Exercise 6

A fast, homogeneous reaction was carried out in a single, straight cylindrical microchannel. A catalytic side-reaction also took place at the channel wall, which was responsible for a selectivity loss of ~2%.

- Channel diameter = 0.1 mm
- Channel length = 1 cm
- Residence time = 0.01 s

In order to better control the heat of reaction, it is proposed to use a parallel multichannel reactor with a channel diameter of 0.05 mm, keeping the same process efficiency (i.e., conversion of the desired reaction) and the same pressure drop.

Questions

- Calculate the new reactor dimensions (N_c, L_c) and the required residence time
- What are the implications of the new design on the mass and heat transfer rates? If any, calculate their relative changes compared to the mono-channel reactor
- Estimate the impact of the new reactor design on the reaction selectivity

Solutions

Same process efficiency → $NOU = \frac{\tau}{t_{op}} = constant$

Homogeneous reaction → $m = 0$ → $t_{op} \propto R^0 = constant$

→ $\boldsymbol{\tau} = constant = \mathbf{0.01\ s}$

$\dot{Q} = constant$ and $\tau = constant$ → $V = constant$

$\Delta p \propto \frac{R^{m-6}}{N_c^2} = \frac{R^{-6}}{N_c^2} = constant \rightarrow N_c \propto R^{-3} \rightarrow \boldsymbol{N_c} = \left(\frac{0.05}{0.1}\right)^{-3} = \mathbf{8}$

$L_c \propto \frac{R^{m-2}}{N_c} \propto \frac{R^{-2}}{R^{-3}} \propto R \rightarrow \boldsymbol{L_c} = \frac{0.05}{0.1} \times 1cm = \mathbf{0.5\ cm}$

The characteristic times for diffusive and convective mass and heat transfers are proportional to $R^2 (m = 2)$: $t_{mass} \propto R^2$ and $t_{heat} \propto R^2$

→ **Mass and heat transfer rates will be multiplied by a factor of** $\left(\frac{0.1}{0.05}\right)^2 = \mathbf{4}$

Characteristic time for a 1st order heterogeneous reaction is proportional to R ($m = 1$): $t_{het,1} \propto R$.

→ In this case the rate of the heterogeneous by-product formation will be increased by a factor of $\left(\frac{0.1}{0.05}\right) = \mathbf{2}$ → It can be assumed, as a first approximation, that the **selectivity loss will be doubled**, i.e., 4% instead of 2%.

Note that if the catalytic reaction is mass-transfer limited, in the new design it its rate would be increased by a factor of $\left(\frac{0.1}{0.05}\right)^2 = \mathbf{4}$ since $t_{mass} \propto R^2$. In that case, as a first approximation, the **selectivity loss would be quadrupled**, i.e., 8% instead of 2%.