



SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: JUNE 2025

COURSE AND CODE: APPLIED REACTOR TECHNOLOGY

ENCH4RT

DURATION: 2 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINERS: PROF D LOKHAT

INTERNAL MODERATOR: DR NM MKHIZE

EXTERNAL MODERATOR: MR M BOTHA

INSTRUCTIONS:

1. **ALL** questions should be attempted.
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. **Blank diagrams are provided on pages 4, 5 and 6. Remove these pages and submit with your answer booklet.**

QUESTION 1

The oxidation of sulphur dioxide is carried out over a V_2O_5 catalyst in a multi-bed adiabatic reactor system with interstage cooling. The feed rate is $2 \text{ kmol}\cdot\text{s}^{-1}$ containing 15% SO_2 (by volume) in air ($O_2:N_2 = 21:79$ by volume) at 450°C .

a) Determine the conversion in a three-bed reactor system. The exit points of each bed lie on the equilibrium curve, and you may begin adiabatic operating lines from the locus of maximum rates. A blank reaction rate plot is provided on **page 4** of this question paper. PLEASE DETACH AND HAND IN WITH YOUR ANSWER BOOKLET. INCLUDE YOUR STUDENT NUMBER.

(15)

b) Repeat part a) but using a 20°C temperature approach to equilibrium. Report the conversion. A blank reaction rate plot is provided on **page 5** of this question paper. PLEASE DETACH AND HAND IN WITH YOUR ANSWER BOOKLET. INCLUDE YOUR STUDENT NUMBER.

(10)

c) Explain, using necessary equations, why the scenario in part b) is more practical than in part a).

(5)

TOTAL /30/**Additional data and equations:**

$$\bar{C}_{p,SO_2} = 59.7 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$$

$$\bar{C}_{p,O_2} = 39.4 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$$

$$\bar{C}_{p,N_2} = 32.2 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$$

$\Delta H_{rxn} = -96 \text{ kJ}\cdot\text{mol}^{-1}$ (based on SO_2 , $\Delta \hat{C}_p \approx 0$ and the heat of reaction may be assumed constant)

$$X = \frac{\sum_{i=1}^n \theta_i \bar{C}_{p_i} (T - T_0)}{-\left[\Delta H_{rxn}^\circ (T_{ref}) + \Delta \hat{C}_p (T - T_{ref}) \right]}$$

QUESTION 2

An ammonia synthesis unit processes a gas mixture containing predominantly hydrogen and nitrogen ($H_2:N_2 = 3:1$) and 15 mol% inerts, using multiple beds and cold-shot cooling. The cold feed is preheated from 25 °C to 500°C, before it enters the first bed of the reactor. The feed flowrate to the first bed is $50 \text{ kmol} \cdot \text{s}^{-1}$. The catalyst is in the form of spheres, with a particle density of $2000 \text{ kg} \cdot \text{m}^{-3}$ (the particle density is the density of the pellet, not the bulk density of the bed).

a) Determine the number of beds required for an exit ammonia mole fraction of at least 0.1. You can assume a 30 °C approach to equilibrium and adiabatic lines beginning at the locus of maximum rates. A blank reaction rate plot is provided on **page 6** of this question paper. Note the rate is given with respect to NH_3 and on a volume basis. PLEASE DETACH AND HAND IN WITH YOUR ANSWER BOOKLET. INCLUDE YOUR STUDENT NUMBER.

(35)

b) Determine the quench flowrate at the exit of the first bed.

(10)

c) Determine the mass of catalyst in the first bed. You may assume a constant average reaction rate.

(10)

Available data:

$$\begin{aligned} \bar{C}_{p,H_2} &= 20 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1} & \bar{C}_{p,NH_3} &= 30 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1} & \bar{C}_{p,I} &= 25 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1} \\ \bar{C}_{p,N_2} &= 22 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1} \end{aligned}$$

$$\Delta H_{rxn} = -95 \text{ kJ} \cdot \text{mol}^{-1} \text{ (per mole of } N_2; \text{ can be approximated as constant)}$$

$$X = \frac{\sum_{i=1}^n \theta_i \bar{C}_{p_i} (T - T_0)}{-\left[\Delta H_{rxn}^\circ (T_{ref}) + \Delta \hat{C}_p (T - T_{ref}) \right]} \quad \frac{F_{exit}}{F_{exit} + F_Q} = \frac{y_M - y_Q}{y_{exit} - y_Q} \quad \frac{F_{exit}}{F_Q + F_{exit}} = \frac{T_M - T_Q}{T_{exit} - T_Q}$$

