



**GWANDA STATE UNIVERSITY**  
**FACULTY OF ENGINEERING AND THE ENVIRONMENT**  
**DEPARTMENT OF METALLURGICAL ENGINEERING**  
**CORROSION ENGINEERING**  
**EMG3208**  
**Part III Examination Paper**  
**APRIL 2025**

This examination paper consists of 6 printed pages

**Time Allowed: 3 hours**

**Total Marks: 100**

**Examiner : S Maphosa**

**INSTRUCTIONS**

- 1. Answer any 4 questions**
- 2. Each question carries 25 marks**

**ADDITIONAL MATERIALS**

- 1. Calculator**
- 2. Data booklet**

### Question 1

- a) Explain the effect of temperature on atmospheric corrosion of steel. [3]
- b) List and explain three metallurgical processes that can lead to the formation of corrosion cells. [6]
- c) It is important to be able to recognize galvanic corrosion. In the following list of cases, explain whether galvanic corrosion is a probable cause of the corrosion.
  - i) Steel rivets in aluminum drain gutters leak after 2 years of service. [2]
  - ii) Aluminum drain plug in a steel automotive oil pan leaks one month after installation.[2]
  - iii) Testing of unconnected aluminum, copper, and steel specimens exposed in a laboratory reactor shows accelerated corrosion of aluminum. [2]
  - iv) Graphite fiber reinforced aluminum composite specimens show delamination of the fiber after exposure to a salt spray test. [2]
  - v) Carbon steel pipe leaks near the weld to stainless steel pipe of nearly the same diameter [2]
- d) Consider a pipeline made of high strength 316 stainless steel, carrying a flow of sea water to a desalination plant. One part is encased in concrete, running into the sea. The rest is buried in moist soil , running into the plant. At the plant it is connected via bolted carbon steel flanges to an electrical pump. The pump housing is a casting in naval brass.
  - i) Is stress corrosion likely in your opinion? Explain your answer.[3]
  - ii) What other types of corrosion maybe expected in this situation, what could be done to manage each problem. ( match type of corrosion expected to remedy) [3]

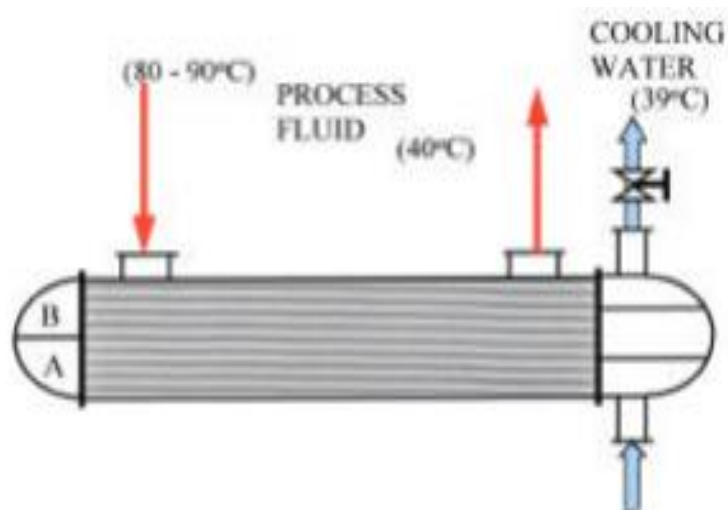
### Question 2

- a) Make a sketch for the underdeposit pitting corrosion of copper in hard waters. Include in your sketch the composition and morphology of all deposits and the flow of all charge carriers. [10]

- b) In May 2000, a concrete pedestrian walkway collapsed in North Carolina, injuring more than 100 people. Investigation revealed that  $\text{CaCl}_2$  had been mixed into the grout that filled the holes around the steel reinforcing cables inside the concrete, resulting in corrosion of the cables, thus weakening the structure. Based on your understanding of corrosion, explain why the use of chloride compounds in steel-reinforced concrete is discouraged by the concrete industry [5]
- c) Briefly state and describe five requirements that are necessary in the design of anodic protection systems [10]

### Question 3

- a) Differentiate between activation polarisation and concentration polarisation
- b) A sample of zinc corrodes uniformly with a current density of  $4.2 \times 10^{-6} \text{ A/cm}^2$  in an aqueous solution.
- What is the corrosion rate of zinc in  $\text{mg/dm}^2$ ? [4]
  - What is the corrosion rate of zinc in  $\text{mm/year}$ ? [4]
- c) The cooler shown below in **Figure 1** for diluted ammonia carbamate solutions from a urea plant has the features presented in Table 1:



**Figure 1: Cooler**

*Ammonia carbamate solution cooler characteristics*

| Characteristic                        | Tube side | Shell side |
|---------------------------------------|-----------|------------|
| Number of passes                      | 4         | 1          |
| Metallurgy                            | 304L      | MS         |
| Number of tubes                       | 228       | -          |
| Cooling water velocity, m/s           | 0.85      | -          |
| Cooling water flow, m <sup>3</sup> /h | 86        | -          |
| Capacity, m <sup>3</sup>              | 0.742     | 0.991      |
| Maximal pressure, MPa                 | 0.5       | 1.8        |
| Tube OD x thickness, mm               | 25 x 1.6  |            |
| Tube length, mm                       | 7890      |            |

**Table 1: ammonia carbamate cooler features**

At a yearly shutdown, large amounts of tubercles (small round mounds of corrosion products) and mud were found in the “A” area of the water turning end of the heat exchanger cooler. The separating wall from that end being in contact with the tube sheet is made of 304L stainless steel as the tube sheet was found to be severely corroded, its thickness being reduced from 5mm to 2mm. No repair was made to the wall but an insulating asbestos gasket was fitted between the water turning and the tube sheet. After another year of operating in inhibited cooling water (128mg/L chlorides, 228mg/L sulphates, 1500µS/cm conductivity, pH 7,9) the corrosion of the separation wall was found to have been accentuated.

