GWANDA STATE UNIVERSITY

FACULTY OF ENGINEERING AND ENVIRONMENT

DEPARTMENT OF METALLURGICAL ENGINEERING

ADVANCED HYDROMETALLURGY

EMR 5102

Part V Supplementary First Semester Examination Paper

April 2024

This examination paper consists of 6 printed pages

Time Allowed: **3 hours**

Total Marks: **100**

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INSTRUCTIONS

1. Answer **ALL questions in Section A and any TWO from Section B**
2. Each question carries 25 marks
3. Use of calculators is permissible

Additional Requirements

MARK ALLOCATION

Section A	50 Marks
Section B	50 Marks
Part Questions	As shown in each part question
Total Attainable	100

Question 1

An engineer with expertise in hydrometallurgy is designing a novel process for lead recovery from battery scrap involving the following steps

a. Leaching – Insoluble lead (II) sulphate is converted to lead chloride by leaching in neutral sodium chloride brine solution
b. Purification – Milk of lime Ca(OH)2 and HCl is introduced to the leach solution to remove the dissolved sulphate as insoluble gypsum (calcium sulphate dehydrate) and keep the neutral pH
c. Electrowinning – finally the metallic lead and oxygen are produced by electrowinning from purified lead chloride solution.

i. Provide the chemical reaction for each of the steps above [6]
ii. Provide a flow sheet for the process above recycling where possible [4]
iii. Calculate the minimum electrowinning potential to electrowin lead at pH 7. Assuming a reasonable lead concentration. State your assumption. [5]
iv. Calculate the maximum electrowinning potential to avoid chloride gas evolution assuming a reasonable chloride concentration. State your assumption. [5]
v. Explain why not work efficiently under very acidic conditions and what process controls one needs to put in place. [5]

Question 2

Reference is made to the Pourbaix diagram given below in Figure Q2.

a. Identify all possible reaction paths (including combined thermochemical/hydrochemical treatment) that may be used to dissolve a feed material consisting of cobalt oxide (Co_3O_4) [8]
b. For each reaction path provide the chemical equation [6]
c. Indicate whether each selected reaction is non-oxidative, oxidative or reductive [5]
d. For each dissolution scheme, provide a corresponding well-labeled simplified flow diagram. [6]

