ORDRE DES INGÉNIEURS DU QUÉBEC

NOVEMBER 2023 SESSION

All documentation permitted Only non-programmable calculators are permitted Time allowed: 3 hours

16-CH-A4 CHEMICAL REACTION ENGINEERING

QUESTION 1 (25 pts)

An isothermal reactor is fed 0.1 kmol min^{-1} of reactant A in air at a mole fraction of 0.01 (y_{Ao} = 0.01). It operates at 400 kPa and 380 ºC. The reaction is irreversible and the first order rate constant is 0.20 min^{-1}

$$A(g) \rightarrow B(g) + C(g)$$

a) What is the molar mass of the feed gas? (5 pts)
b) What is the volume of a continuously stirred tank reactor (CSTR) to achieve 75 % conversion? (5 pts)
c) What is the volume of a plug flow reactor (PFR) to achieve 75% conversion? (5 pts)
d) If the mole fraction of A is 100 % (y_{Ao} = 1), what would the conversion be in each of these reactors? (10 pts)

QUESTION 2 (25 pts)

The following gas phase reaction takes place isothermally

$$N_2 + 3H_2 \xrightarrow{k_1} 2NH_3$$

The feed contains an excess of 10 % H_2 and the reaction is at 16.4 atm and 227 °C.

a) Construct a stoichimetric table for the reaction. (5 pts)
b) Calculate C_{Ao}, δ, and ε ? [$C_A = C_{Ao}(1 - \varepsilon X)$, $\varepsilon = y_{Ao}\delta$] (10 pts)
c) Calculate the concentration of ammonia when the H_2 conversion reaches 60 %. (10 pts)

QUESTION 3 (50 pts)

n-butane reacts to form maleic anhydride in a fluidized bed reactor that is 9.1 m in diameter and 18 m tall. The exit pressure is 2 bar and the temperature is 623 K :

$$C_4H_{10} + 3.5\ O_2 \longrightarrow C_4H_2O_3 + 4\ H_2O$$

$$C_4H_{10} + 4.5\ O_2 \longrightarrow 4\ CO + 5\ H_2O$$

$$C_4H_{10} + 6.5\ O_2 \longrightarrow 4\ CO_2 + 5\ H_2O$$

The superficial gas velocity at the entrance is 0.7 m s^{-1} (U_g). Assume the reaction is first order in n-C_4H_{10} and the selectivity is 70 %, 15 %, et 15 %, for maleic anhydride, CO, and CO2, respectively. The mole fraction of n-butane in air in the feed is 4 %.

a) Calculate the mass of catalyst in a reactor half full when the particle density is 1900 kg m^{-3} (ρ_p) and $U_g = 0.7$ m s^{-1}. (5 pts)

$$\varepsilon = (1 + U_g)/(2 + U_g)$$

b) What is the pressure at the reactor entrance? (5 pts)

c) Calculate the kinetic rate constant when the conversion is 98% based on the volumetric flow rate at the entrance. State 4 assumptions to simplify the problem (10 pts)

d) Calculate the kinetic rate constant based on the volumetric flow rate at the exit? (5 pts)

e) Calculate the kinetic rate constant taking into account pressure: P = f(z) ($\Delta P = \rho\, g\, h$) (15 pts)

f) Propose three ways to increase conversion. (10 pts)