UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF CHEMICAL AND BIOENGINEERING TECHNOLOGY

FINAL EXAMINATION
OCTOBER 2025 SEMESTER

COURSE CODE	:	CCB 31602
COURSE NAME	:	REACTION ENGINEERING 2
PROGRAMME NAME	:	BACHELOR OF CHEMICAL ENGINEERING WITH HONOURS
DATE	:	27 JANUARY 2026
TIME	:	2:00 PM – 5:00 PM
DURATION	:	3 HOURS

INSTRUCTIONS TO CANDIDATES

1. Please read the instructions given in the question paper CAREFULLY.
2. This question paper is printed on both sides of the paper.
3. This question paper contains of FOUR (4) questions. Answer ALL questions.
4. Please write your answers on the answer booklet provided.
5. Please answer all questions in English only.

THERE ARE 4 PAGES OF QUESTIONS AND APPENDIX, EXCLUDING THIS PAGE.

Total: 100 marks

Answer ALL questions.
Please use the answer booklet provided.

Question 1

(a) A heterogeneous catalytic process takes place across multiple phases, typically involving a solid catalyst while the reactants and products are in either liquid or gaseous form. Identify the sequence of steps involved in a heterogeneous catalytic reaction.

(7 marks)

(b) Product C is obtained by the gas-phase reaction over a solid catalyst based on the reaction mechanism as follows:

$$A + S \leftrightarrow A \cdot S$$
$$A \cdot S + B \leftrightarrow C \cdot S$$
$$C \cdot S \leftrightarrow C + S$$

Derive a rate law for this catalytic reaction if the surface reaction is the rate-limiting step.

(18 marks)

Question 2

A gas-phase reaction 2A $\rightarrow$ B + C is carried out isothermally in a packed bed reactor (PBR) with diameter of 1.5 m, operating at 300°C with an initial pressure of 300 kPa. An inlet gas stream of pure A with the density and viscosity of 1.6 kg m^{-3} and 5.12 x 10^{-6} kg m^{-1} s^{-1}, respectively, enters the PBR at 30 mol s^{-1}. The packed bed, which has a void fraction of 0.35, is composed of catalyst particles with a density of 1,250 kg m^{-3} and a diameter of 0.12 cm. Calculate the catalyst weight (in kg) if the pressure drop in the packed bed is expected to be 80 kPa.

(25 marks)

Question 3

An isothermal gas-phase reaction of methane and chlorine: $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ is carried out in a packed bed reactor (PBR) at a temperature of 850°C and a pressure of 12 atm. The reactor contains a packed bed with a length of 6.5 m and a void fraction of 0.38. It is packed with cubic catalyst particles, each having a side length of 1.5 cm and a density of 1050 kg m^{-3}. An equimolar feed of methane and chlorine gas enters the reactor at a velocity of 2.0 m s^{-1}. The gas mixture has a kinematic viscosity of 7.2×10^{-5} m^2 s^{-1}, a density of 290 g m^{-3}, and a diffusivity of 2.8×10^{-7} m^2 s^{-1}. Assuming the reaction is limited by external mass transfer and that pressure drop is negligible, calculate the conversion of methane.

(25 marks)

Question 4

A gas-phase reaction A $\rightarrow$ B is conducted isothermally in a packed bed reactor (PBR) operating at a temperature of 520°C and an inlet pressure of 450 kPa. The feed stream contains 90 mol% species A and the rest as inert, with a total molar flow rate of 48 mol s^{-1}. The reactor is packed with spherical catalyst particles that have a diameter of 0.4 cm, a bulk density of 1200 kg m^{-3}, and a bed void fraction of 0.36. The specific reaction rate is given as 1.6×10^{-4} m^3 kg^{-1} s^{-1}, and the effective diffusivity is 1.0×10^{-8} m^2 s^{-1}.

(a) Verify that the reaction is limited by internal diffusion using the Weisz–Prater criterion.

(8 marks)

(b) Determine the conversion of A and the mass of catalyst (in kg) required to generate 50 mol m^{-3} of product B.