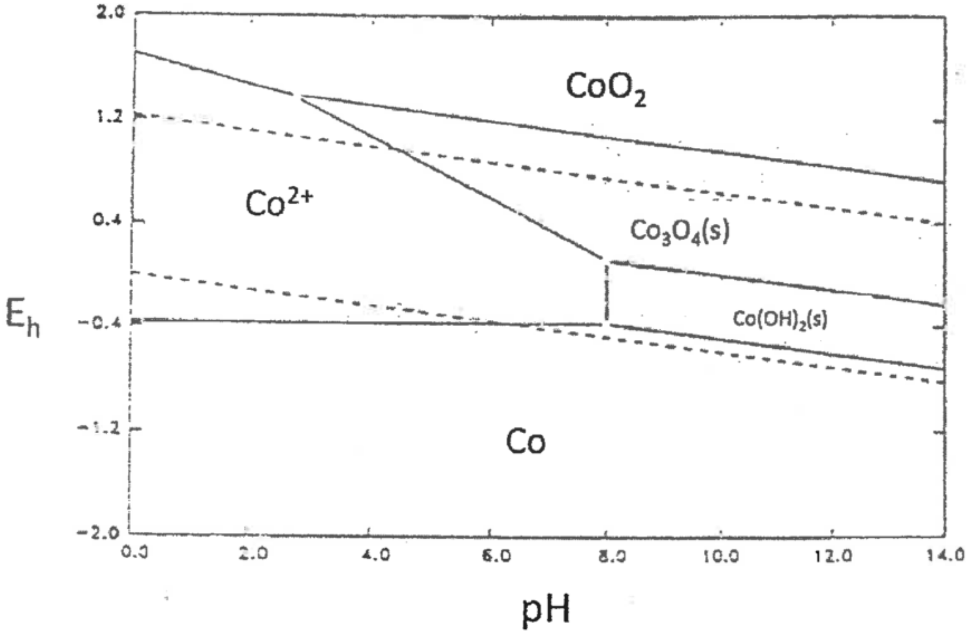


Figure Q2 Pourbaix diagram for Cobalt

Question 3

A gold miner uses vat or percolation leaching to recover gold using sodium cyanide. Residence time, cyanide concentration, tails grade and pH are some of the parameters they monitor in operation. However, they hardly measure the dissolved oxygen concentration, yet it is believed to be the rate-limiting factor.

The rate of oxygen consumption in a gold vat leaching operation is 6.67 x 10^{-6}l/(m^{2}s) at STP and only 3% of the oxygen is consumed in the gold dissolution reaction involving cyanide. The plant vat leach tanks have an ore profile 1.0 m high, containing 1500 kg/m^3 ore with 1.5g/ton gold. At STP molar volume is 22.4 litres.

a. Estimate the rate of gold dissolution by cyanide leaching. [4]
b. How long will it take to extract 80% of the gold at that rate? [4]
c. How long will it take to extract 80% of the gold if only 0.45% of the oxygen were utilised for the cyanide gold reaction? [5]
d. What two factors might cause different proportions of dissolved oxygen to be overly consumed by the cyanide gold reaction? [4]
e. In what two different ways can the plant operator increase the rate of this gold dissolution reaction? [4]
f. Explain how one of the factors you mentioned above will be better than the other in effectively increasing the rate of gold dissolution in cyanide. [4]

Question 4

A small-scale gold miner in Mangwe district is facing low recovery challenges in leaching its ore in vat leach tanks using alkaline sodium cyanide. The plant crushes ore using jaw crushers, mills it with a stamp mill, recovers free course gold using a centrifugal concentrator and leaches in vat leach tanks before carbon elution. The mine vat solutions turn from pure water colour to sky blue, violet and finally reddish brown. Gold is leached in an alkaline cyanide solution by the reaction Q4i

$4\ Au + 8\ NaCN + O_2 + 2\ H_2O \rightarrow 4\ Na[Au(CN)_2] + 4\ NaOH$ Reaction Q4i

Copper compounds react with alkaline cyanide solutions by the reaction Q4ii and Q4ii

$4Cu_2S + 22NaCN + 5O_2 + 2H_2O \rightarrow 4NaCu(CN)_2 + 4Na_2Cu(CN)_3 + 2NaCNS + 2Na_2SO_4 + 4NaOH$

90.2% copper dissolution at 25°C pH 10 1g/l NaCN Reaction Q4ii

$2CuCO_3 + 7NaCN + 2NaOH \rightarrow 2Na_2Cu(CN)_3 + 2Na_2CO_3 + NaCNO + H_2O$

90.5% copper dissolution at 25°C pH 10 1g/l NaCN Reaction Q4iii

a. Describe the test works you would carry out to ascertain the cause of this low recovery. [8]
b. In what way can the mine improve its recovery if the ore is found to contain 5% copper as malachite $CuCO_3.Cu(OH)_2$ and azurite $2CuCO_3.Cu(OH)_2$? [6]
c. In what way can the mine improve its recovery if the ore is found to contain 5% copper as chalcocite Cu_2S content? [6]
d. In what way can the mine improve its recovery if the ore is found to contain 10% copper as malachite $CuCO_3.Cu(OH)_2$, azurite $2CuCO_3.Cu(OH)_2$ and chalcocite Cu_2S? [5]

Question 5

Zimbabwe's platinum industry is not fully beneficiating its products locally. Some of the local mines export concentrates for smelting and some exports matte for refining. Understanding the platinum beneficiation and possibly improving it locally will help add local value to the precious finite resource to maximise local value. Platinum is leached by hydrochloric acid in PGM refining. Zinc cementation can be used to recover platinum from the solution.

