THE PAPUA NEW GUINEA UNIVERSITY OF TECHNOLOGY

THIRD YEAR MINERAL PROCESSING ENGINEERING

MP344 - PYROMETALLURGY II

SECOND SEMESTER EXAMINATION

FRIDAY 30th OCTOBER 2020 – 12:50 PM

TIME ALLOWED – 3 HOURS

INFORMATION FOR STUDENTS

1. You have 10 minutes to read the paper. You **MUST NOT** begin writing during that time.
2. **Attempt ALL questions.** Write all answers in the answer booklet provided.
3. Write your **NAME** and **STUDENT NUMBER** clearly on the **ANSWER BOOKLET.** Do this **NOW.**

Marking Scheme:

Marks allocated to each question are as indicated. Total mark is 100.

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Question 1

(a) Design a flow sheet to produce 99.9 % Cu from Ok Tedi deposit of copper grade 1 – 2 % Cu. Assays of the tails report 0.1 -0.2 % Cu whilst the Cu concentrate reported 20 – 30 % Cu. Slag to the waste is 0.3 – 1 % Cu with the Cu matte records 50 – 70 % Cu. Hence, slag from the refinery is re - circulated back to the matte smelting. Blister copper assayed 98 % Cu and at the cathodes with 99.5 % Cu. Finally, the waste electrolyte contains Ni, Cr, Co etc. and the noble metals (Au, Ag and Pt) are collected at the anode.

Note: Indicate flow of material, addition of fluxes and air, exit of volatile substances and wastes. Show all processes involved in the flow sheet.

(10 marks)

(b) Study Figure 1.0 and answer the following questions:

i. Assuming Henry's law to be valid within the α and γ phases, estimate the chemical activity of carbon, relative to graphite at 800 °C and 1000 °C as function of composition. (At low concentrations mole fraction may be taken proportional to weight percentage.)

ii. A steel with 0.5 percent C is to be bright annealed at 800 °C in a CO-CO_2 atmosphere. Estimate the gas ratio $(p_{CO})^2/p_{CO_2}$ which would be in equilibrium with the steel, when for the reaction C $_{(graphite)}$ + CO_2 = 2CO the equilibrium constant at 800 °C is 6.0. Estimate the gas composition if $p_{CO} + p_{CO_2} = 0.2\ atm.$

iii. Calculate the Gibbs energy change for the reaction C $_{(graphite)}$ = $\underline{C}$ (1 %) at 800 °C and 1000 °C under the above assumption, and calculate the activity a'_C (relative to 1 % solution) at graphite saturation.

iv. Actually carbon in austenite shows positive deviation from Henry's law in which direction will this affect the values calculated under point in (c)?

v. The addition of silicon is known to increase the activity coefficient of carbon dissolved in iron. How will the addition of silicon affect the solubility limit for graphite in austenite?

vi. For the reaction C $_{(graphite)}$ = C $_{(diamond)}$ ΔG°_{1273}= +7.33 kJ. Estimate the solubility of diamond in austenite at this temperature if graphite is not formed.

(18 marks)

Question 2

(a) Discuss with the aid of a diagram the Blast Furnace operation for pig iron production.

(10 marks)

(b) A steel melt contains 0.9 % C, 1.30 % Si, and 0.10 % S.

i. Calculate the activity a'_S in the melt.

ii. Calculate the gas ratio $\frac{p_{H_2S}}{p_{H_2}}$, at 1600 °C as function of [% S], when for the reaction:-

$$S + H_2 = H_2S \qquad \Delta G^\circ = 41170 + 27.36\,T\ J$$

(10 marks)

Question 3

(a) What is Sievert's law? Describe the relationship between nitrogen pressure and concentration of nitrogen in Figure 2.0 in accordance to Sievert's law.

(6 marks)

(b) Study Figure 3.0 and answer the following questions:

i. Discuss the composition of an acid slag and explain how it produces high viscous melt.

ii. Why are the following properties important in valuing refractory materials?

