National Exams December 2009

98-Met-A3, Metal Extraction Processes

3 hours duration

NOTES:

1. Answer only **five** questions. Any five questions(out of seven) constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.

2. All questions are of equal value(20 marks each out of 100).

3. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper a clear statement of any assumptions made.

4. Candidates may use one of two calculators, the Casio or Sharp approved models. This is a closed book exam.

5. The exam consists of five pages

Question 1:	(a) 4, (b) 4, c) 4, d) 4, (e) 4
Question 2:	(a) 4, (b) 4, (c) 4, (d) 4, (e) 4
Question 3:	(a) 4, (b) 4, (c) 4, (d) 4, (e) 4
Question 4:	(a) 4, (b) 4, (c) 4, (d) 4, (e) 4
Question 5:	(a) 4, (b) 4, (c) 4, (d) 4, (e) 4
Question 6:	(a) 4, (b) 4, (c) 4, (d) 4, (e) 4
Question 7:	(a) 20

Problem No. 1(20 marks): In the electro-refining of copper cathodes from copper anodes, the copper dissolves in the sulphuric acid electrolyte as Cu^{2+}. Density of copper = 8.96 g/cm^3, Molecular mass = 63.55 g/mol. The following conditions apply: A) current density 190 A/m^2, B) current efficiency 98%, C) the applied voltage is 0.45 V.

a) Describe briefly the electro-refining process of copper cathodes from copper anodes. What is the purpose; properties of the electrolyte, what happens to all the impurities, how is iron removed
b) What is the rate of copper deposition on the cathode(mol/m^2/second)
c) What is the growth rate of copper(mm/day(24 hrs)) on the cathode surface
d) What is the power consumption(kWHr/kg Cu) per unit amount of cathode formed
e) Which factors may limit the rate of refining

Data: The Faraday's constant is 96500 Columb/mol.

Problem No. 2(20 marks): Iron and steelmaking

a) Describe briefly the iron blast furnace and its operation
b) What are the roles of the various feed materials(solid and gaseous) that enter the blast furnace and how are they pre-treated
c) Describe the main principles and purposes of the basic oxygen furnace(BOF) for treating pig iron from the blast furnace
d) A particular BOF has to treat a batch of 200 metric tonnes of pig iron(composition: 4.0 wt% C, 1.5 wt% Si and 0.8 wt% Mn, the rest is pure Fe) by injecting pure oxygen gas. How many kg of oxygen is required to remove all these impurities in addition to 4.5 metric tonnes of iron oxidized to FeO. Assume that of the total amount of carbon present in the pig iron, half is oxidized to CO and half goes to CO_2.
e) What is the composition(wt%) of the slag formed(assume only FeO, MnO and SiO_2)

$M_{Fe} = 55.8$ g/mol, $M_C = 12$ g/mol, $M_O = 16$ g/mol, $M_{Mn} = 54.9$ g/mol, $M_{Si} = 28.1$

Problem No. 3(20 marks): Aluminum(Al) is produced at 960 °C by electrolysis of alumina(Al_2O_3) dissolved in a cryolite based bath using a consumable carbon anode.

a) Describe the main unit operations in the Bayer process used to refine bauxite to alumina
b) Make a schematic of a pre-baked Hall-Heroult electrolytic cell for aluminum production
c) Describe why the electrolyte mainly consists of cryolite(Na_3AlF_6)

In one particular aluminum cell, the current is 250,000 A, the cell voltage is 4.45 V and the current efficiency is 94%.

d) How much(kg) aluminum is produced in one hour
e) What is the specific energy consumption(kWhr/kg Al)

M_{Al} = 26.98 g/mol; Faradays constant = 96,500 Columb/mol
1 kWHr = $3.6\text{x}10^6$ J

