

## Problem 1. (15%)

A certain dose of anti-cancer drug doxorubicin, DOX (A), is delivered into a breast cancer cell with a liposome carrier. The cancer cell has a volume of  $4\pi R^3/3$ , where  $R$  is the radius of the cell. Initially, there is  $N_{A0}$  mole of DOX present in the cell, and then the cancer cell tries its best to decompose DOX to prevent from dying. Assume that DOX decomposition is a first-order reaction with a rate constant  $k$ , and the decomposition rate is uniform throughout the interior of the cell.

- (A) Derive the time ( $t$ ) required for DOX decomposition as a function of conversion  $X$ ,  $k$ ,  $R$ , and/or  $N_{A0}$  (Hint: You may not require all parameters, and imagine the cell as a batch reactor (BR) for DOX decomposition.) (8%)
- (B) Assume that the cancer cell must achieve 90% decomposition of DOX ( $X = 90\%$ ) within 2 hrs before being killed. Will the cancer cell be survived or killed if  $N_{A0} = 10$  nmole,  $R = 5 \mu\text{m}$ , and  $k = 1 \text{ hr}^{-1}$ ? Why? (Hint:  $\ln 10 \cong 2.3$ ) (7%)

## Problem 2 (20%)

Serum creatinine (A), a detectable byproduct of muscle metabolism, is viewed as a biomarker of kidney health because it is removed from the blood mainly by the kidneys. It is known that creatinine has a constant half-life ( $t_{1/2}$ , hr) while removed in the kidneys. Now, a microfluidic PFR (plug-flow reactor) made of 3D human kidney cell culture is fabricated for creatinine metabolism study, where the microfluidic PFR with a cross-section area of  $S$  ( $\mu\text{m}^2$ ) and a length of  $L$  (cm), and an artificial blood stream containing a creatinine concentration of  $C_{A0}$  is pumped into the kidney-PFR at a constant volumetric flow rate  $v_0$  ( $\mu\text{l/hr}$ ).

- (A) Prove that the creatinine removal reaction is a first-order reaction. (5%)
- (B) Derive a design equation relating the length of the microfluidic PFR kidney ( $L$ ) to the entering concentration of creatinine ( $C_{A0}$ ), the conversion of creatinine removal ( $X$ ), the half-life ( $t_{1/2}$ ), the volumetric flow rate  $v_0$ , and the microfluidic channel cross-sectional area  $S$ . (8%)
- (C) Plot the conversion of creatinine removal ( $X$ ) vs. the length of the microfluidic PFR ( $L$ ) for (i) large  $S/v_0$  and (ii) small  $S/v_0$  while other parameters are kept the same. (7%)

## Problem 3. (15%)

The rate law for hydrolysis of cellulose (A) by cellulase (E) can be described by the following equation.

$$-r_A = \frac{r_{max}C_A}{K_M + C_A}$$

- (A) Assume that the above reaction is carried out in a CSTR. Prove that

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$$C_A = -K_M + r_{max} \left( \frac{C_A \tau}{C_{A0} - C_A} \right)$$

where  $\tau$  is the space time of the CSTR. (10%)

- (B) Compare the  $C_A$  vs.  $C_A \tau / (C_{A0} - C_A)$  plots for the CSTR using (i) a low-efficient cellulase and (ii) a high-efficiency cellulase. (5%)

Problem 4. (25%)

Use the van der Waals equation of state to determine the inversion temperature (the temperature at which the Joule-Thomson coefficient is zero)

- (A) in the low pressure limit. (13%)  
 (B) The locus of inversion temperatures in the  $(P, T)$  plane. (12%)

The van der Waals equation of state is given by

$$P = \frac{RT}{(V-b)} - \frac{a}{V^2}$$

where  $a = \frac{27R^2T_c^2}{64P_c}$  and  $b = \frac{RT_c}{8P_c}$ .

Recall that the Joule-Thomson coefficient is defined by

$$\mu = \left( \frac{\partial T}{\partial P} \right)_H = \frac{T}{C_p} \left[ \left( \frac{\partial V}{\partial T} \right)_P - \frac{V}{T} \right]$$

Problem 5. (25%)

As an engineer, you have been asked to check the behavior of our steam flood of a certain reservoir. In this process, steam is injected into the ground to mobilize the oil, which is produced at the production well. Water is present in both the liquid and gas phases. Since iron pyrite ( $\text{FeS}_2$ ) is present in the reservoir, there is concern about chemical reactions that will produce  $\text{H}_2\text{S}$ . Your boss asks you to perform a quick calculation of the concentration of  $\text{H}_2\text{S}$  to expect in the vapor phase at the producing well. A geochemist has told you that the components present in a reacting mixture are:

Component	$\Delta G_{f,298}^\circ$ (kJ/mole)	$\Delta H_{f,298}^\circ$ (kJ/mole)
$\text{Fe}_2\text{O}_3$ (s) (Hematite)	-742.200	-824.200
$\text{Fe}_3\text{O}_4$ (s) (Magnetite)	-1015.400	-1118.400
$\text{FeS}_2$ (s) (Pyrite)	-166.900	-178.200
$\text{H}_2\text{O}$ (l) (Water)	-237.129	-285.830
$\text{H}_2\text{O}$ (g) (Water)	-228.572	-241.818
$\text{H}_2\text{S}$ (g)	-33.560	-20.630

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科目：熱力學與反應工程

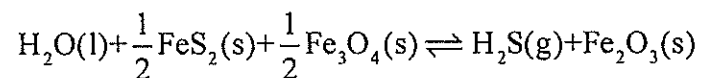
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The standard states in the above table are gases (g): the pure ideal gas at 1 atm and 25 °C; liquids (l) and solids (s): the pure substance at 1 atm and 25 °C.

(A) Determine the equilibrium constant for this reaction at 264 °C. (13%)



(B) Assuming that all of the condensed phases are pure and the gas phase is ideal, calculate the expected partial pressure of  $\text{H}_2\text{S}$  in the reservoir. (12%)

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