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:

R1: $C_4H_{10} + 3.5O_2 \rightarrow C_4H_2O_3 + 4H_2O$

R2: $C_4H_{10} + 5.5O_2 \rightarrow 2CO + 5H_2O + 2\,CO_2$

R3: $C_4H_2O_3 + O_2 \rightarrow 4CO + H_2O$

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.

<u>Data</u>:

<u>Reaction kinetics</u> (partial pressures in atm, reaction rate in mol/kg$_{cat}$/s):

$$r_1 = k_1 \frac{p_{\mathrm{C_4H_{10}}}^{0.54}}{1 + k_{C_4H_2O_3} p_{C_4H_2O_3}}$$

$$r_2 = k_2 p_{C_4H_{10}}$$

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

With:

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

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

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

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

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

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

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/m^3

Mass of catalyst = 27318 kg

ε_{mf} = 0.42

Mixture properties:

Diffusion coefficient = 3 10^{-5} m^2/s

Viscosity: 3.28 10^{-5} Pa s

Ergun equation:

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

Correlations:

$$\mathrm{v_{single\ bubble}} = \ 0.711(\mathrm{gd_{bubble}})^{0.5}$$

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

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

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

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

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

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

$$\mathrm{L} = \frac{m_{cat}}{rho_{cat}(Area_{reactor})(1 - \varepsilon_{\mathrm{bed}})}$$

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

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

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

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