TOTAL /55/

QUESTION 3

The decomposition of a volatile organic compound (VOC) is carried out in a fluidized bed reactor filled with a cerium catalyst. The reaction is approximately first order. The performance of the unit is given by the Kunii-Levenspiel model. The bubble rise velocity in the reactor is $2.2 \text{ m} \cdot \text{s}^{-1}$ and the expanded bed height is 4 m.

a) Determine the conversion of the VOC. (10)

b) Is there any reaction occurring in the bubble phase? Explain why. (2)

c) Discuss two operating parameters that can affect the performance of the fluidized bed. (3)

Addition data and equations:

Fraction of solids in the bubble phase = 0.005

Fraction of solids in the cloud phase = 0.75

Fraction of solids in the emulsion phase = 0.5

First order reaction rate constant = $1.8 \text{ m}^3 \text{ bed} / \text{m}^3 \text{ solids} \cdot \text{s} = 1.8 \text{ s}^{-1}$

Gas interchange rate coefficients:

Bubble-cloud = 3 s^{-1}

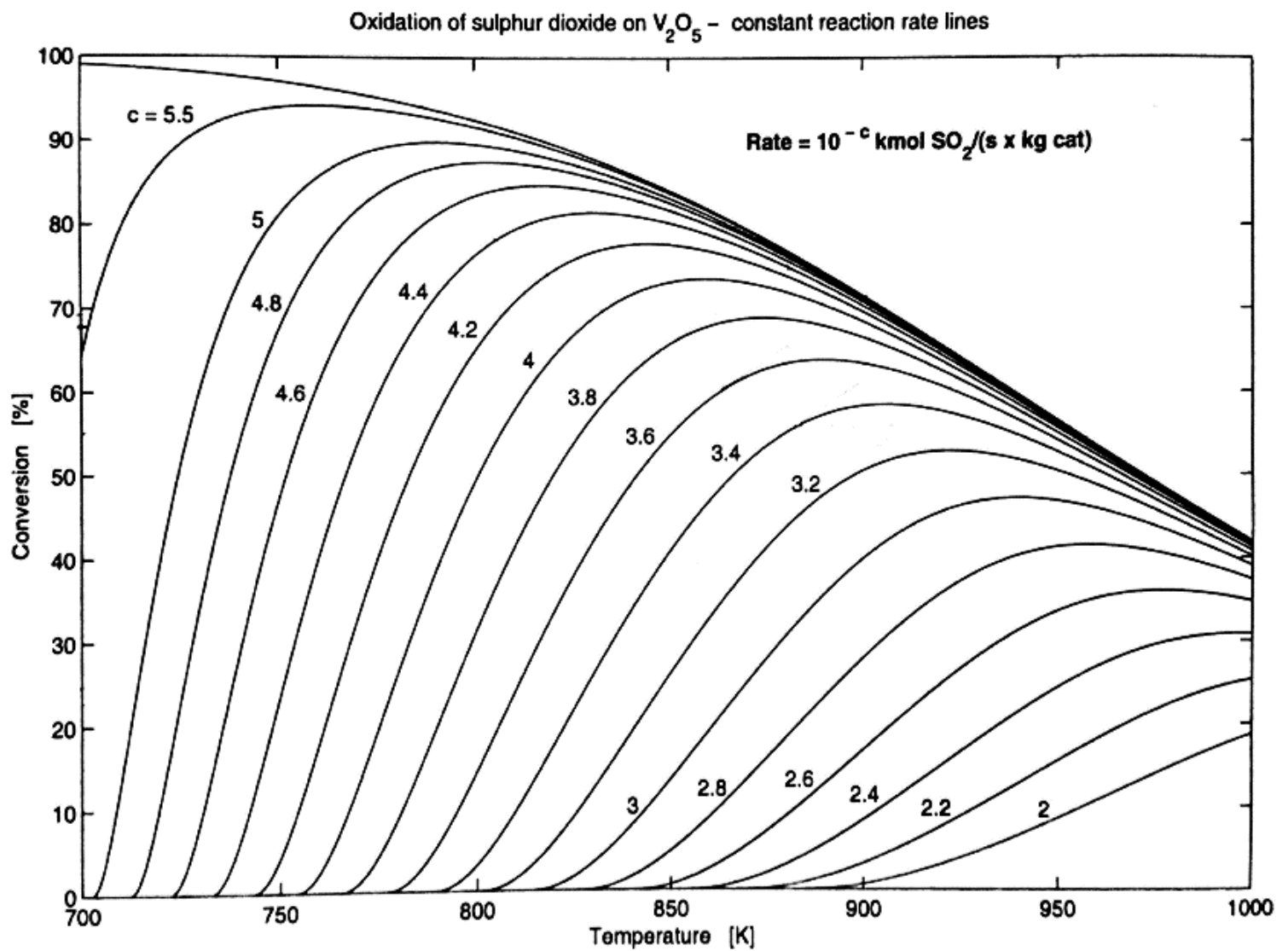
Cloud-emulsion = 2 s^{-1}

Overall rate constant for the fluidized bed:

