Exercise 17

A novel type of loop reactor is tested by carrying-out a second-order reaction. The reaction is performed in two distinct solvents with significantly different viscosities. The residence time distribution of the loop reactor corresponds closely to the RTD of an ideal CSTR. The energy dissipation rate, the space-time and the first Damköhler number are kept constant for both reaction systems.

Data

$A_1 + A_2 \rightarrow P$ $\quad r = kc_1c_2$

$DaI = 20$ $\quad M = 1$

$\tau = 2\ s$ $\quad \varepsilon = 0.5\ W\ kg^{-1}$

	Reaction system 1	Reaction system 2
Viscosity $(\boldsymbol{Pa \cdot s})$	10^{-3}	$5 \cdot 10^{-2}$
Density $(\boldsymbol{kg \cdot m^{-3}})$	1000	1000
Diffusion coefficient $(\boldsymbol{m^2 \cdot s^{-1}})$	$5 \cdot 10^{-9}$	$3 \cdot 10^{-10}$

Questions

Calculate the mixing time for both systems using the engulfment model and the shear elongation & diffusion model. Determine which mechanism is controlling. Calculate the conversion of reagent A_1. Find out if the reaction is affected by mixing. If yes, determine the energy dissipation rate required to reach 98% of the conversion that would be reached in an ideally "micromixed" CSTR.

Solution

1. Calculate $t_{Ds} \cong 2\sqrt{\frac{\nu}{\varepsilon}}\, arc\ sinh\big(0.05\ Sc\big)$
2. Calculate $t_E = 17.2\sqrt{\frac{\nu}{\varepsilon}}$
3. Find the mixing time $t_{mx} = \max(t_{Ds};\ t_E)$
4. Calculate the second Damköhler number $DaII_{mx} = \frac{t_{mx}}{t_r}$
5. Calculate the intensity of segregation $I_s = \frac{1}{1+\frac{DaI}{DaII_{mx}}}$
6. Calculate the conversion :

$$X = \frac{\left(1 + M + \frac{1}{DaI}\right) - \sqrt{\left(1 + M + \frac{1}{DaI}\right)^2 - 4M(1 - I_s)}}{2}$$

7. The conversion in a micromixed CSTR is given by : $X_{micro} = \frac{\left(1+M+\frac{1}{DaI}\right)-\sqrt{\left(1+M+\frac{1}{DaI}\right)^2-4M}}{2}$

- Conversion in micromixed system: **80.0%**
- Conversion for system 1 (low viscosity): **77.5% (slightly affected by mixing)**

- Conversion for system 2 (high viscosity): **65.2% (strongly affected by mixing)**
- Energy dissipation to reach 78.4% conversion in system 1 (low viscosity): **1.3 W/kg**
- Energy dissipation to reach 78.4% conversion in system 2 (high viscosity): **84 W/kg**

		System 1		System 2	
mu	Pa*s	1.00E-03	1.00E-03	5.00E-02	5.00E-02
ro	kg/m^3	1.00E+03	1.00E+03	1.00E+03	1.00E+03
D	m^2/s	5.00E-09	5.00E-09	3.00E-10	3.00E-10
eps	W/kg	0.50	1.31	0.50	84.00
nu		1.00E-06	1.00E-06	5.00E-05	5.00E-05
Sc		2.00E+02	2.00E+02	1.67E+05	1.67E+05
tE	s	2.43E-02	1.50E-02	1.72E-01	1.33E-02
tDS	s	8.48E-03	5.24E-03	1.94E-01	1.50E-02
tmx	s	2.43E-02	1.50E-02	1.94E-01	1.50E-02
DaIImx		0.24	0.15	1.94	0.15
Is		1.20E-02	7.46E-03	8.86E-02	7.44E-03
X		**77.5%**	78.40%	**65.2%**	78.40%

Xtarget	78.4%
Xmicro	**80.0%**