UNIVERSITY OF
KWAZULU-NATAL

INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

EXAMINATIONS: JUNE 2019

COURSE AND CODE: APPLIED REACTOR TECHNOLOGY ENCH4RT

DURATION: 2 HOURS

TOTAL MARKS: 80

INTERNAL EXAMINER(S): DR D LOKHAT

INTERNAL MODERATOR(S): PROF R RAWATLAL

EXTERNAL MODERATOR: MR M BOTHA

INSTRUCTIONS:

1. **ALL** questions should be attempted. Answer in ink.
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. A Rate Plot is provided for question 1 on page 5. Detach this page and submit with your answer book.
5. This examination question paper, together with all associated diagrams **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

QUESTION 1

Sulphur dioxide is oxidized over V_2O_5 catalyst loaded onto 8 mm porous alumina spheres in a *single* adiabatic reactor. The feed rate is 5 $kmol{\cdot}s^{-1}$, containing 13% SO_2 at 450 °C. Construction of the adiabatic operating line on the rate plot for the system is shown on the last page of this question paper.

a) What is the adiabatic equilibrium temperature and conversion for this feed?

(2)

b) Determine how many reactor beds would be required to achieve a final SO_2 conversion of greater than 75%. Apply an optimal design approach, i.e. begin adiabatic operating lines from the locus of maximum rates and stay 15 °C away from equilibrium. PLEASE DETACH THE RATE PLOT AND SUBMIT WITH YOUR ANSWER BOOKLET. INCLUDE YOUR STUDENT NUMBER.

(15)

c) Determine the mass of catalyst in the **last bed** assuming an average reaction rate in this bed. External mass transfer resistance can be ignored. The catalyst has an average effectiveness of 0.35 in this bed.

(7)

d) Suppose that the feed temperature is increased to 477 °C. What would be the new exit conversion obtained in the **first bed** if operation is 20 °C away from equilibrium?

(3)

e) Suggest a method of improving the effectiveness of the catalyst. Discuss how this change could affect other parameters in your system and the overall performance of the fixed bed reactor unit.

(3)

TOTAL /30/

QUESTION 2

The diagram shown in Figure 1 represents an ammonia synthesis reactor consisting of three adiabatic reactor beds in series with inter-stage cooling provided by quench streams.

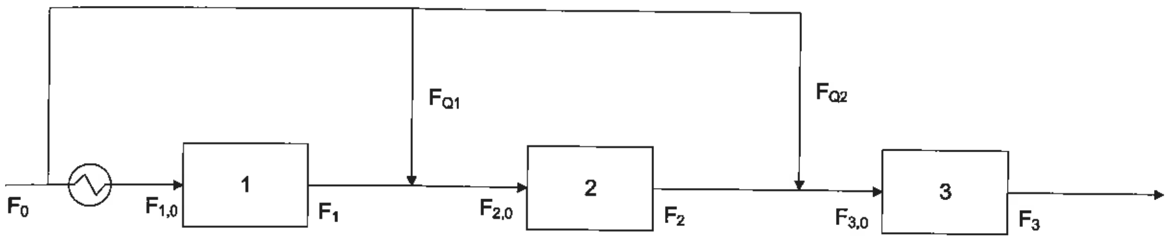

Figure 1. Three-bed ammonia synthesis reactor

The feed to the unit consists of N_2 and H_2 in the ratio 1:5 (hydrogen in excess).

a) Develop an expression relating the ammonia mole fraction and the conversion of nitrogen. Note that the nitrogen conversion is based on the molar flowrate into the first bed.

(5)

b) Show, using necessary equations, how you would calculate the quench flowrates at the two mixing points, provided that the ammonia mole fraction at **all** points and total feed flowrate are known. State any assumptions. The actual numerical values are not required.

(10)

c) Using simple sketches of conversion-temperature diagrams, explain why it is necessary to have a large difference in the temperature of the cold feed and the temperature at the inlet to the first bed. Consider the case of an exothermic reaction.

(5)

Additional data and equations:

$$\frac{F_{exit}}{F_{exit}+F_Q} = \frac{y_M - y_Q}{y_{exit} - y_Q}$$

TOTAL /20/

QUESTION 3

A first-order catalytic reaction is carried out in an isothermal fixed bed reactor. Find the conversion in a 2 m long bed, considering both the intraparticle and external mass transfer resistance. The reaction is equimolar (volumetric flowrate can be assumed constant) and pressure drop can be ignored. The intrinisic reaction rate at the catalyst surface is:

$$r = kC_{As} \quad \text{kmol·kg}^{-1}\text{·s}^{-1}$$

where C_{As} is the gas-phase concentration of reactant at the catalyst surface, with units of kmol·m^{-3}. The gas can be considered ideal at the reaction conditions.

Hint: Consider a mass balance across the external film. Please watch your units!

Additional data and equations:

temperature, $T = 300$ K
total pressure, $P = 1$ bar
total molar feed flow rate, $F = 2$ kmol·hr^{-1}
reaction rate constant at 300 K, $k = 4.2 \times 10^{-3}$ m^{3}·kg^{-1}·s^{-1}
mass transfer coefficient, $k_G = 3.3 \times 10^{-4}$ m·s^{-1}
catalyst particle diameter, $d_p = 8$ mm
particle effectiveness factor, $\eta = 0.15$
particle density, $\rho_p = 1300$ kg·m^{-3}
bed diameter, $D = 0.4$ m
bed voidage, $\varepsilon_b = 0.31$
universal gas constant, $R = 8.314$ J·mol^{-1}·K^{-1}

$$a_m = \frac{6}{d_p \rho_p}$$

TOTAL /25/

QUESTION 4

A first order reaction occurs in a fluidized bed catalytic reactor. Calculate the expanded bed height required to achieve a 75% conversion in the fluidized bed reactor, if the performance of the unit is given by the Kunii-Levenspiel model. You may assume that there is **no** catalyst present in the bubble and cloud phases, and that the bubbles are rising at 1 $m \cdot s^{-1}$.

Addition data and equations:

First order reaction rate constant = 2 m^3 bed/m^3 solids/s = 2 s^{-1}
Gas interchange rate coefficients:
Bubble-cloud = 5 s^{-1}
Cloud-emulsion = 2 s^{-1}

Overall rate constant for the fluidized bed

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

TOTAL /5/

RATE PLOT FOR QUESTION 1

STUDENT NUMBER: ______________________________

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