- i) Explain what caused the initial corrosion of the separating wall and further corrosion after installation of the asbestos gasket. [7]
- ii) As an engineer what precautions, measures would you take with the given cooler design to minimise corrosion [10]

**Question 4**

- a) Explain the following terms as used in corrosion engineering
  - i) Exchange current density [2]
  - ii) Standard cell potential [1]
- b) Convert 0.122 mg/mm<sup>2</sup> /second to mm/year. [3]
- c) A steel coupon with an anode surface area of 1000 cm<sup>2</sup> is placed in an electrolyte. The corrosion current is measured to be 1 mA.

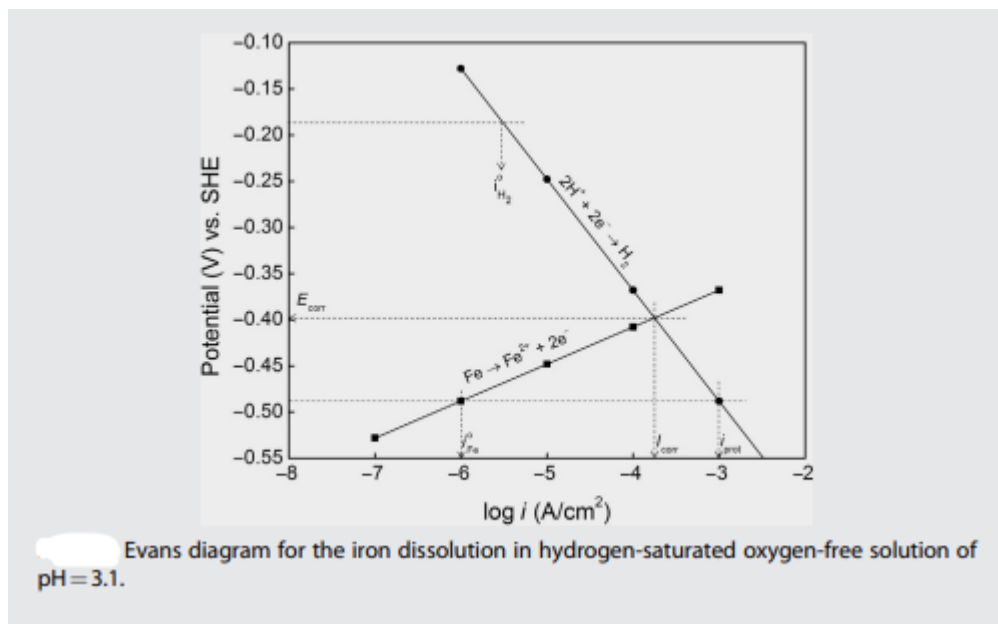
- i) What mass of steel will be lost in 6 hours? [5]
- ii) What is the corrosion rate in  $\mu\text{g}/\text{cm}^2/\text{day}$ ? In mpy? Assume valence of 2. [6]
- d) Calculate the driving emf for the following reaction.

$\text{Pt}||\text{Fe}^{3+} (\text{activity} = 0.1), \text{Fe}^{2+} (\text{activity} = 0.001), \text{Zn}^{2+} (\text{activity} = 0.01) || \text{Zn}$   
 The iron redox reaction is assumed to be the cathode.

[8]

### Question 5

- a) Any coating that keeps a part free from environments that can cause rust can help reduce corrosion. What must paint manufacturers do to produce a paint that is specifically designed to help prevent corrosion?[4]
- b) Calculate also using Evans diagram below



- i) the corrosion rate of iron in an oxygen-free solution at a pH of 3.1 [5]
- ii) the exchange current density for hydrogen evolution on iron [3]
- iii) the cathodic current required to reduce the corrosion of iron to zero. The concentration of the iron at the electrode interface is 0.02 M. The exchange current density for iron dissolution is  $i^0_{\text{Fe}} = 9 \times 10^{-7} \text{ A}/\text{cm}^2$  and the anodic slope  $b_a = 0.04 \text{ V}/\text{decade}$ ; the corrosion potential of iron is 0.215 V vs. RHE and

$E^{\circ}_{\text{Fe}^{2+}/\text{Fe}}=0.44\text{V}$  vs: SHE. For hydrogen evolution reaction (HER), the cathodic slope  $b_c=0.12$  V/decade. The required quantities can be obtained from the Evans diagram for the corrosion of iron in hydrogen-saturated, oxygen-free solution. Assume that charge-transfer kinetics controls the reaction rates and that the high-field approximation applies.[7]

- c) State THREE specific parameters determine whether the mixed potential is close to the equilibrium value of the anode reaction or the cathode reaction.[3]
- d) Under what conditions is a corroding system cathodically controlled [3]