

## National Exams

### 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 six pages

Question 1:	(a) 4, (b) 4, (c) 4, (d) 4, (e) 4
Question 2:	(a) 5, (b) 5, (c) 5, (d) 5
Question 3:	(a) 4, (b) 4, (c) 4, (d) 8
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) 10, (b) 5, (c) 5

**Problem No. 1(20 marks):** Use the Ellingham diagram to answer the following questions

- What is  $\Delta G^\circ$ (kJ/mol) of formation of NiO at 1000 °C and what is the equilibrium p-O<sub>2</sub>, CO/CO<sub>2</sub> ratio and H<sub>2</sub>/H<sub>2</sub>O ratio for the Ni/NiO system at 1000 °C
- What is  $\Delta G^\circ$  for the reaction:  $\text{Cr}_2\text{O}_3 + 3\text{Fe} = 2\text{Cr} + 3\text{FeO}$  at 1600 °C. Calculate the equilibrium constant and use that to discuss how any Cr<sub>2</sub>O<sub>3</sub> impurities in the iron blast furnace feed will behave.
- When you want to reduce TiO<sub>2</sub> to metallic Ti at 1600 °C, would you use CO(gas) or coke(solid) as a reductant. Use calculations to justify your answer(s).
- You have to do an experiment that requires a nitrogen gas stream with an oxygen pressure of 10<sup>-20</sup> atm or less to prevent sample oxidation. The nitrogen gas you have available in the lab contains roughly 10<sup>-10</sup> atm oxygen. Describe a method you can use to lower the oxygen pressure to the required value. Explain and justify.
- What CO/CO<sub>2</sub> ratio is required for a gas to reduce solid FeO to a metallic iron alloy with an iron activity of 0.6. The temperature is 800 °C and the activity of the solid FeO is 0.3.

$$R = 8.314 \text{ J/mol}\times\text{K}$$

**Problem No. 2(20 marks):** A copper ore-body with 1.9 wt% Cu in the ore is treated in a mineral processing facility producing a copper concentrate that is basically pure chalcopyrite (CuFeS<sub>2</sub>). The mill(mineral processing facility) has a copper recovery of 93%. The concentrate is then fed to a copper smelter which uses a Outokumpu flash furnace, Peirce Smith converters, anode furnaces followed by casting to copper anodes.

- Describe what unit operations are typically used in such a mineral processing facility.
- Describe what you think are the main emission sources of sulfur to the environment during mineral processing, smelting, converting and refining.(form, roughly how much, what can be done and possible environmental impacts)
- Assuming that the slag leaving the smelter contains 45 wt% iron, how much slag is produced per tonne of copper produced.
- Assuming that in the smelter the copper recovery is 95%, how much ore has to be mined on a daily basis in order to generate copper sales worth 1.0 million dollars per day. The price of copper can be assumed to be 4,500 \$/tonne.

Molecular masses: Cu = 63.5, Fe = 55.8, S = 32.0, O = 16.0 gram/mol

**Problem No. 3(20 marks):** In the recycling of copper scrap, the copper scrap which initially is at 25 °C, is heated and melted in a reverberatory(box) furnace. The furnace is heated by the combustion of natural gas(100 mol% CH<sub>4</sub>) with 25% excess air above the stoichiometric ratio. The natural gas is fed to the furnace at 25 °C and 1.0 atm at a volumetric flowrate of 16 mol/s. The air also enters the furnace at 25 °C. The natural gas is completely combusted and the molten copper as well as the off-gases, leave the furnace at 1150 °C and 1.0 atm. The furnace treats 90 mol/s of copper.

- Draw a schematic diagram of the process.
- Determine the molar flowrate(mol/s) of air to the furnace.
- Determine the theoretical minimum energy(kJ/mol Cu) required to heat up and melt copper at 1150 °C
- What is the energy efficiency of the scrap melting process

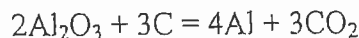
Table of Data

	Molecular Mass g/mole	Standard Enthalpy of Formation (kJ/mole)	Heat Capacity (J/mole·°C)
CH <sub>4</sub> (g)	16	-75	38
H <sub>2</sub> O(g)	18	-242	39
CO <sub>2</sub> (g)	44	-394	51
O <sub>2</sub> (g)	32	0	34
N <sub>2</sub> (g)	28	0	32