(17 marks)

END OF EXAMINATION PAPER

Appendix:

List of Equations

$$F_{A0}\frac{dX}{dW} = -r'_A$$

$$W = F_{A0}\int_0^X \frac{dX}{-r'_A}$$

$$-r_A = \rho_b\left(-r'_A\right) = \rho_b S_a\left(-r''_A\right)$$

$$k = \rho_b\left(k'\right) = \rho_b S_a\left(k''\right)$$

$$G = \rho U = \frac{\dot{m}}{A_c}$$

$$\varepsilon = y_{A0}\delta$$

$$C_{A0} = \frac{y_{A0}P_0}{RT_0}$$

$$C_{A0} = \frac{F_{A0}}{v_0}$$

$$\beta_0 = \frac{G(1-\phi)}{\rho_0 g_c D_p \phi^3}\left[\frac{150(1-\phi)\mu}{D_p} + 1.75G\right]$$

$$\alpha = \frac{2\beta_0}{A_c(1-\phi)\rho_c P_0}$$

$$\frac{P}{P_0} = (1-\alpha W)^{1/2}$$

$$\frac{P}{P_0} = \left(1-\frac{2\beta_0 z}{P_0}\right)^{1/2}$$

$$\frac{k_c d_p}{D_{AB}}\left(\frac{\phi}{1-\phi}\right)\frac{1}{\gamma} = \left[\frac{Ud_p}{\nu(1-\phi)\gamma}\right]^{\frac{1}{2}}\left[\frac{\nu}{D_{AB}}\right]^{\frac{1}{3}}$$

$$\Omega = \frac{\eta}{1+\dfrac{\eta k_1}{k_c a_c}}$$

$$\ln\frac{1}{1-X} = \frac{k_c a_c}{U}L$$

$$L = \frac{-U\ln(1-X)}{k_1\Omega}$$

$$v = v_0(1+\varepsilon X)\frac{P_0}{P}\frac{T}{T_0}$$

$$a_c = \frac{6(1-\phi)}{d_p}$$

$$\frac{C_A}{C_{A0}} = \exp\left(-\frac{k_c a_c}{U}z\right)$$

$$C_{Ab} = C_{Ab0}\exp\left[-\frac{\Omega k_1 z}{U}\right]$$

$$d_p = \left(\frac{6}{\pi}V\right)^{\frac{1}{3}}$$

$$\gamma = \frac{\text{External Surface Area}}{\pi d_p^{\,2}}$$

$$\lambda = \frac{r}{R}$$

$$\psi = \frac{C_A}{C_{As}}$$

$$\psi = \frac{1}{\lambda}\left[\frac{\sinh(\phi_1\lambda)}{\sinh\phi_1}\right]$$

$$\eta = \frac{3}{\phi_1^{\,2}}\left(\phi_1\coth\phi_1 - 1\right)$$

$$MR = \frac{-r'_A\rho_b Rn}{k_c C_{Ab}}$$

$$C_{WP} = 3(\phi_1\coth\phi_1 - 1)$$

$$A_c = \frac{\pi D^2}{4}$$

$$F_{Az} = W_{Az} A_c$$

$$W_{Az} = -D_{AB}\frac{dC_A}{dz} + C_A U$$

$$U = \frac{v_0}{A_c}$$

$$Sh' = 1.0(\text{Re}')^{1/2}(Sc)^{1/3}$$

$$Sh = 2 + 0.6\,\text{Re}^{1/2}\,Sc^{1/3}$$

$$Sh = \frac{k_c d_p}{D_{AB}}$$

$$Sc = \frac{\nu}{D_{AB}}$$

$$W = \rho_b A_c z = \rho_c (1-\phi) A_c z$$

$$W_{Az} = k_c (C_{Ab} - C_{As})$$

$$\text{Re} = \frac{\rho d_p U}{\mu} = \frac{d_p U}{\nu}$$

$$\coth(x) = \frac{\cosh(x)}{\sinh(x)} = \frac{e^x + e^{-x}}{e^x - e^{-x}}$$

$$X = 1 - \exp\left[-\frac{k_1 \Omega L}{U}\right]$$

$$W = \frac{v_0}{\Omega k_1'}\ln\frac{1}{1-X}$$

$$X = \frac{\dfrac{kC_{Ao}W}{v_0}\left(1-\dfrac{\alpha W}{2}\right)}{1+\dfrac{kC_{A0}W}{v_0}\left(1-\dfrac{\alpha W}{2}\right)}$$

$$W = \frac{1-\left\{1-\left[\dfrac{2v_0\alpha}{kC_{A0}}\right]\left[\dfrac{X}{1-X}\right]\right\}^{1/2}}{\alpha}$$

$$\phi_1 = R\sqrt{\frac{k_1}{D_e}} = R\sqrt{\frac{k_1'\rho_b}{D_e}} = R\sqrt{\frac{k_1''\rho_b S_a}{D_e}}$$

$$1\,Pa = 1\frac{N}{m^2} = 1\frac{kg}{m \cdot s^2}$$

$$R = 8.314\frac{J}{mol \cdot K} = 8.314\times10^{-3}\frac{kPa \cdot m^3}{mol \cdot K} = 8.206\times10^{-5}\frac{atm \cdot m^3}{mol \cdot K} = 8.314\times10^{-5}\frac{bar \cdot m^3}{mol \cdot K}$$