
UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session of 2005/2006

November 2005

EBB 522/3 - Corrosion and Protection

Time : 3 hours

Please make sure that this examination paper consists of NINE printed pages before you begin with the exam.

This paper is made up of SEVEN questions.

Answer any FIVE questions. If a candidate answers more than five questions, only the first five answered will be examined and awarded marks.

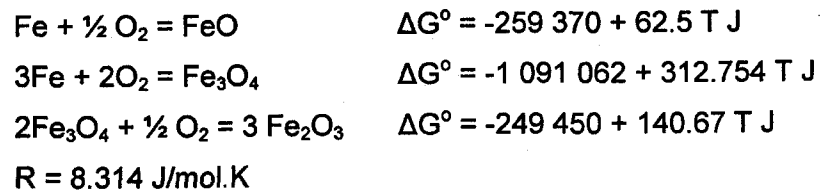
Answer to any question must start on a new page.

All questions should be answered in English.

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1. [a] In a CO/CO₂ atmosphere the partial pressure of oxygen is very low. Above 570°C iron may be oxidized to form either a single FeO layered scale or two layered scales consisting of FeO and Fe₃O₄. Determine the ranges of oxygen partial pressure in every case when the oxidation forms only one layer of FeO and when oxidation forms layers of FeO and Fe₃O₄ at 1000°C.

The following thermodynamics data should be considered:



(60 marks)

- [b] Iron is oxidized in air at 1000°C to form three layered oxide scales of FeO (wustite), Fe₃O₄ (magnetite) and Fe₂O₃ (haematite) [FeO:Fe₃O₄:Fe₂O₃=95:4:1]. Discuss briefly why the growing rate of wustite is much faster than both magnetite and hematite.

(15 marks)

- [c] Write the interfaces reactions which occur during iron oxidation at the temperatures above 570°C.

(15 marks)

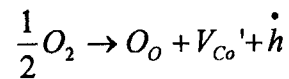
- [d] Suggest the applied temperature range for mild steels when:

- (i) the steels are used for rotary dryer liners and
- (ii) the steels are used for high pressure boiler tubes.

(10 marks)

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2. [a] Oxidation of cobalt to CoO at 950°C is influenced by partial pressure of oxygen (10^{-5} at $\ll p_{O_2} < 1$ at). Most of the defects formation of CoO can be described as:



Establish the relationship between its parabolic rate constant, k'_{Co} , and partial pressure of oxygen, p_{O_2} .

$$k' = \frac{1}{z_c^2 F^2 C_M} \int_{\mu_M}^{\mu_M'} \sigma_c \partial \mu_M \dots \text{cm}^2 \cdot \text{s}^{-1}$$

(30 marks)

- [b] CoO behaves as a p-type metal deficient semiconductor; visualize the defect formation in FeO.

(30 marks)

- [c] Dissolution of a very small amount of Cr_2O_3 in CoO may occur in two ways. Write two possible equilibrium equations of the dissolution of Cr_2O_3 in CoO and visualize the influence of the dissolution to the rate of high temperature corrosion of CoO.

(40 marks)

3. [a] Consider the following volatile species diagram for Cr

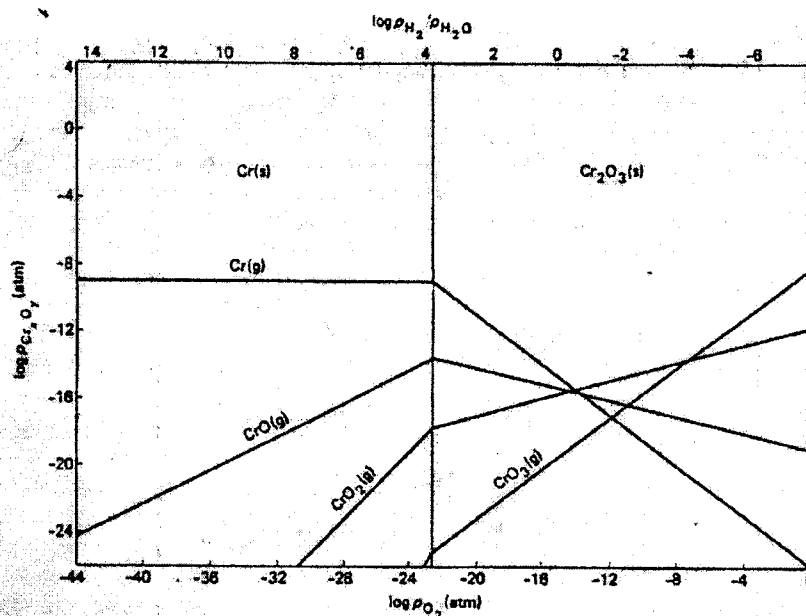


Fig. 2.6 Cr-O system volatile species at 1250 K

Using the following thermodynamics data:

Species	Log K _p (1250K)
Cr ₂ O ₃ (s)	33.95
Cr (g)	-8.96
CrO (g)	-2.26
CrO ₂ (g)	4.96
CrO ₃ (g)	8.64

Derive the equilibrium equations between:

- (i) Cr (g) and Cr₂O₃ (s),
- (ii) CrO (g) and Cr,
- (iii) Cr (s) and Cr₂O₃ (s) and
- (iv) CrO₃ (g) and Cr₂O₃ (s).