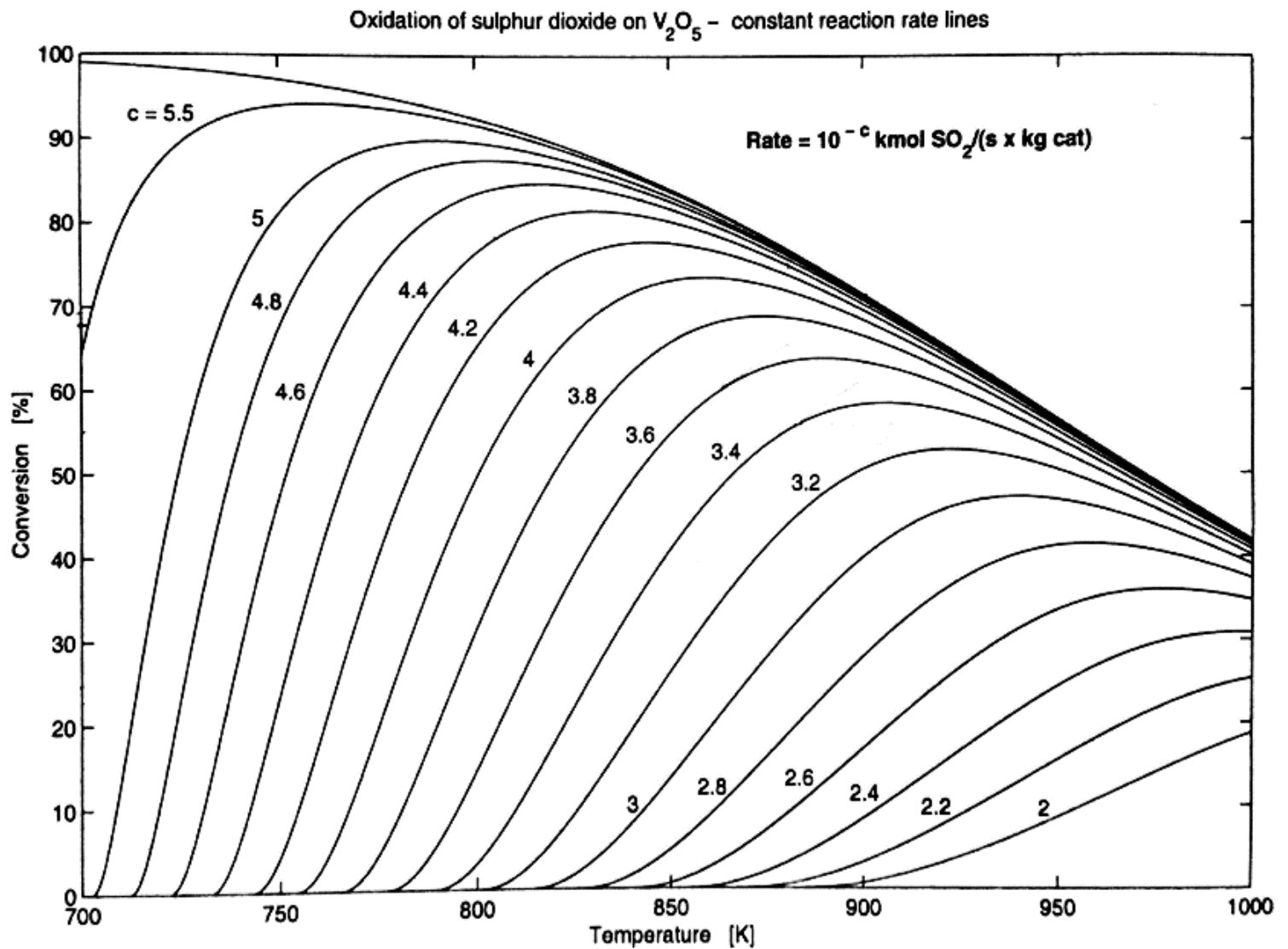
$$K_f = \left[\gamma_b K_r + \frac{1}{\frac{1}{K_{bc}} + \frac{1}{\gamma_c K_r + \frac{1}{\frac{1}{K_{ce}} + \frac{1}{\gamma_e K_r}}}} \right]$$

TOTAL /15/

Student number: _____



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