UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**CEB4022 - MATERIAL SCIENCE FOR CHEMICAL ENGINEERING**
DATE	**:**	**31 JULY 2024 (WEDNESDAY)**
TIME	**:**	**2.30 PM - 4.30 PM (2 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **EIGHT (8)** pages in this Question Booklet including the cover page and appendix.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. As a chemical engineer, you are tasked with selecting material for constructing a chemical reactor that will be used for the production of a highly corrosive acid at elevated temperatures. The material must withstand corrosive environments, high temperatures, and provide mechanical strength. **TABLE Q1** summarizes the relevant properties of four potential materials. Evaluate the suitability of each material for the chemical reactor by discussing the implications of each property. Provide a recommendation for the best material and justify your choice.

TABLE Q1: Mechanical properties of selected engineering materials and their applications

Properties	Stainless Steel	Hastelloy	Teflon (PTFE)
Corrosion Resistance	Moderate	High	Very High
Maximum Operating Temperature (°C)	600	1200	260
Tensile Strength (MPa)	485	690	23
Thermal Conductivity (W/m-K)	16	11	0.25
Cost (RM/kg)	5	30	15

[17 Marks]

b. **FIGURE Q1** represents the eutectic phase diagram of Mg-Pb alloy system. A 60 wt% Mg–40 wt% Pb alloy is slowly cooled to a temperature within the α + L phase. If the composition of the liquid phase is 55 wt% Pb, estimate:

i. The temperature at which the first solid is formed.

[2 marks]

ii. The composition of the α phase.

[2 marks]

iii. The mass fraction of the α and L phases and the temperature at which the liquid solidifies.

[4 marks]

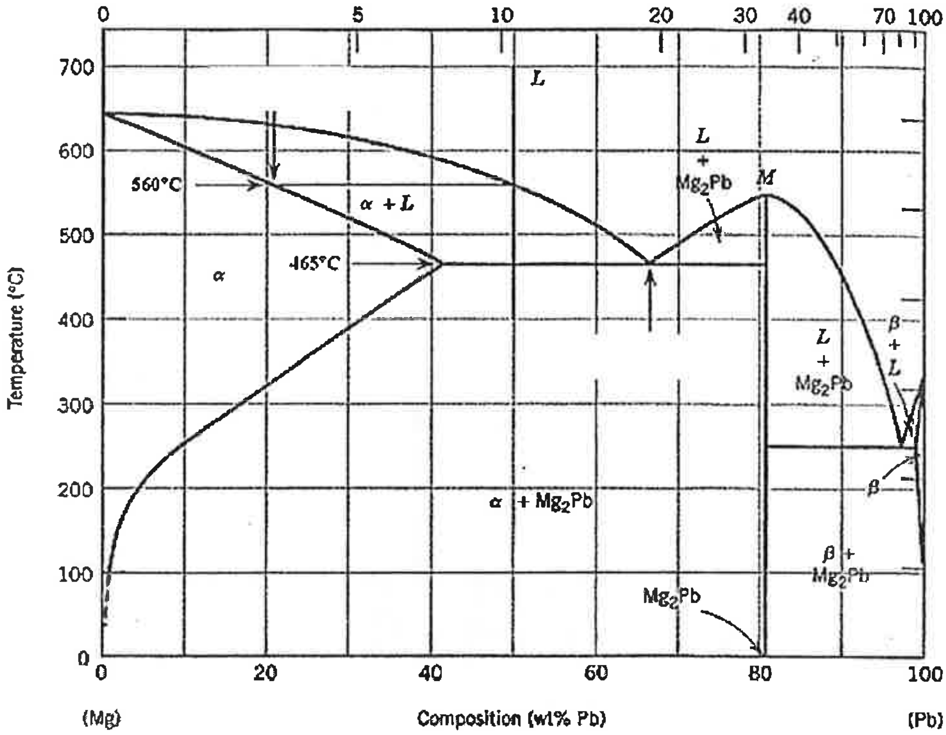

FIGURE Q1: Phase diagram of Mg-Pb alloy system

2. a. A cylindrical steel rod with a diameter of 10 mm and a gauge length of 50 mm is subjected to a tensile test. During the test, the rod is elongated by 0.2 mm when a load of 20000 N is applied. Calculate the Young Modulus of the steel rod.

[9 Marks]

b. A heat exchanger in a chemical plant needs to be designed to transfer heat from a hot fluid at 150°C to a cold fluid at 50°C. The heat exchanger needs to transfer a minimum of 5000 kW/m^2 given that the tube wall thickness is 15 mm. Copper, Tungsten, 1025 Steel and Brass have been suggested as potential materials for the heat exchanger. Propose with justifications the best out of the suggested materials. Refer to **APPENDIX 1** for the properties of the selected materials.

[16 Marks]

3. a. Chemical looping reforming of methanol is a process that involves the conversion of methanol to hydrogen and carbon dioxide using a solid oxygen carrier. A potential solid oxygen carrier is CeO_2 which can be produced from thermal decomposition of Cerium (III) nitrate hexahydrate ($Ce(NO_3)_3 \cdot 6H_2O$). The thermogravimetric analysis (TGA) of the (Ce $(NO_3)_3 \cdot 6H_2O$) is represented by curve A in **FIGURE Q3**.

i. Show using appropriate equations the possible thermal events corresponding to each weight loss stage during the TGA analysis (line A) of the Ce $(NO_3)_3 \cdot 6H_2O$.