$PtCl_6^{2-} + 4e^- = Pt + 6Cl^-$ E^θ +0.74V
$PdCl_4^{2-} + 2e^- = Pd + 4Cl^-$ E^θ 0.64V
$ZnCl_3^{4-} + 2e^- = Zn + 3Cl^-$ E^θ -0.78V

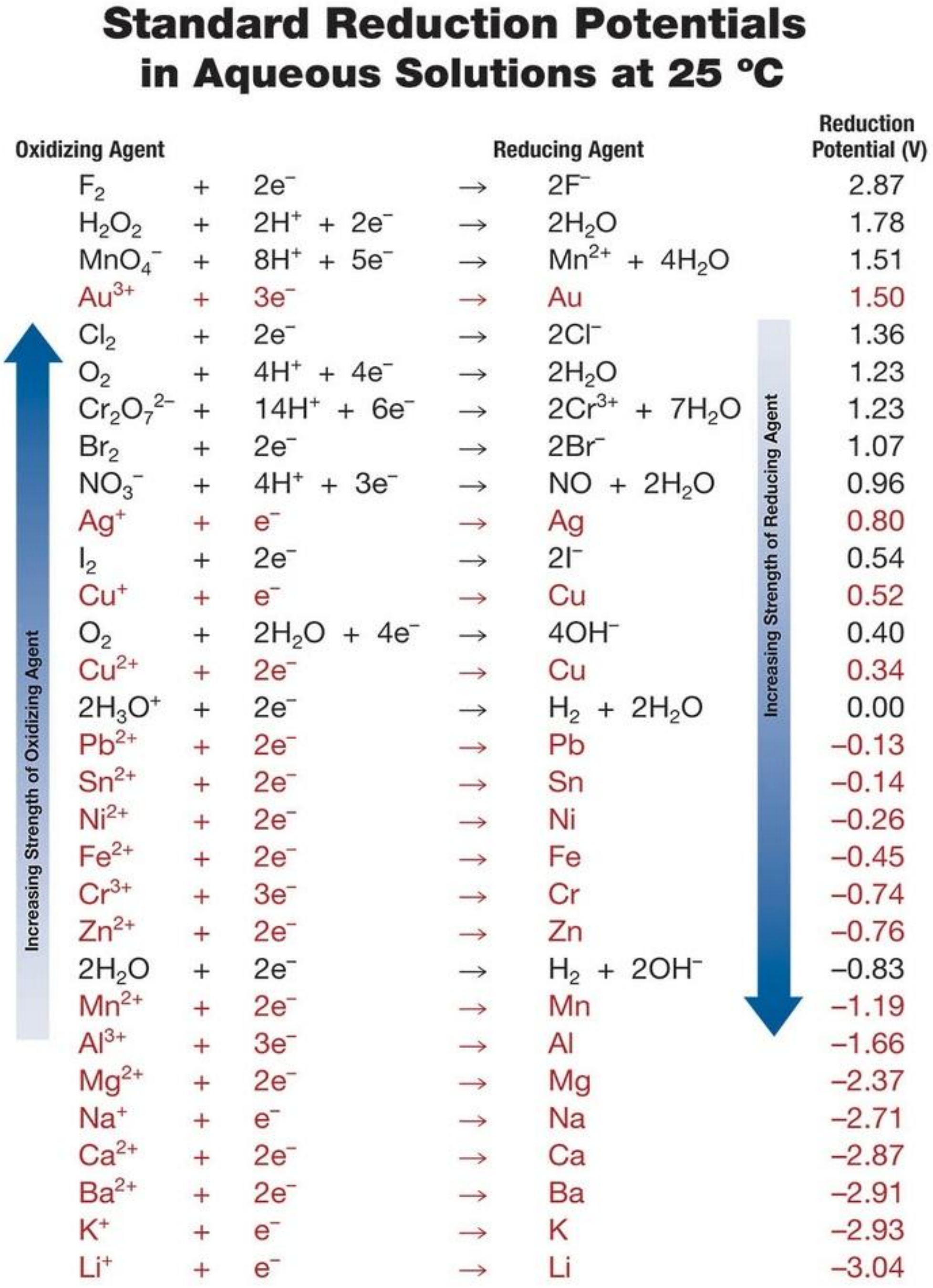
a. Write balanced chemical equations for the cementation of Pt and Pd using Zn solids from the solution. Calculate the standard potential for the cementation. [4]
b. Consider the typical pregnant solution concentration of Pt 59.4mg/l, Pd 37.2mg/l and Zn 7.7mg/l, and calculate the nonstandard potential for cementation on solid zinc. Atomic masses Pt 195 g/mol, Pd 106g/mol Zn 65 g/mol and Cl 35 g/mol, RT/F is 0.0592mV where R is the gas constant, T the temperature and F the Faraday constant. [6]

