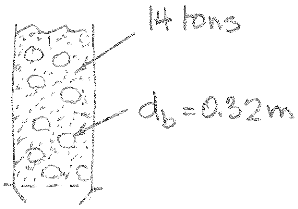
20.1



Refer to Example 1, from which we have

$$\delta = 0.196 \qquad f_b = 0.001$$
$$\varepsilon_f = 0.6 \qquad f_c = 0.047$$
$$K_{bc} = 0.614\ s^{-1} \qquad f_e = 0.352$$
$$\left.\begin{matrix} f_b \\ f_c \\ f_e \end{matrix}\right\} f = 0.4$$
$$K_{ce} = 0.133\ s^{-1} \qquad H_{BFB} = 2(2.875) = 5.57\,m$$

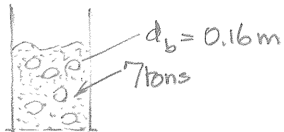
The performance expression becomes

$$\ln\frac{C_{A0}}{C_A} = \frac{[\text{-----}]}{0.4} \cdot \frac{5.57(0.4)}{0.3} = 0.0415\,(18.568) = 0.77$$

see Fig 10

$$\frac{C_A}{C_{A0}} = 0.463 \quad \text{--- or ---} \quad X_A = 53.7\%$$

20.3



Solve the material balances

$$u_{br} = 0.711(gd_b)^{1/2} = 0.711(9.8\times0.16)^{1/2} = 0.8904\ m/s$$
$$u_b = 0.30 - 0.03 + 0.8904 = 1.16\ m/s$$
$$\delta = (0.3-0.03)/1.16 = 0.2327$$
$$\varepsilon_f = 1-(1-0.5)(1-0.2327) = 0.6164$$

$$K_{bc} = 4.5\left(\frac{0.03}{0.16}\right) + 5.85\left[\frac{(20\times10^{-6})^{1/2}(9.8)^{1/4}}{(0.16)^{5/4}}\right] = 1.301\ s^{-1}$$

$$K_{ce} = 6.77\left[\frac{0.5\,(2\times10^{-5})\,1.16}{(0.16)^3}\right]^{1/2} = 0.3609\ s^{-1}$$

$$f_b = 0.001$$
$$f_c = 0.2327(0.5)\left[\frac{3\times0.03/0.5}{0.89-0.03/0.5} + 0.33\right] = 0.0636$$
$$f_e = (1-0.6164) - 0.0636 - 0.001 = 0.3190$$
$$\left.\begin{matrix} f_b \\ f_c \\ f_e \end{matrix}\right\} f = 0.3836$$

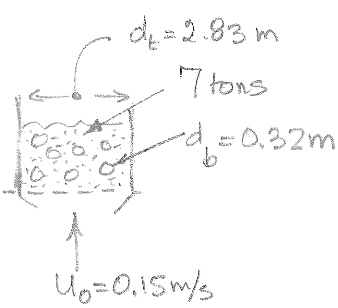
$$H_{BFB} = \frac{W}{\rho A(1-\varepsilon_f)} = \frac{7000}{2000\,\pi\,(1-0.6164)} = 2.904\ m$$

$$\ln\frac{C_{A0}}{C_A} = \left[0.001(0.8) + \cfrac{1}{\cfrac{1}{0.2327(1.301)} + \cfrac{1}{0.0636(0.8) + \cfrac{1}{\cfrac{1}{0.2327(0.3609)} + \cfrac{1}{0.3190(0.8)}}}}\right]\frac{2.904}{0.3}$$

$$= [0.0837]\,9.68 = 0.8102$$

$$\therefore \quad \frac{C_A}{C_{A0}} = 0.445 \quad \text{--- or} \quad X_A = 55.5\%$$