[8 Marks]

ii. Explain the possible causes and recommend what should be done assuming there is a sudden increase in the TGA curve indicated by point C on line B of **FIGURE Q3**.

[2 Marks]

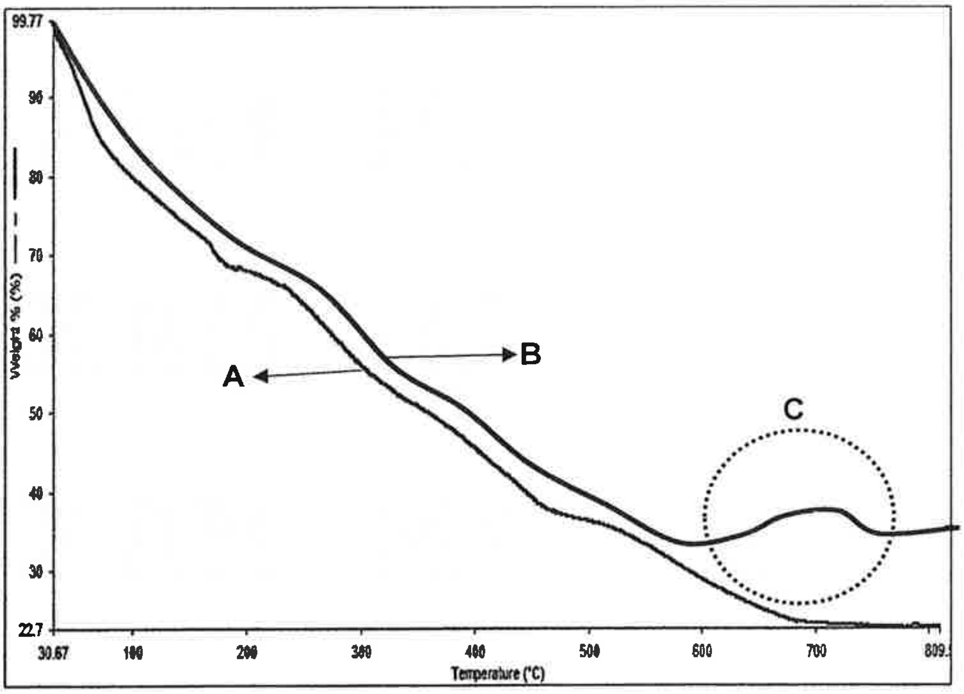

FIGURE Q3: Thermogravimetric analysis of ($Ce(NO_3)_3 \cdot 6H_2O$)

b. It is required to further probe the properties of the CeO_2 produced in **part (a).** Examine appropriate characterization techniques that can be used to determine the crystallinity, microstructure, morphology and surface area of the CeO_2.

[15 Marks]

4. a. It is required to design a new reactor vessel for a chemical processing plant that will be used to process a highly corrosive acidic solution containing sulfuric acid (H_2SO_4) at a concentration of 60% by weight. The operating temperature of the reactor will be 90°C. The material engineer is considering the materials in **TABLE Q4** for the construction of the reactor vessel which is projected to have an area of 400 cm^2. Examine the suitability of each material based on their corrosion rates assuming the materials will be used for one-year. Make a recommendation for the best material choice and justify your decision.

TABLE Q4: Properties of proposed materials

Materials	Density (g/cm^3)	Weight loss (g)/year	Cost (RM)/cm^2
Stainless Steel 304	7.93	700	185
Stainless steel 316	7.87	720	200
Titanium	4.51	620	165
Carbon steel	7.84	750	190

[16 Marks]

b. Propose and explain **THREE (3)** ways the selected best material in **part (a)** can be prevented from corrosion.

[9 Marks]

- END OF PAPER –

APPENDIX 1

TABLE A1: Thermal parameters of selected materials

Material	c_p $(J/kg\cdot K)^a$	α_l $[(^\circ C)^{-1} \times 10^{-6}]^b$	k $(W/m\cdot K)^c$	L $[\Omega\cdot W/(K)^2 \times 10^{-8}]$
		Metals		
Aluminum	900	23.6	247	2.20
Copper	386	17.0	398	2.25
Gold	128	14.2	315	2.50
Iron	448	11.8	80	2.71
Nickel	443	13.3	90	2.08
Silver	235	19.7	428	2.13
Tungsten	138	4.5	178	3.20
1025 Steel	486	12.0	51.9	—
316 Stainless steel	502	16.0	15.9	—
Brass (70Cu–30Zn)	375	20.0	120	—
Kovar (54Fe–29Ni–17Co)	460	5.1	17	2.80
Invar (64Fe–36Ni)	500	1.6	10	2.75
Super Invar (63Fe–32Ni–5Co)	500	0.72	10	2.68
		Ceramics		
Alumina (Al_2O_3)	775	7.6	39	—
Magnesia (MgO)	940	13.5^d	37.7	—
Spinel ($MgAl_2O_4$)	790	7.6^d	15.0^e	—
Fused silica (SiO_2)	740	0.4	1.4	—
Soda–lime glass	840	9.0	1.7	—
Borosilicate (Pyrex) glass	850	3.3	1.4	—
		Polymers		
Polyethylene (high density)	1850	106–198	0.46–0.50	—
Polypropylene	1925	145–180	0.12	—
Polystyrene	1170	90–150	0.13	—
Polytetrafluoroethylene (Teflon)	1050	126–216	0.25	—
Phenol-formaldehyde, phenolic	1590–1760	122	0.15	—
Nylon 6,6	1670	144	0.24	—
Polyisoprene	—	220	0.14	—