c. What is the thermodynamic theoretically achievable recovery of platinum from solution using zinc cementation for batch pregnant solutions in (b)? [6]

d. Nowadays resins are used to enrich the concentration of pregnant solution. Typical values would be Pt 2430 mg/l and Pd 499 mg/l. Discuss the effects of cementation on the lean pregnant solution or after resin concentration on the overall recovery, costs, reagent consumption and final product quality. [6]

e. Another option for the recovery of Pt after ion exchange concentration is electrowinning. How does electrowinning compare to cementation in terms of costs, product quality and recovery? [3]

Additional Data



Standard Reduction Potentials in Aqueous Solutions at 25 °C

Oxidizing Agent				Reducing Agent	Reduction Potential (V)
F_2	+	$2e^-$	→	$2F^-$	2.87
H_2O_2	+	$2H^+ + 2e^-$	→	$2H_2O$	1.78
MnO_4^-	+	$8H^+ + 5e^-$	→	$Mn^{2+} + 4H_2O$	1.51
Au^{3+}	+	$3e^-$	→	Au	1.50
Cl_2	+	$2e^-$	→	$2Cl^-$	1.36
O_2	+	$4H^+ + 4e^-$	→	$2H_2O$	1.23
$Cr_2O_7^{2-}$	+	$14H^+ + 6e^-$	→	$2Cr^{3+} + 7H_2O$	1.23
Br_2	+	$2e^-$	→	$2Br^-$	1.07
NO_3^-	+	$4H^+ + 3e^-$	→	$NO + 2H_2O$	0.96
Ag^+	+	e^-	→	Ag	0.80
I_2	+	$2e^-$	→	$2I^-$	0.54
Cu^+	+	e^-	→	Cu	0.52
O_2	+	$2H_2O + 4e^-$	→	$4OH^-$	0.40
Cu^{2+}	+	$2e^-$	→	Cu	0.34
$2H_3O^+$	+	$2e^-$	→	$H_2 + 2H_2O$	0.00
Pb^{2+}	+	$2e^-$	→	Pb	–0.13
Sn^{2+}	+	$2e^-$	→	Sn	–0.14
Ni^{2+}	+	$2e^-$	→	Ni	–0.26
Fe^{2+}	+	$2e^-$	→	Fe	–0.45
Cr^{3+}	+	$3e^-$	→	Cr	–0.74
Zn^{2+}	+	$2e^-$	→	Zn	–0.76
$2H_2O$	+	$2e^-$	→	$H_2 + 2OH^-$	–0.83
Mn^{2+}	+	$2e^-$	→	Mn	–1.19
Al^{3+}	+	$3e^-$	→	Al	–1.66
Mg^{2+}	+	$2e^-$	→	Mg	–2.37
Na^+	+	e^-	→	Na	–2.71
Ca^{2+}	+	$2e^-$	→	Ca	–2.87
Ba^{2+}	+	$2e^-$	→	Ba	–2.91
K^+	+	e^-	→	K	–2.93
Li^+	+	e^-	→	Li	–3.04

SHE in aqueous solutions at 25 C.

END OF QUESTION PAPER