- Melting point.
- Resistance towards molten slags and metals.
- Resistance to oxidation and reduction.

iii. To melt a slag with 50 % SiO_2, 30 % CaO, and 20 % Al_2O_3 at 1400 to 1500 °C you have a choice between crucibles of silica, mullite, magnesia, and graphite. Which of these crucibles would be your first and which your second choice? Give reasons and explain your answers.

(16 marks)

Question 4

(a) Which furnace/reactor is used for the pyrometallurgical processes listed below? Explain the operation of each of the reactor to process the ore/concentrates.

(b)

i. sulfide ore

ii. zinc & magnesium concentrates

(4 marks)

(c) By means of Stokes' law and viscosity data given in Figure 4.0, calculate the settling velocity of a spherical pig iron droplet of 1 mm diameter in a slag with 60 % SiO_2, 30 % CaO, and 10 % Al_2O_3 at 1450 °C. The densities of iron and slag are taken to be 7.15 and 2.45 g/cm^3 respectively. Remember that 1 poise = 1 g/ (s. cm). Repeat the calculation for 0.1 mm droplets.

Terminal settling velocity of the particle of a stagnant fluid in a laminar region, given by Stokes' law is:-

$$V_t = \frac{(\rho_s - \rho) g d_m^2}{18\mu}$$

Where g = acceleration of gravity, d_m = mean diameter of solid, μ = viscosity of slag

(10 marks)

Question 5

(a) What are the advantages of roast reaction in a matte smelting process?

(6 marks)

(b) The binary systems of Fe - S and Cu – S are showing in Figures 5.0 (a) and 5.0 (b), respectively. Study the binary systems and answer the following questions:

i. As the temperature increases, what happens to the stability of sulfur in the system?

ii. What is happening in the Fe – S system at between temperatures 988 °C and 1365 °C and between 800 °C and 1000 °C?

iii. What are the approximate compositions of iron sulfide and copper sulfide at equilibrium with the metallic phase?

iv. What are two immiscible liquids co-exist between 1105 °C and 1600 °C in the Cu – S system?

(10 marks)

END OF PAPER

DATA SHEET

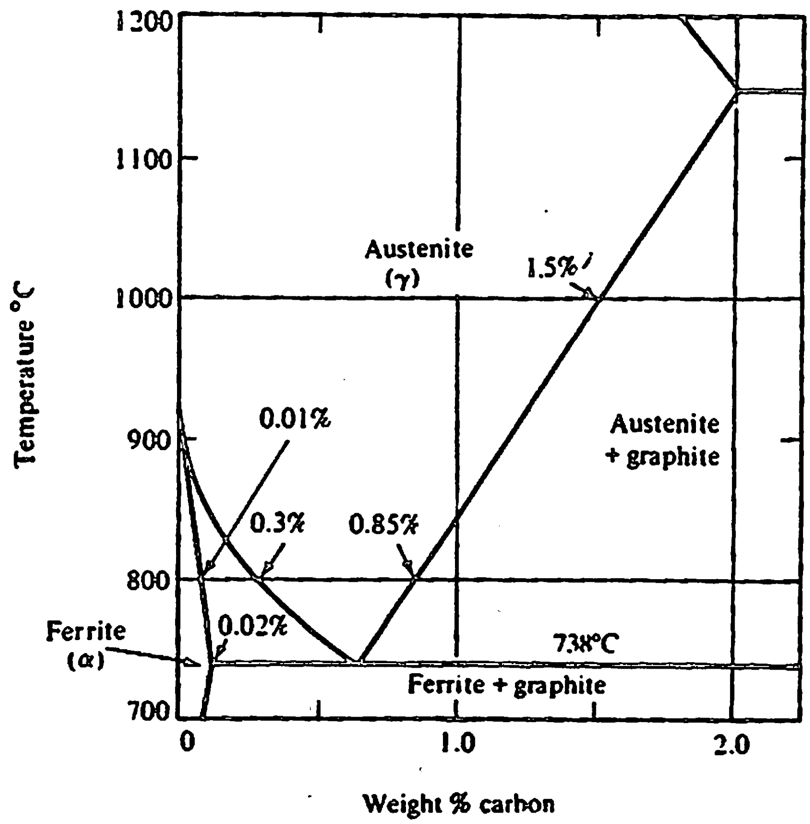

Figure 1.0. The austenite field of the stable iron-graphite phase diagram. Notice the expanded scale for the ferrite (α) field.

