Exercise 23

A second order quasi-instantaneous reaction $A_1 + A_2 \rightarrow P$ is carried out in a microreactor. Multi-point injection of reactant A_2 is required to reduce the hot spot.

Data

Mean heat capacity of reaction mixture $c_p = 1700\, J\, kg^{-1} K^{-1}$

Density of reaction mixture $\rho = 1142\, kg\, m^{-3}$

Reaction enthalpy $\Delta H_r = -120\, kJ\, mol^{-1}$

Inlet concentrations $c_{1,0} = c_{2,0} = 1.56\, kmol\, m^{-3}$

Total inlet flowrates $\dot{V}_{10} = \dot{V}_{20} = 0.9 \cdot 10^{-7}\, m^3\, s^{-1}$

Number of injection points for reactant A_2 = 6

Equal flow partition of reactant A_2

Microchannel diameter $d = 150 \cdot 10^{-6} m$

Overall volumetric heat transfer coefficient : $U_v = 5 \cdot 10^6\, W m^{-3} K^{-1}$

Cooling temperature and inlet flow temperatures $T_c = T_{inj} = T_0 = 50°C$

Questions

- Calculate the adiabatic temperature rise at each injection point assuming $t_{rx} \ll t_{heat}$ and $t_{rx} \ll t_{mx}$
- For each segment, calculate the length required to remove 50% of the reaction heat.

Solution

For $j = 1\ to\ 6$:

$$\Delta T_{ad,j} = \frac{(\dot{n}_{2,0}/N)(-\Delta H_r)}{(\rho \dot{V}_j) c_p}$$

Where $\dot{n}_{2,0} = \dot{V}_{20} \cdot c_{2,0}$

And $\dot{V}_j = \dot{V}_{1,0} + j \frac{\dot{V}_{2,0}}{N}$

$$T_{in,1} = T_0 + \Delta T_{ad,1}$$

$$T_{in,j} = \frac{\dot{V}_{j-1}}{\dot{V}_j} T_{out,j-1} + \frac{\dot{V}_{2,0}/N}{\dot{V}_j} T_0 + \Delta T_{ad,j}$$

Where $T_{out,j-1}(50\%\ heat\ removal) = T_c + 0.5(T_{in,j-1} - T_c)$

$$L_j = u_j \frac{\rho c_p}{U_V} ln\left(\frac{T_{in,j} - T_c}{T_{out,j} - T_c}\right)$$

With $u_j = \frac{\dot{V}_j}{\pi \frac{d^2}{4}}$

j	$\dot{V}_j$ (m³/s)	u_j (m/s)	$\Delta T_{ad,j}$ (K)	$T_{in,1}$ (°C)	$T_{out,1}(50\%)$ (°C)	τ_j (s)	L_j (m)
1	$1.05 \cdot 10^{-7}$	5.9	13.8	63.8	56.9	0.27	1.6
2	$1.20 \cdot 10^{-7}$	6.8	12.1	68.1	59.0	0.27	1.8
3	$1.35 \cdot 10^{-7}$	7.6	10.7	68.7	59.4	0.27	2.1
4	$1.50 \cdot 10^{-7}$	8.5	9.6	68.1	59.0	0.27	2.3
5	$1.65 \cdot 10^{-7}$	9.3	8.8	67.0	58.5	0.27	2.5
6	$1.80 \cdot 10^{-7}$	10.2	8.0	65.8	57.9	0.27	2.7
							13.0