20.5



Solve the material balance

$$u_{br} = 0.711\,(9.8 \times 0.32)^{1/2} = 1.2592 \text{ m/s}$$

$$u_b = 0.15 - 0.03 + 1.2592 = 1.3792 \text{ m/s}$$

$$\delta = (0.15 - 0.03)/1.3792 = 0.087$$

$$\varepsilon_f = 1 - (1-0.5)(1-0.087) = 0.5435$$

$$K_{bc} = 4.5\left(\frac{0.03}{0.32}\right) + 5.85\left[\frac{(2\times10^{-5})^{1/2}\,(9.8)^{1/4}}{(0.32)^{5/4}}\right] = 0.6140 \text{ s}^{-1}$$

$$K_{ce} = 6.77\left[\frac{0.5\,(2\times10^{-5})\,1.2592}{(0.32)^3}\right]^{1/2} = 0.1327 \text{ s}^{-1}$$

$$\left.\begin{aligned} f_b &= 0.001 \\ f_c &= 0.087\,(0.5)\left[\frac{3\,(0.03)/0.5}{1.25 - 0.03/0.5} + 0.33\right] = 0.0209 \\ f_e &= (1-0.5435) - 0.0209 - 0.001 = 0.4346 \end{aligned}\right\} f = 0.4565$$

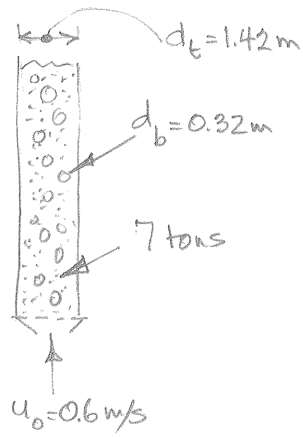
$$H_{BFB} = W/\rho A(1-\varepsilon_f) = 7000/2000\,(2\pi)(1-0.5435) = 1.22 \text{ m.}$$

$$\ln\frac{C_{A0}}{C_A} = \left[0.001(0.8) + \cfrac{1}{\cfrac{1}{0.087(0.614)} + \cfrac{1}{0.0209(0.8) + \cfrac{1}{\cfrac{1}{0.087(0.1327)} + \cfrac{1}{0.4346(0.8)}}}}\right]\frac{1.22}{0.15}$$

$$= [0.0263]\;8.133 = 0.2139$$

$$\therefore \frac{C_{Af}}{C_{A0}} = 0.8074 \quad \text{--- or} \quad X_A = 19\%$$

20.7



$K_{ce} = 6.78$

Again solve

$$u_{br} = 1.26 \text{ m/s}$$

$$u_b = 0.6 - 0.03 + 1.26 = 1.83 \text{ m/s}$$

$$\delta = \frac{0.6 - 0.03}{1.83} = 0.3115$$

$$\varepsilon_f = 1 - (1-0.5)(1-0.3115) = 0.6558$$

$$\left.\begin{aligned} K_{bc} &= 0.614 \text{ s}^{-1} \\ K_{ce} &= 0.133 \text{ s}^{-1} \end{aligned}\right\} \text{from Example 1}$$

20.7 continued

$$f_b = 0.001$$

$$f_c = 0.3115(1-0.5)\left[\frac{3\times 0.03/0.5}{1.26-0.03/0.5} + 0.33\right] = 0.0748 \quad \Bigg\} \; f = 0.3442$$

$$f_e = (1-0.6558) - 0.0748 - 0.001 = 0.2684$$

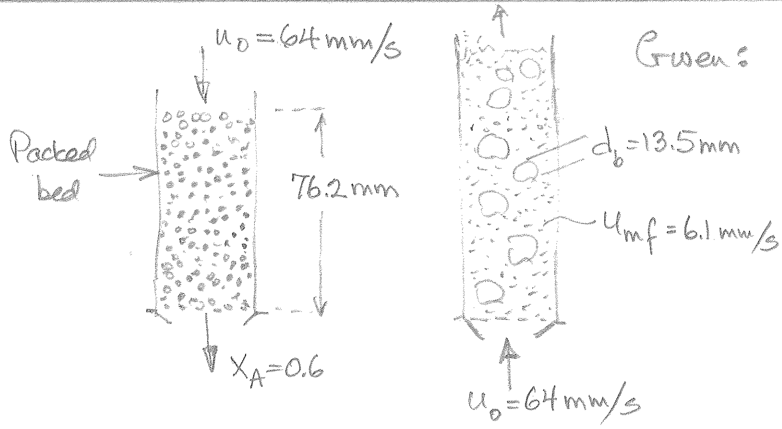
$$H_{BFB} = W/\rho A(1-\varepsilon_f) = 7000/2000(\pi/2)(1-0.6558) = 6.4735\text{ m}$$

$$\ln\frac{C_{A0}}{C_A} = \left[0.001(0.8) + \cfrac{1}{\cfrac{1}{0.3115(0.614)} + \cfrac{1}{0.0748(0.8) + \cfrac{1}{\cfrac{1}{0.3115(0.133)} + \cfrac{1}{0.2684(0.8)}}}}\right]\frac{6.4735}{0.6}$$