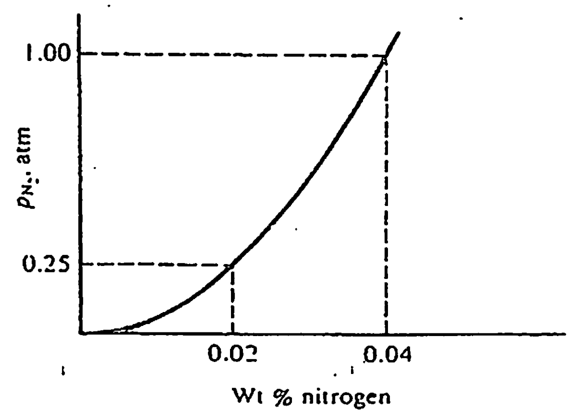

Figure 2.0 Pressure of N_2 in the iron-nitrogen system.

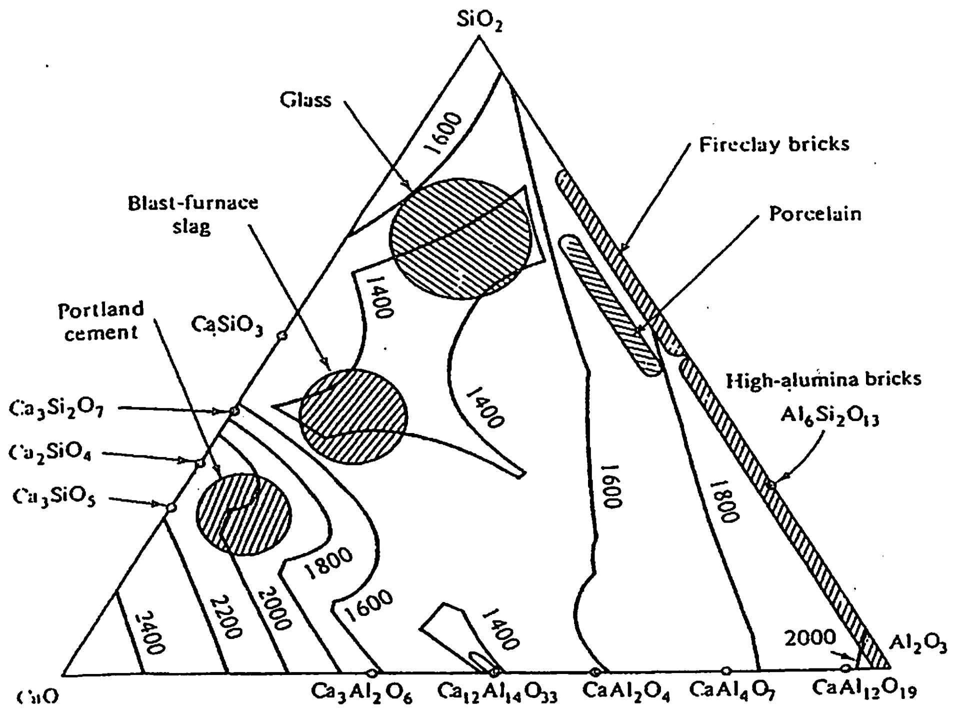

Figure 3.0 Liquidus isotherms in the $SiO_2 - CaO - Al_2O_3$ system