(60 marks)

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- [b] One of the most important features of the oxidation of chromium and chromium containing alloys which rely on the protective layer of Cr_2O_3 , is the scale thinning by formation of CrO_3 (g). At 1250K and at under 1at pressure of O_2 , the growth rate of oxide scale formation can be written as:

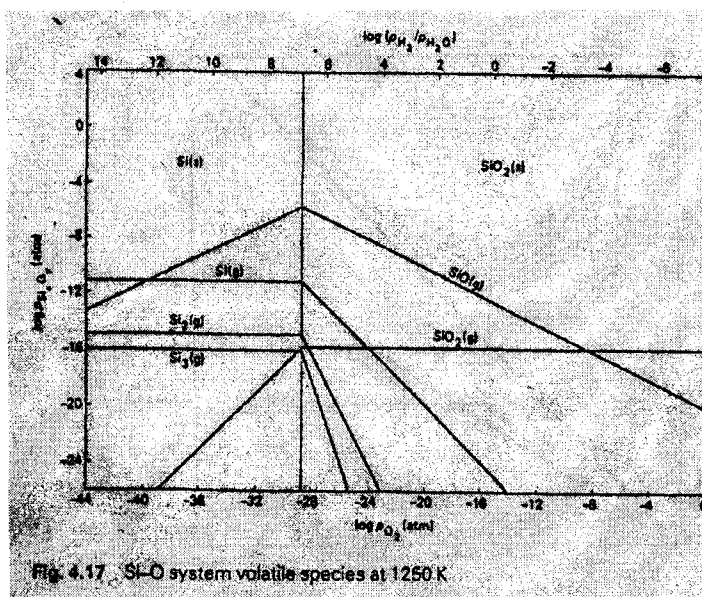
$$\frac{dx}{dt} = \frac{k'_d}{x} - k'_s$$

Draw a schematic diagram which exhibits the relationship between the scale thickness and time at two temperatures 1250K and 1350K (both in one diagram). Then show how to compute the maximum thickness of Cr_2O_3 oxide scale.

(20 marks)

- [c] At high temperatures, silicon can be oxidized to form volatile species. Among of those volatile species, there is one important volatile specie that should be considered. What is it? Catastrophic corrosion of silicon will occur when the p_{O_2} at the surface of silicon lower than the critical partial pressure of oxygen. Describe how to compute this critical p_{O_2} pressure. Discuss briefly the differences between the formation of volatile species of chromium and silicon.

(20 marks)



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4. [a] During decarburization of a carbon steel containing 0.4%C at 950°C, the carbon concentration profile at the surface of a semi-infinite slab can be obtained by solving Fick's second law $\frac{\partial C_c}{\partial t} = D_c \frac{\partial^2 C}{\partial x^2}$. By assuming diffusion coefficient of carbon, D_c , is constant, the general solution of this equation applied for semi infinite slab is $C_c = A + B \operatorname{erf} [x/2(D_c t)^{1/2}]$, where A and B are the constants. The carbon steel is heating in CO-CO₂ atmosphere which is in equilibrium with 0.01%C. How thick will the decarburization layer be?

$$D_c = 24.6 \exp (-17540/T) \text{ mm}^2\text{s}^{-1}.$$

(70 marks)

- [b] Discuss briefly the effect of scaling rate on decarburization of the steel in an oxidizing atmosphere.

(15 marks)

- [c] Decarburization layer of steels which are occur in reducing atmosphere, may consist of two layers of alpha and gamma phases. Discuss briefly when this type of decarburization occurs.

(15 marks)

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5. [a] Calculate the CO-CO₂ atmosphere composition which is required to prevent oxidation and decarburization of steel containing 0.8% C. You may use the following thermodynamics data in your computation:

$$\log a_c = \log [X_c/(1-5X_c)] + 2080/T - 0.64$$



where X_c is the mole fraction of C in the steel and $R = 8.314 \text{ J/mol.K}$.

(60 marks)

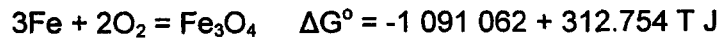
- [b] The affinity of chromium to react with carbon to form chromium carbide is much higher than iron. Therefore oxidation and carburization prevention of chromium cannot be conducted in CO-CO₂ atmosphere. Discuss which typical atmosphere should be maintained to avoid oxidation and decarburization of stainless steels during their softening (annealing) processes.

(20 marks)

- [c] Metal dusting is a catastrophic carburization. This high temperature corrosion may occur on a stainless steel used as high temperature material (i.e. HK 40). Describe briefly the mechanism of metal dusting on HK 40 and suggest how to decrease the susceptibility of this material against metal dusting attack.

(20 marks)

6. [a] Construct from the following thermodynamic data:



the iron-sulfur-oxygen phase diagram at 900°C. Then explain how the duplex scales can be formed on the iron.

(75 marks)

- [b] Gives at least three reasons why the degradation of metals due to sulfidation is usually worse than the degradation of metals due to oxidation. Explain briefly why the high temperature corrosion rate of iron which forms duplex oxide-sulfide scales is higher than its oxidation rate.

(25 marks)

7. [a] Describe briefly the differences between low activity pack aluminizing and high activity pack aluminizing. Which one do you recommend to be applied for coating jet turbine blades? Justify your answer.

(30 marks)

- [b] Explain why chromo-aluminizing is preferable to increase the hot corrosion resistance of turbine blades?

(20 marks)

- [c] Generally efficiency of turbine will increase with the temperature. However the temperature inside turbine will be limited with the turbine components materials that can be produced. Discuss briefly which coating processes should be performed to produce turbine blades which can be used at the temperature about 1250°C.

(20 marks)

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- [d] Describe briefly the differences between basic fluxing and acid fluxing during hot corrosion of metal. Your descriptions should contain examples of the mechanisms of hot corrosion of nickel caused by basic fluxing and caused by acid fluxing.

(30 marks)