Enzyme Problem Set 3

A) You purchase the enzyme glucose isomerase immobilized on spherical porous spherical support. An experiment is conducted with the following results:

particle diameter = 400 μm
glucose concentration = 80 mM
observed reaction rate = 3.75 mmoles glucose consumed/cm^3 particle·min.
effective diffusivity = 4.5×10^{-4} cm^2/min

a) What is internal effectiveness factor?
b) Is the process mass-transfer limited, kinetically limited, or balanced between the two regimes?

B) A first order reaction A → B has a rate constant of 0.118 s^{-1}. The reaction occurs inside a porous catalyst having D_{eff} = 6.3×10^{-6} cm^2/s. The surface concentration of A is 5.8 mmol/L,

a) What diameter particle is necessary to ensure that the reaction is not mass transfer limited?
b) If the particle diameter is 250 μm, what is the internal effectiveness factor?
c) If the particle diameter is 250 μm, what is the concentration of A at the center of a catalyst?

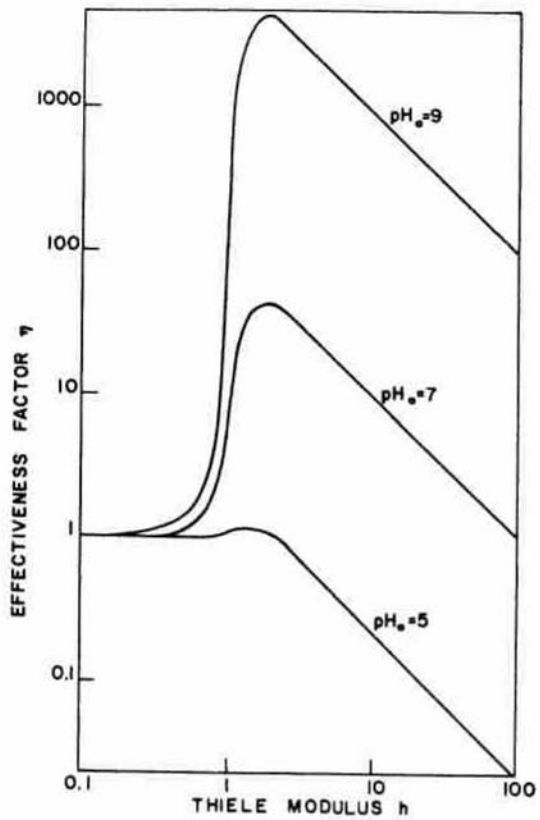
C) As the lead engineer in charge of an immobilized enzyme process using a nonporous catalyst, you are dissatisfied with the quantity of product being formed during a given time. A sample from the reactor indicates that the substrate concentration is 5.5 g/L. The supplier of the enzyme guarantees a maximum reaction rate to be 5.2×10^{-3} mg/cm^2·min. You calculate the impeller to provide a mass transfer coefficient of 3.1×10^{-4} cm/s.

i. Would you characterize the system as reaction-limited, mass transfer-limited or balanced between these two limitations?
ii. What courses of action could you suggest to increase product formation at these conditions? Explain.
iii. If the K_M value for the enzyme is reported to be 1.3 g/L, find the actual rate of reaction.
iv. Which of the following would result in the greatest impact in increase the reaction rate (i.e., give me numeric proof):
   a) doubling the enzyme activity
   b) doubling the substrate concentration in the reactor
   c) doubling the mass transfer coefficient

D) An enzyme catalyzing the following reaction:

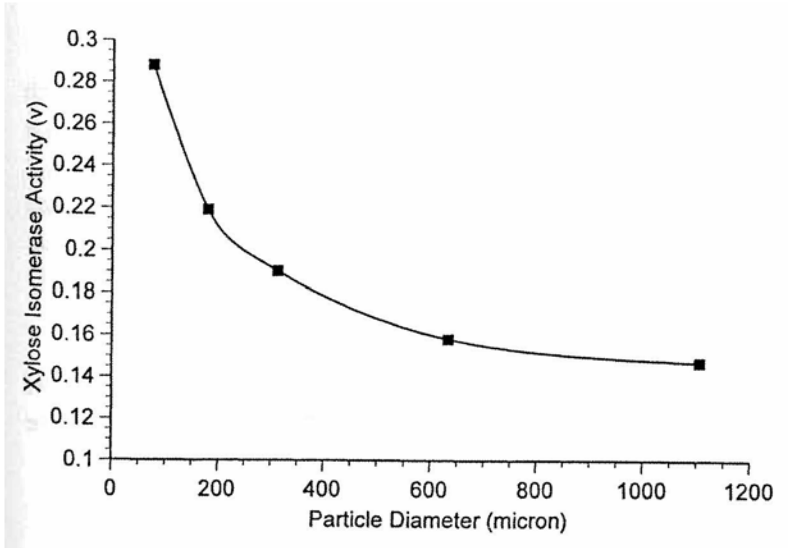
$$R_1COOR_2 \rightarrow R_1COO^- + H^+ + R_2OH$$

is immobilized through an uncharged, flat porous membrane. In solution the enzyme exhibits optimal activity at a pH of 4.6. The following plats of effectiveness factor versus observable Thiele modulus were obtained for this system at the indicated external pH values. Explain this behavior. (ref. Blanch and Clark, Biochemical Engineering, p.149).



E) Sweetzyme Q is a commercial preparation of glucose isomerase immobilized in a porous spherical particle (Novo Industries, Denmark). Plotted below are initial rates of xylose isomerization catalyzed by Sweetzyme Q (in units of μmols xylose isomerized/mg particle·min). The external concentration of xylose is 1.5 M the density of the catalyst is 1.4 g/cm^3, and the measured K_M is 0.209M. *Assume that the maximum activity plotted in the figure would not increase if the particle diameter were further reduced.* (ref. Blanch and Clark, Biochemical Engineering, p.155).

i) Estimate the effective diffusivity of xylose in the Sweetzyme Q catalyst. Use definition of Actual Modulus.
ii) What is the largest potential source of error in the calculation in part i.
iii) Using the effective diffusivity calculated in part i., for a particle diameter of 620 μm, estimate the internal effectiveness factor.



F) A specific enzyme exhibits substrate inhibition. Why would it be quite possible to increase the reaction rate by immobilizing the enzyme in a porous spherical particle compared to using the free enzyme in solution? Explain.

G) You have a porous particle used for a first order reaction with a $k = 6.32\ \text{min}^{-1}$ and an effective diffusivity $= 3.5 \times 10^{-4}\ \text{cm}^2/\text{min}$. The concentration of the reactant A at the surface is 100 mM

i. Use Excel or some other software to plot the Internal Effectiveness Factor (η_I) and the concentration of A at the center of the catalyst as a function of catalyst diameter (10 μm – 1000 μm).

ii. Construct same plot except with a rate constant four times as great ($25.28\ \text{min}^{-1}$).

iii. Construct same plot except with a rate constant one-fourth as great ($1.58\ \text{min}^{-1}$).