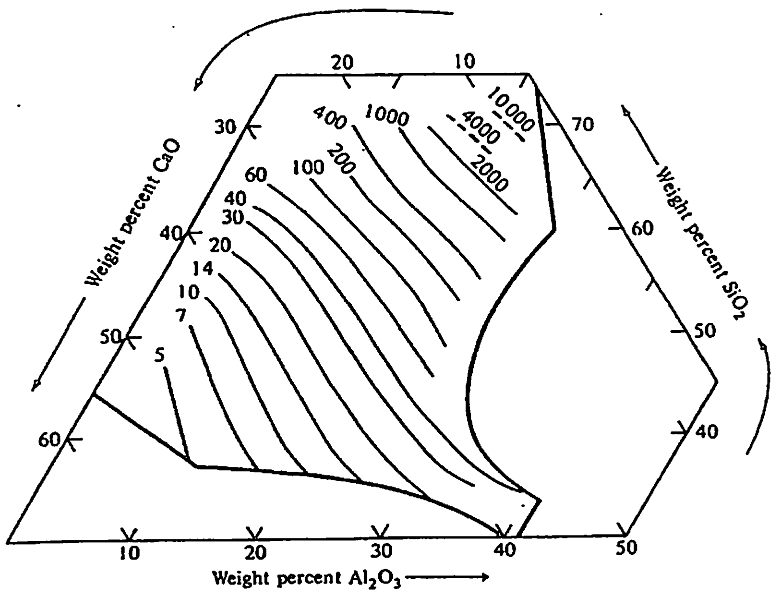

Figure 4.0 Viscosity in poises for SiO_2 – CaO – Al_2O_3 slags at 1450 °C

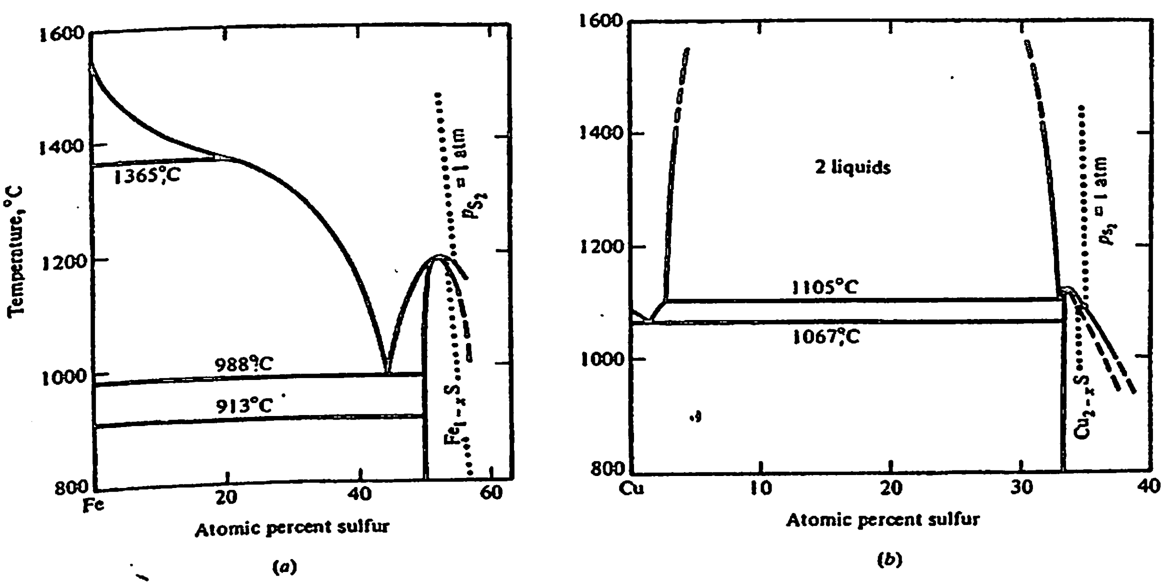

Figure 5.0 (a) Part of the iron-sulfur system. (b) Part of the copper-sulfur system.