Copper: Melting point = 1083 °C,  $\Delta H_{\text{melt}} = 13.01$  kJ/mol

$C_p(\text{solid}) = 22.76 + 0.0061 \times T(\text{K})$ ; J/mol·K;  $C_p(\text{liquid}) = 31.4$ ; J/mol·K

**Problem No. 4(20 marks):** An aluminum electrolytic cell operates with a current density of 7500 Amps/m<sup>2</sup> and a cell voltage of 4.4Volts, and with a current efficiency of 96%. The molecular mass of aluminum is 0.027 kg/mol, the density is 2300 kg/m<sup>3</sup> and Faraday's constant is 96,500 Coulomb/mol. 1 kWhr = 3.6x10<sup>6</sup> J



- how thick a layer of molten aluminum is produced per hour
- what is the specific energy consumption(kWh/kg of Al)
- based on the information available to you(ellingham diagram), estimate the theoretical minimum amount of energy required per kg of aluminum produced and discuss the difference with actual value from part b)
- Determine the minimum specific CO<sub>2</sub> emissions(kg CO<sub>2</sub>/kg Al) assuming that all the carbon from the anode forms CO<sub>2</sub>.
- Describe briefly the Bayer Process

**Problem No. 5(20 marks):** Copper is extracted from a copper oxide ore where the copper content is 1.5 wt%. The ore can be mined as open pit since it is close to the surface.

- Describe briefly an overall flow diagram for a process that can be used to extract copper from this ore body; show the flow of materials
- Describe the solvent extraction process, how it works and why it is used
- What is the rate of copper deposition on the cathode( $\text{mol}/\text{m}^2/\text{second}$ ) assuming that all the copper in the solution is in the form of  $\text{Cu}^{2+}$
- What is the power consumption( $\text{kWhr}/\text{kg Cu}$ ) per unit amount of cathode formed
- Discuss main environmental and energy issues

Data: The Faraday's constant is 96500 Columb/mol. Density of copper =  $8.96 \text{ g}/\text{cm}^3$ , Molecular mass =  $63.55 \text{ g}/\text{mol}$ . The following conditions apply; A) current density  $400 \text{ A}/\text{m}^2$ , B) current efficiency 98%, C) the applied voltage is 2.2 V.

**Problem No. 6(20 marks):** Iron and steelmaking

- Describe briefly the iron blast furnace and its operation
- What are the roles of the various feed materials(solid and gaseous) that enter the blast furnace and how are they pre-treated
- Describe the main principles and purposes of the basic oxygen furnace(BOF) for treating pig iron from the blast furnace
- 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 the other half goes to  $\text{CO}_2$ .
- Can steel scrap be treated in a BOF? What factors affect how much scrap can be treated.

$M_{\text{Fe}} = 55.8 \text{ g}/\text{mol}$ ,  $M_{\text{C}} = 12 \text{ g}/\text{mol}$ ,  $M_{\text{O}} = 16 \text{ g}/\text{mol}$ ,  $M_{\text{Mn}} = 54.9 \text{ g}/\text{mol}$ ,  $M_{\text{Si}} = 28.1$

**Problem No. 7(20 marks):** In the Kivcet process for the production of lead, lead sulphide is oxidized in a reaction shaft to form metallic lead as well as some lead oxide. The PbO is then recovered from the slag by reduction using carbon. Assume the process takes place at 1500 K

- Construct the predominance area diagram for the Pb-O-S system at 1500 K. Use  $\log(P-O_2)$  as x-axis and  $\log(P-SO_2)$  as y-axis, Use a scale from -10 to +5 for both axis.
- Based on the thermodynamic data, explain how/why it is possible to oxidize PbS directly to Pb without much formation of PbO or PbSO<sub>4</sub>
- Describe a process that can be used to refine the lead bullion to pure lead

Thermodynamic Data at 1500 K( $R = 8.314 \text{ J/mol}\times\text{K}$ )

	Species	$\Delta G^0(\text{kJ/mol})$
1	Pb	0.0
2	PbO	-79.0
3	PbS	-36.7
4	PbSO <sub>4</sub>	-350.3
5	O <sub>2</sub> (g)	0.0
6	SO <sub>2</sub> (g)	-252.8