Problem No. 4(20 marks): Assuming you have a sulfidic mixed nickel($(NiFe)_8S_9$)-copper ($CuFeS_2$) ore that contains 1.3% Ni and 1.4% Cu by weight. The ore also contains FeS, FeS_2 and SiO_2 as well as some precious metals(0.2 g Au/tonne and 40 g Ag/tonne) The ore is underground and will have to be explored using underground mining. The price of nickel is 10,000 US$/tonne, copper can be assumed to stay at 3,500 US$/tonne, gold at 900 US$/troy ounce(1 troy ounce = 31 g), silver at 12 US$/troy ounce).

a) Determine the value of the ore per tonne, and elaborate on its economic feasibility
b) Draw a schematic flow diagram of **mineral processing steps** that will have to be applied after the ore is mined until it forms a nickel-copper concentrate that can be fed to a smelter for further processing.
c) Describe briefly the principles of the various unit operations used in the mill
d) What are the main environmental issues(advantages and disadvantages) with such mineral processing operations
e) Describe briefly a possible smelting process that can be used to treat this nickel concentrate from the mill

Problem No. 5(20 marks): NiO is reduced from a NiO containing slag(NiO – FeO – MgO – SiO_2) to metallic ferro-nickel(Fe-Ni alloy) at 1600 °C with CO(gas) according to the following reaction:

$$NiO(liquid) + CO(g) = Ni(liquid) + CO_2 \qquad \text{Eq. 1}$$

a) Calculate ΔG^o at 1600 °C for this reaction(Eq. 1)
b) Determine the minimum CO/CO_2 ratio required to reduce NiO dissolved in a slag to metallic ferro-nickel at 1600 °C. The metallic nickel product formed consists of 35 mole% nickel and 65 mole% iron, assume ideality. The activity of NiO in the slag is 0.015.
c) Why are nickel lateritic ores dried, calcined and partially reduced before thye are treated in an electric smelting furnace.
d) What key factors determine if a nickel lateritic ore can be processed hydrometallurgically instead of by the reduction and smelting route.
e) Describe schematically a hydrometallurgical flowsheet that can be used to treat nickel rich limonitic laterite ores.

Data:

CO(g) at 1600 °C: ΔG^o = -275 kJ/mol
CO_2(g) at 1600 °C: ΔG^o = -396 kJ/mol
NiO at 1600 °C: ΔG^o = -60 kJ/mol
R = 8.314 J/mol·K = 1.987 cal/mol·K

Problem No. 6(20 marks):

a) Describe the main process units(unit operations) that are used in the treatment of a copper concentrate($CuFeS_2$) to produce metallic copper. Draw a schematic flow diagram(do not include mining and mineral processing)
b) What are some of the properties of the matte(Cu_2S + FeS) and the slag(FeO-Fe_3O_4-SiO_2) produced during smelting. Why is a SiO_2 based flux used?
c) Using pure $CuFeS_2$ as feed, what is the specific amount of sulphuric acid formed (kg H_2SO_4/kg Cu) assuming 95% capture efficiency of SO_2
d) Describe the main process units(unit operations) that are used in the treatment of a oxidic based copper ore(Cu_2O) to produce metallic copper(cathode copper). How does solvent extraction work
e) What are some of the advantages of heap leaching of oxidic copper ores versus sulphide smelting processes. How are the environmental impacts different.

Data: M_{Cu} = 63.5 g/mol, M_S = 32 g/mol, M_O = 16 g/mol, M_H = 1 g/mol

Problem No. 7(20 marks): Construct a predominance area diagram for Zn-S-O system at 1000 K using the following data. Use $\log P_{O2}$ as x-axis and $\log P_{SO2}$ as y-axis.

Reaction	ΔG^{o}(J at 1000 K)
$Zn(l) + 0.5O_2 = ZnO(s)$	-247,000
$Zn(l) + 0.5S_2 = ZnS(s)$	-169,000
$Zn(l) + 0.5S_2 + 2O_2 = ZnSO_4(s)$	-612,000
$0.5S_2 + O_2 = SO_s(g)$	-289,000