$$= \left[0.0641\right] 10.7892 = 0.6914$$

$$\therefore \frac{C_A}{C_{A0}} = 0.5009 \quad \cdots \text{ or } X_A = 50\%$$

20.9



Given: First order reversible rx

$X_{Ae} = 0.94$

$u_{mf} = 6.1$ mm/s

$\varepsilon_m = 0.4$

$\varepsilon_{mf} = 0.5$

$\alpha = 0.33$

$\mathcal{D} = 2\times 10^{-5}$ m²/s

Find $X_{Af_2} = ?$

For a reversible first order reaction Eq 3.54 or Eq 5.22 gives

For plug flow: $$X_{Ae}\ln\frac{X_{Ae}}{X_{Ae}-X_{Ap}} = k''' \tau''' \quad \cdots\cdots\cdots (i)$$

$$\text{or } k''' = \frac{v}{V} X_{Ae}\ln\frac{X_{Ae}}{X_{Ae}-X_A} = \frac{u_0 A}{H_p A(1-\varepsilon_m)} X_{Ae}\ln\frac{X_{Ae}}{X_{Ae}-X_A}$$

$$= \frac{64}{76.2(1-0.4)}(0.94)\ln\frac{0.94}{0.94-0.60} = 1.3381 \frac{m^3}{m^3\text{cat}\cdot s}$$

For the fluidized bed the performance equation (compare with eq (i)) is

$$X_{Ae}\ln\frac{X_{Ae}}{X_{Ae}-X_A} = \underbrace{\left[f_b k''' + \frac{\quad}{\quad}\right]}_{f_{total}} \underbrace{\frac{H_{BFB} f_{total}}{u_0}}_{\tau'''} \quad \cdots (ii)$$

20.9 continued

Evaluate terms in units of meters, not millimeters

$$u_{br} = 0.711(9.8 \times 0.0135)^{1/2} = 0.2586 \text{ m/s}$$

$$u_b = 0.064 - 0.0061 + 0.2586 = 0.3165 \text{ m/s}$$

Is this reactor in the BFB regime? Let's see

$$\frac{u_b}{u_e} = \frac{0.316}{0.006/0.5} = 26.3 \quad \text{--- yes it is a vigorously fluidized bed}$$

$$\delta = (0.064 - 0.0061)/0.3165 = 0.1829$$

$$\varepsilon_f = 1 - (1-0.5)(1-0.1829) = 0.5915$$

$$K_{bc} = 4.5\left(\frac{0.0061}{0.0135}\right) + 5.85\left[\frac{(2\times10^{-5})^{1/2}(9.8)^{1/4}}{(0.0135)^{5/4}}\right] = 2.0333 + 10.0589 = 12.0922 \text{ s}^{-1}$$

$$K_{ce} = 6.77\left[\frac{0.5(2\times10^{-5})0.3165}{(0.0135)^3}\right]^{1/2} = 7.6785 \text{ s}^{-1}$$

$$\left.\begin{aligned} f_b &= 0.001 \\ f_c &= 0.1829(1-0.5)\left[\frac{3(0.0061)/0.5}{0.2568 - 3(0.0061)/0.5} + 0.33\right] = 0.2393 \\ f_e &= (1-0.5915) - 0.2393 - 0.001 = 0.1682 \end{aligned}\right\} f = 0.4085$$

$$H_{BFB} = H_{fixed}\left(\frac{1-\varepsilon_m}{1-\varepsilon_{mf}}\right)\frac{1}{1-\delta} = (0.0762)\left(\frac{1-0.4}{1-0.5}\right)\frac{1}{1-0.1829} = 0.1119 \text{ m}$$

Now replace values into Eq (ii)

