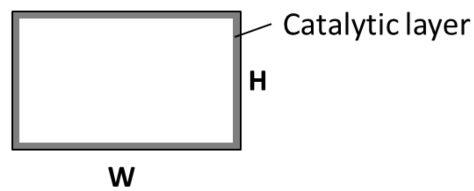
Exercise 7

A single rectangular microchannel coated with a heterogeneous catalyst was used to carry out a gas phase catalytic reaction. An unwanted homogeneous reaction (combustion) took place in the gas phase. You are asked to propose a multichannel design to reduce the contribution of the homogeneous reaction by a factor of ten.



Data

$r_{hom} = k_{hom} c_{gas}^2 (mol \cdot m^{-3} \cdot s^{-1}) \qquad k_{hom} = 0.94\, mol^{-1} m^3 s^{-1}$

A pseudo-homogeneous model can be used to describe the kinetics of the heterogeneous reaction

$r_{het} = k_{het} c_{gas}^{0.5}\ (mol \cdot m^{-2} \cdot s^{-1}) \qquad k_{het} = 1.8 \cdot 10^{-2}\ mol^{0.5} m^{-0.5} s^{-1}$

Channel dimensions in mm $(H \times W \times L) = 0.25 \times 0.5 \times 50$

Flowrate $\dot{Q} = 8.3 \cdot 10^{-8} m^3 s^{-1}$

Density $\rho = 4.81\ kgm^{-3}$

Viscosity $\mu = 1.8 \cdot 10^{-5} Pa \cdot s$

Inlet concentration of reactant $c_0 = 12\ mol\ m^{-3}$

Questions

1. Calculate the ratio of characteristic times $\varphi = \frac{t_{het}}{t_{hom}}$ for the single channel reactor
2. Design a multichannel reactor to treat the same flowrate, keeping the residence time, the channel length and the aspect ratio $\frac{H}{W}$ constant, such that φ is decreased by a factor of ten
3. Calculate the Reynolds number for the mono-channel and multi-channel reactors. What is the flow regime? ($hydraulic\ diameter = d_h = 4 \frac{\text{cross−sectional area}}{\text{wetted perimeter}}$)

Solution

$$t_{hom} = \frac{1}{k_{hom} C_0^{n-1}} = \frac{1}{k_{hom} C_0} \neq f(H, W)$$

$$t_{het} = \frac{1}{a\, k_{het} C_0^{m-1}} = \frac{1}{k_{het} C_0^{-0.5}} \frac{H\, W}{2(H+W)}$$

$$\varphi_1 = \frac{t_{het}}{t_{hom}} = \frac{k_{hom}}{k_{het}} \frac{H_1\, W_1}{2(H_1 + W_1)} C_0^{1.5} \rightarrow \varphi_1 = 0.18$$

$$\varphi_2 = 0.1 \varphi_1\ \ \&\ \ \frac{H}{W} = \frac{1}{2} = const.$$

$$0.018 = \frac{k_{hom}}{k_{het}} \frac{H_2\, (2H_2)}{2(H_2 + 2H_2)} C_0^{1.5} \rightarrow\ H_2 = 2.5 * 10^{-5}\ m$$

$W_2 = 2H_2 \rightarrow W_2 = 5 * 10^{-5}\,m$

Constant τ and $\dot{Q} \rightarrow$ constant volume: $V = \dot{Q}\tau = N_1 H_1 W_1 L_1 = N_2 H_2 W_2 L_2$

$L_1 = L_2$ and $\frac{H_1}{W_1} = \frac{H_2}{W_2} \rightarrow N_2 = N_1 \left(\frac{W_1}{W_2}\right)^2 \rightarrow N_2 = 1 * (10)^2 = 100$

$Re = \frac{\rho u d_h}{\mu}$ & $d_h = 4\frac{H.W}{2(H+W)} = 2\frac{H.W}{(H+W)} \rightarrow Re_1 = 59.4\ \&\ Re_2 = 5.9$

		Reactor 1	Reactor 2	
W	m	5.0E-04	5.0E-05	
L	m	5.0E-02	5.0E-02	
N channels	-	**1**	**100**	
H	m	2.5E-04	2.5E-05	
dh	m	3.3E-04	3.3E-05	
Vol_channel	m^3	6.3E-09	6.3E-11	
Vol_tot	m^3	6.3E-09	6.3E-09	
Cross section	m^2	1.3E-07	1.3E-09	
u	m/s	6.7E-01	6.7E-01	
tau	s	0.075	0.075	
t_het	s	1.6E-02	1.6E-03	
t_hom	s	8.8E-02	8.8E-02	
t_het / t_hom	-	**18%**	**1.8%**	
r_het / r_hom	-	5.5	55.1	
Re	-	**59.4**	**5.9**	Laminar