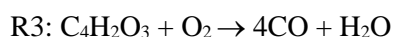
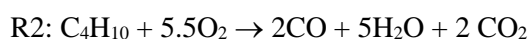
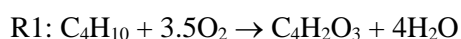


Practical 10

Fluidized Bed Reactor

Exercise 1

Maleic Anhydride (MA) is industrially produced by the oxidation of the n-butene. The n-butene diluted in air is fed to a fluidized bed reactor filled with Geldart A particles. In this condition, the solid particles are well mixed into the system allowing isothermal operations. As a first approximation, assume a CSTR behavior of the gas in the emulsion phase. Details of the configuration, catalysts, and operating conditions are given below. The reaction network is given by the following three reactions:



The system can be considered a mixture of ideal gases.

Considering a three-phase Kunii-Levenspiel model:

- 1) Calculate the value of the minimum fluidization velocity and the maximum fluidization ratio that can be adopted for this system.
- 2) Calculate the pressure drops across the reactor.
- 3) Calculate the fraction of the molar gas flow rate in the bubble phase.
- 4) Report the mass fraction profile of the n-butene in the bubble, cloud, and emulsion phases along the tube (report the qualitative graph with the values at 0.5, 1, 2, and 2.5 m).
- 5) Assess if slugging mode can occur in the reactor.
- 6) Assess what would be the impact on the outlet conversion in case the gas in the emulsion is considered to be static.

Data:

Reaction kinetics (partial pressures in atm, reaction rate in mol/kg_{cat}/s):

$$r_1 = k_1 \frac{p_{\text{C}_4\text{H}_{10}}^{0.54}}{1 + k_{\text{C}_4\text{H}_2\text{O}_3} p_{\text{C}_4\text{H}_2\text{O}_3}}$$

$$r_2 = k_2 p_{\text{C}_4\text{H}_{10}}$$

$$r_3 = k_3 \frac{p_{C_4H_2O_3}}{(1 + k_{C_4H_2O_3} p_{C_4H_2O_3})^2}$$

With:

$$k_1 = 2.2 \cdot 10^{-3} \exp\left(\frac{60}{T_{ref} R_{gas}} \left(1 - \frac{T_{ref}}{T_{in}}\right)\right) \left[\frac{mol}{kg_{cat} s atm^{0.4}}\right]$$

$$k_2 = 0.3 \cdot 10^{-3} \exp\left(\frac{45}{T_{ref} R_{gas}} \left(1 - \frac{T_{ref}}{T_{in}}\right)\right) \left[\frac{mol}{kg_{cat} s atm^{0.4}}\right]$$

$$k_3 = 0.22 \cdot 10^{-2} \exp\left(\frac{190}{T_{ref} R_{gas}} \left(1 - \frac{T_{ref}}{T_{in}}\right)\right) \left[\frac{mol}{kg_{cat} s atm}\right]$$

$$k_{C_4H_2O_3} = 185 [atm^{-1}]$$

$$T_{ref} = 673 [K]$$

$$R_{gas} = 0.008314 \left[\frac{kJ}{mol}\right]$$

Operating conditions:

Outlet pressure = 1 atm

Feed Temperature = 430 °C

Diluted conditions: n-butene to air ratio (v/v) 4% (LFL 1.8%)

Inlet gas flowrate = 25 cm/s

Reactor configuration:

Reactor diameter = 5 m

Gamma bubble = 0.005

$$f_w = 0.2$$

Catalyst:

Sphere diameter = 125 micron

Catalyst density = 1200 kg/m³

Mass of catalyst = 27318 kg

$$\varepsilon_{mf} = 0.42$$

Mixture properties:

Diffusion coefficient = $3 \cdot 10^{-5} \text{ m}^2/\text{s}$

Viscosity: $3.28 \cdot 10^{-5} \text{ Pa s}$

Ergun equation:

$$\frac{\Delta P}{L} = 150 \frac{(1 - \varepsilon)^2 \mu v_g}{\varepsilon^3 d_p^2} + 1.75 \frac{(1 - \varepsilon) \rho v_g^2}{\varepsilon^3 d_p}$$

Correlations:

$$v_{\text{single bubble}} = 0.711(g d_{\text{bubble}})^{0.5}$$

$$v_{\text{bubble}} = (v_{\text{in}} - v_{\text{mf}}) + v_{\text{single bubble}}$$

$$f_{\text{cl}} = 3 \frac{\frac{v_{\text{mf}}}{\varepsilon_{\text{mf}}}}{v_{\text{bubble}} - \frac{v_{\text{mf}}}{\varepsilon_{\text{mf}}}}$$

$$\delta = \frac{(v_{\text{in}} - v_{\text{mf}})}{(v_{\text{bubble}} - (1 + (f_{\text{cl}} + f_w))v_{\text{mf}})}$$

$$\gamma_{\text{cloud}} = (1 - \varepsilon_{\text{mf}})(f_{\text{cl}} + f_w)$$

$$\gamma_{\text{emulsion}} = (1 - \varepsilon_{\text{mf}}) * \frac{(1 - \delta)}{\delta} - \gamma_{\text{cloud}}$$

$$\varepsilon_{\text{bed}} = 1 - (\delta * \gamma_{\text{bubble}} + (1 - \delta) * (1 - \varepsilon_{\text{mf}}))$$

$$L = \frac{m_{\text{cat}}}{\rho_{\text{cat}}(\text{Area}_{\text{reactor}})(1 - \varepsilon_{\text{bed}})}$$

$$K_{\text{bc}} = 4 \left(\frac{v_{\text{mf}}}{d_{\text{bubbles}}} \right) + 5.85 (D_{\text{mix}}^{0.5} * \frac{g^{0.25}}{d_{\text{bubbles}}^{\frac{5}{4}}})$$

$$K_{\text{ce}} = 6.77 \left(\frac{D_{\text{mix}} \varepsilon_{\text{mf}} v_{\text{bubble}}}{d_{\text{bubbles}}^3} \right)^{0.5}$$

$$d_{\text{bubble,max}} = 0.652 \left(\frac{\pi d_{\text{reactor}}^2}{4} (v_{\text{in}} - v_{\text{mf}}) \right)^{0.4} [\text{cm}]$$

$$v_{terminal} = \frac{d_{particle}^2 g(\rho_{particle} - \rho_{gas})}{18\mu}$$