UNIVERSITY OF
KWAZULU-NATAL

INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: JUNE 2023

COURSE AND CODE: APPLIED REACTOR TECHNOLOGY ENCH4RT

DURATION: 2 HOURS

TOTAL MARKS: 65

INTERNAL EXAMINERS: PROF D LOKHAT

INTERNAL MODERATOR: PROF R RAWATLAL

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. **A blank diagram is provided on page 4. Remove this page and submit with your answer booklet.**

QUESTION 1

An ammonia converter is fed with a synthesis gas containing 72 mol% H_2, 24 mol% N_2 (H_2:N_2 = 3:1) and 4 mol% inerts. The cold feed is passed through a pre-heater to increase its temperature from 25 °C to 475°C, before it enters the first bed of the reactor. The feed flowrate to the first bed is 100 $kmol \cdot s^{-1}$ and the unit consists of two beds.

a) Determine the exit conversion after the second bed. You can assume a 25 °C approach to equilibrium and cooling according to the maximum-reaction-rate temperature policy. A blank reaction rate plot is provided on page 4 of this question paper. Note that the rate plot is in terms of bed volume. PLEASE DETACH AND HAND IN WITH YOUR ANSWER BOOKLET. INCLUDE YOUR STUDENT NUMBER.

(15)

b) Determine the quench flowrate that must be injected after the first bed.

(8)

c) Estimate the mass of catalyst in the second bed. You may use an arithmetic average rate for sizing. The total molar flowrate through this *second bed* can be assumed constant. The bulk density of the catalytic bed is 3000 $kg \cdot m^{-3}$. Note the rate is given with respect to NH_3 and on a volume basis.

(7)

d) The control valve on the quench line is malfunctioning and the quench flowrate is now only 75% of the original design quench flowrate. Determine the new temperature of the mixed feed to the second bed.

(5)

Available data:

$\bar{C}_{p,H_2} = 20\ J \cdot mol^{-1} \cdot K^{-1}$ $\quad \bar{C}_{p,NH_3} = 30\ J \cdot mol^{-1} \cdot K^{-1}$ $\quad \bar{C}_{p,I} = 25\ J \cdot mol^{-1} \cdot K^{-1}$

$\bar{C}_{p,N_2} = 22\ J \cdot mol^{-1} \cdot K^{-1}$

ΔH_{rxn} = -100 $kJ \cdot mol^{-1}$ (per mole of N_2; **can be assumed constant)**

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

TOTAL /35/

QUESTION 3

In dry reforming, methane and carbon dioxide are passed over a nickel-based catalyst to produce hydrogen and carbon monoxide. The reaction is approximately first order.

a) Consider a pilot-scale fluidized bed reactor for dry reforming of methane. The performance of the unit is given by the Kunii-Levenspiel model. Determine the expanded bed height required to achieve a 90% conversion. The bubble rise velocity in the pilot-scale reactor is 2 m s^{-1}

(10)

b) The reaction is carried out in a commercial-scale unit with an expanded bed height of 10 m. Determine the bubble rise velocity in the commercial unit, assuming all other parameters (including conversion) are the same as in the pilot-scale unit. Comment on the practicality of using a very high velocity.

(5)

c) Suggest two ways in which the conversion may be improved in the fluidized beds and comment on the limitations.

(5)

Addition data and equations:

Fraction of solids in the bubble phase = 0.005
Fraction of solids in the cloud phase = 0.7
Fraction of solids in the emulsion phase = 0.5
First order reaction rate constant = 3 m^3 bed/m^3 solids/s = 3 s^{-1}
Gas interchange rate coefficients:

Bubble-cloud = 4 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 /20/

Student number: ____________________