PROBLEM 13-8

Correction: Add, the ethanol yield is 0.47 kg ethanol/kg of glucose consumed. The correct unit for the rate coefficient, *k*, is 1/s, <u>not</u> kg/m^3·s

a) The time for a batch reaction is given by Eq. 13-8. Since N_i/V_R is the reactant concentration, glucose in this case, the equation can be written as

$$\theta = \int_{c_{\text{glucose},i}}^{c_{\text{glucose},f}} \mathrm{d}(c_{\text{glucose}})/(r_{\text{glucose}}) \approx \sum_{j=1}^{j=g} (\Delta c_{\text{glucose}})/(r_{\text{glucose}})_{j,\text{average}}$$

where $c_{\text{glucose},f}$ is the final glucose concentration = (0.05*10) kg/m^3, $c_{\text{glucose,i}}$ the initial glucose concentration=10 kg/m^3, $\Delta c_{\text{glucose}}$ the incremental change of glucose concentration in the numerical integration (a negative quantity), and $g=(c_{\text{glucose},f} - c_{\text{glucose},i})/\Delta c_{\text{glucose}}$. Because the rate is a complicated form in concentration, a numerical integration is recommended. Any acceptable numerical integration routine may be used. Here, integration was performed with a spreadsheet using the trapezoidal approximation. The Δ-increment size was decreased in successive integrations until the result does not change significantly with increment size. The term $(r_{\text{glucose}})_{j,\text{average}} = (r_{\text{glucose},j-1} + r_{\text{glucose},j})/2$ for integration by the trapezoidal method.

The reaction rate is given by

$$r_{\text{glucose}} = -(1.53*10^{-3})\left(1 - (c_{\text{ethanol}}/93)\right)^{0.52}\left((c_{\text{glucose}})(c_{S.cerevisiae})/(c_{\text{glucose}} + 1.7)\right)$$

The concentrations are related as follows:

$$c_{\text{glucose},j} = c_{\text{glucose},i} + \sum_{j=1}^{j} \Delta c_{\text{glucose}} \qquad c_{\text{ethanol},j} = -(0.47)\sum_{j=1}^{j} \Delta c_{\text{glucose},j}$$

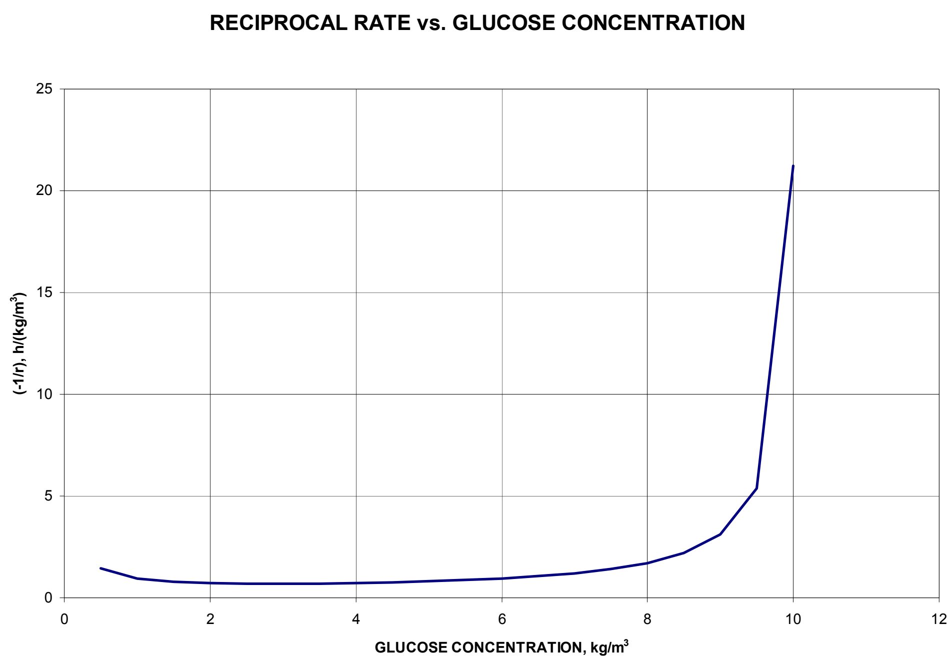
$$c_{S.cereisiaei,j} = 0.01 - (0.06)\sum_{j=1}^{j} \Delta c_{\text{glucose}}$$

