and answer as best you can .

1. A copper ore assaying 2% Cu is heap leached to produce a Pregnant Solution of <5 kg Cu m^{-3}. This can be concentrated either by;

   Discuss the best hydrometallurgical processing route to take to produce high purity copper cathode with the aid of a flowsheet and chemical equations.

2. A copper ore assaying 8% Cu is heap leached to produce a Pregnant Solution of 40 kg Cu m^{-3}. This can be concentrated either by;

   Discuss the best hydrometallurgical processing route to take to produce high purity copper cathode with the aid of a flowsheet and chemical equations.

3. An oxidized gold ore assaying <2g/t Au is crushed and ground to 80% passing 38 micron size and agitation leached with sodium cyanide to produce a Pregnant Solution of 150 kg Au m^{-3}.

Discuss the best hydrometallurgical processing route to take to eventually produce a high purity gold bullion bar.

For the copper-water system, the relevant information is:

SOLIDS	μo	SOLUTES	μo
Cu	0 kJ mol^{-1}	Cu^+	50.2 kJ mol ^{1}
Cu_2O	-146.2 kJ mol^{-1}	Cu^{2+}	64.9 kJ mol ^{1}
CuO	-127.1 kJ mol^{-1}	$HCuO_2^-$	- 256.7 kJ mol ^{1}
		CuO_2^{2-}	- 181.8 kJ mol ^{1}
SOLVENT:			
H_2O	-237.0 kJ mol^{-1}		

The values of μ °, or $\Delta G^o{}_f$, for a large number of compounds have been tabulated by Pourbaix (1966). Some such data are listed in Table 3.1.

Table 3.1: Standard Chemical Potentials at 25°C (273°K for some compounds and ions. (Adapted from Australian Mineral Foundation 1974). Units:kJ/mol

SYSTEM	Compound	μ°	Ion	μ°
Water	H_2O (l)	- 237.0	H^+	- 0.0
	H_2O (g)	- 228.4	OH^-	- 157.3
Sulphur	H_2S (g)	- 32.99	HS^-	- 12.56
	H_2S (soln)	- 27.34	S^{2-}	- 91.78
	SO2 (g)	- 300.1	HSO_4^-	- 752.2
			SO_4^{2-}	- 741.3
Titanium	TiO	- 488.7	Ti^{2+}	- 313.9
	Ti_2O_3	- 1430.9	Ti^{3+}	- 349.4
	$Ti(OH)^3$	- 1048.8	TiO^{2+}	- 576.8
	TiO_2	- 887.5	$HTiO_3^-$	- 955.0
	TiO_2H_2O	- 1057.5	TiO_2^{2+}	- 466.8
Chromium	Cr_2O_3	- 1045.8	Cr^{2+}	- 176.0
	$Cr(OH)_2$	- 587.3	Cr^{3+}	- 215.3
	$Cr(OH)^3$	- 900.0	$Cr_2O_7^{2-}$	- 1318.4
	$Cr(OH)^4$	- 1013.2	$HCrO_4^-$	- 772.9
			CrO_4^{2-}	- 736.1
			CrO_3^{3-}	- 602.8
Manganese	$Mn(OH)_2$	- 614.0	Mn^{2+}	- 227.4
	Mn_3O_4	- 1279.1	Mn^{3+}	- 81.93
	Mn_2O_3	- 887.4	MnO_4^{2-}	- 503.3
	MnO_2	- 464.4	MnO_4^-	- 448.9
			$HMnO_2^-$	- 505.4
Iron	Fe_3O_4	- 1013.2	Fe^{2+}	- 84.85
	$Fe(OH)_2$	- 483.1	Fe^{3+}	- 10.58
	Fe_2O	- 740.3	$HFeO_2^-$	- 370.0
Nickel	$Ni(OH)_2$	- 452.7	Ni^{2+}	- 48.2
	Ni_3O_4	- 711.2	$HNiO_2^-$	- 349.0
	Ni_2O_3	- 469.3		
	NiO_2	- 214.9		
Copper	**Cu_2O**	**- 146.2**	**Cu^+**	**50.16**
	CuO	**- 127.1**	**Cu^{2+}**	**64.92**
	$Cu(OH)_2$	**- 356.6**	**CuO_2^{2-}**	**- 181.8**

Zinc	$Zn(OH)_2$	- 558.6	Zn^{2+} ZnO_2^{2-}	- 147.1 - 388.6
Cadmium	$Cd(OH)_2$	- 472.9	Cd^{2+} $HCdO_2^{2-}$	- 77.6 - 361.6
Tin	$Sn(OH)_2$ SnO_2 $Sn(OH)_4$	- 491.6 - 515.0 - 915.6	Sn^{2+} Sn^{4+} SnO_2^{2-} $HSnO_2^{3-}$	- 26.23 - 2.72 - 574.4 - 409.6
Lead	Pbo Pb_3O_4 PbO_2	- 189.1 - 617.2 - 218.8	Pb^{2+} Pb^{4+} $HPbO_2^-$ PbO_3^{2-}	- 24.29 - 302.2 - 338.6 - 277.3

Table 2.1 – Standard potentials of selection redox systems

Redox system	E° /V
$S_2O_8^{2-} + 2e = 2SO_4^{2-}$	+2.00
$H_2O_2 + 2H^+ + 2e = 2H_2O$	1.77
$2HClO + 2H^+ + 2e = Cl_2 + 2H_2O$	1.63
$MnO_4^- + 8H^+ + 5e = Mn^{2+} + 4H_2O$	1.51
$2BrO_3^- + 12H^+ + 10e = Br_2 + 6H_2O$	1.50
$2ClO_3^- + 12H^+ + 10e = Cl2 + 6H_2O$	1.47
$Cl_2 + 2e = 2Cl^-$	1.359
$Cr_2O_7^{2-} + 14H^+ + 6e = 2Cr^{3+} + 7H_2O$	1.33
$2HNO_2 + 4H^+ + 4e = N_2O + 3H_2O$	1.29
$MnO_2 + 4H^+ + 4e = Mn^{2+} + 2H_2O$	1.23
$O_2 + 4H^+ + 4e = 2H_2O$	1.229
$2IO_3^- + 12H^+ + 10e = I_2 + 6H_2O$	1.195
$Br_2 + 2e = 2Br^-$	1.087
$2Hg^{2+} + 2e = 2Br^-$	0.92
$Fe^{3+} + e = Fe^{2+}$	0.771
$Cu^{2+} + Br^- + e = CuBr$	0.64
$Cu^{2+} + Cl^- + e = CuCl$	0.54
$CuS = Cu^{2+} + S^o + 2e$	0.59
$Cu^{2+} + 2e = Cu$	0.34