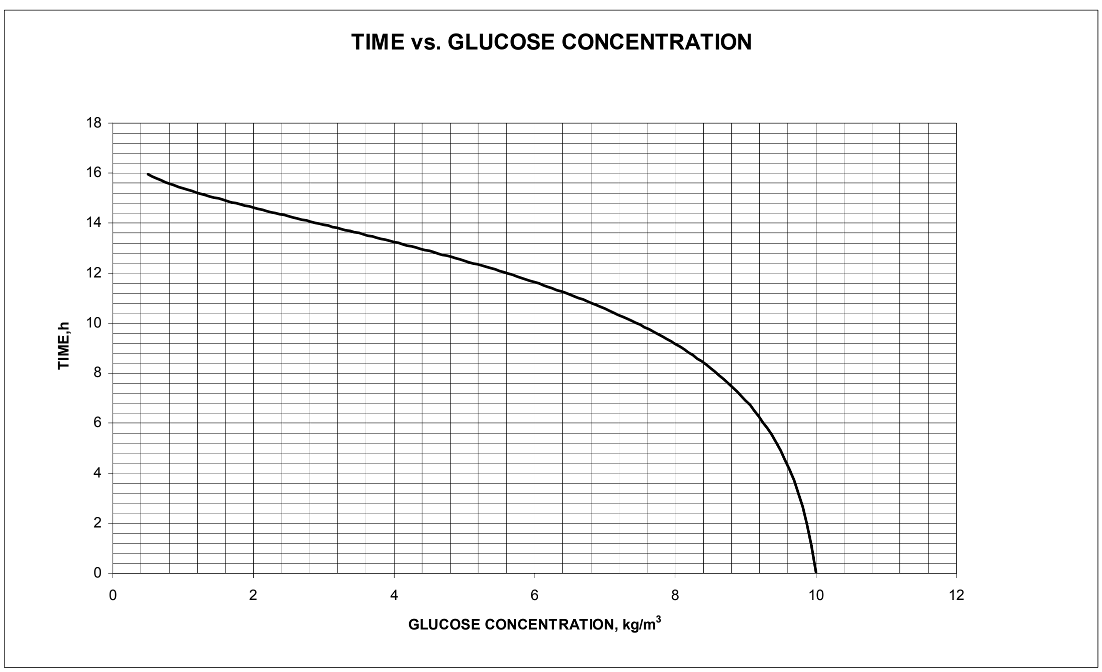
The reciprocal of rate as a function of c_{glucose} and the value of the integral (which is time) as a function of c_{glucose} are shown on the next page.

The result for these conditions is

<u>θ = 16.0 h</u> <u>ANSWER</u>

PROBLEM 13-8 (continued-1)





PROBLEM 13-8 (continued-2)

b) The PFR will have a volume of 7 m^3. Eq. (13-13a) can be written in terms of the total volumetric flowrate V, assumed constant, and glucose concentration as

$$V_R = (V)\int_{c_{\text{glucose},i}}^{c_{\text{glucose},f}} \mathrm{d}(c_{\text{glucose}})/(r_{\text{glucose}})$$

The integral must be reevaluated with the new initial concentration of $c_{S.cerevisiae}$ (=0.9 kg/m^3). The result is a value of 2.23 h.

Thus, the flow rate needed is

$$V = V_R/(2.23) = (7 \text{ m}^3)/(2.23 \text{ h}) = \underline{\underline{3.1 \text{ m}^3/\text{h}}} \ \underline{\underline{\text{ANSWER}}}$$

c) The volume of a single CSTR for this reaction, assuming that the feed concentration of $c_{S.cerevisiae}$ the same as in part b), is obtained from Eq. (13-18) in the volumetric flowrate/concentration form as

$$V_R = V(c_{\text{glucose},f} - c_{\text{glucose},i})/(r_{\text{glucose},f})$$

where $r_{\text{glucose},f}$ is the rate of glucose reaction at the conditions leaving the reactor.

$$V_R = (3.1 \text{ m}^3/\text{h})(0.5 - 10 \text{ kg/m}^3)/(-1.79 \text{ kg/m}^3\cdot\text{h}) = \underline{\underline{16.6 \text{ m}^3}} \ \underline{\underline{\text{ANSWER}}}$$

From Fig. 13-15, choosing a glass-lined, jacketed, agitated reactor, the cost is estimated to be

$\underline{\underline{\text{\$ 120,000 \quad ANSWER}}}$

For the case of three equal volume reactors, an iterative solution is required, wherein reactor sizes are represented as rectangular areas on a reciprocal rate vs. concentration graph. The outlet concentration is varied until the three reactor volumes (rectangular areas on the graph) are equal. See Ex. 13-7. The result, as shown on the graph on the following page, is that the value of the integral for each of the three reactors is 0.90 h. Thus, the volume of each reactor is

$$V_R = V^*(0.90) = (3.1)(.90) = 2.8 \text{ m}^3$$

and the total volume of the 3 reactors = 3*2.8 = $\underline{\underline{8.4 \text{ m}^3 \text{ ANSWER}}}$

From Fig. 13-15, again choosing the glass-lined reactor, the cost is estimated to be

$\underline{\underline{\text{\$ 50,000 each, or \$150,000 for the three \quad ANSWER}}}$

Even though the total volume is just half of that for a single CSTR, the cost is greater for the three reactors. This is a consequence of the economy of scale for such reactors. There are other factors, such as flexibility of multiple reactors that would influence such a selection. If a material other than glass-lined was chosen, the cost figures would be different, but the relative values would be very similar.

PROBLEM 13-8 (continued-3)