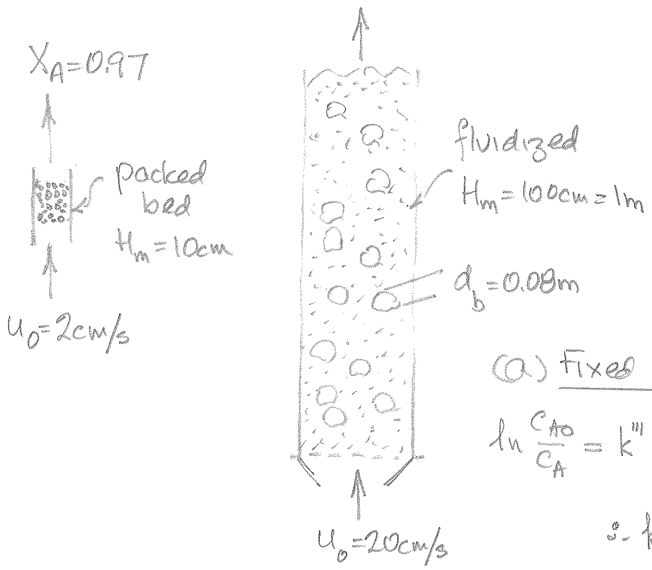
$$X_{Ae} \ln \frac{X_{Ae}}{X_{Ae}-X_A} = \left[0.001(1.3383) + \cfrac{1}{\cfrac{1}{0.1829(12.0922)} + \cfrac{1}{0.2393(1.3381) + \cfrac{1}{\cfrac{1}{0.1829(7.6785)} + \cfrac{1}{0.1682(1.3381)}}}}\right]\frac{0.1119}{0.064}$$

$$\ln \frac{0.94}{0.94 - X_A} = \left[0.4185\right] 1.7484 \left(\frac{1}{0.94}\right) = 0.7784$$

$$\therefore \quad \frac{X_{Ae}}{X_{Ae}-X_A} = 2.1780 \quad \text{or} \quad X_A = 0.5084$$

<u>Note.</u> Compare this calculated X_A value with that found experimentally, as shown in Fig 3, pg 520 of Mathis & Watsons paper.

20.11



$\varepsilon_m = \varepsilon_{mf} = 0.5$
$\mathcal{D} = 3\times10^{-5}\ m^2/s$
$u_{mf} = 0.032\ m/s$
$\alpha = 0.34$

(a) Fixed bed experiment

$$\ln\frac{C_{A0}}{C_A} = k'''\frac{V_s}{v} = k'''\frac{H_m A(1-\varepsilon_m)}{u_0 A} = k'''\frac{0.1(1-0.5)}{0.02}$$

$$\therefore\ k''' = \frac{0.02}{0.1(1-0.5)}\ln\frac{100}{3} = 1.4026\ m^3/m^3_{cat}\cdot s \quad \text{— (a)}$$

(b) Fluidized bed

$$u_{br} = 0.711(9.8\times0.08)^{1/2} = 0.6295\ m/s$$

$$u_b = 0.2 - 0.032 + 0.6295 = 0.7975\ m/s$$

$$\delta = (0.2-0.032)/0.7975 = 0.2107$$

$$\varepsilon_f = 1-(1-0.5)(1-0.2107) = 0.6053$$

$$K_{bc} = 4.5\left(\frac{0.032}{0.08}\right) + 5.85\left[\frac{(3\times10^{-5})^{1/2}(9.8)^{1/4}}{(0.08)^{5/4}}\right] = 3.1325\ s^{-1}$$

$$K_{ce} = 6.77\left[\frac{0.5(3\times10^{-5})0.6295}{(0.08)^3}\right]^{1/2} = 0.9194\ s^{-1}$$

$$\left.\begin{aligned} f_b &= 0.001\\ f_c &= 0.2107(1-0.5)\left[\frac{3(0.032)/0.5}{0.7975-0.032/0.5}+0.34\right] = 0.0634\\ f_e &= (1-0.6053) - 0.0634 - 0.001 = 0.3303 \end{aligned}\right\} f = 0.3947$$

$$H_{BFB} = \frac{H_m(1-\varepsilon_m)}{1-\varepsilon_f} = \frac{1.0(0.5)}{1-0.6053} = 1.2668\ m$$

$$\ln\frac{C_{A0}}{C_A} = \left[0.001(1.4026) + \cfrac{1}{\cfrac{1}{0.2107(3.1325)} + \cfrac{1}{0.0634(1.4026) + \cfrac{1}{\cfrac{1}{0.9194(0.2107)} + \cfrac{1}{0.3303(1.4026)}}}}\right]\frac{1.27}{0.2}$$

$$= [0.1695]\,6.334 = 1.0736$$

$$\therefore\ \frac{C_A}{C_{A0}} = 0.3418 \quad \text{--- or}\quad X_A = 34\% \quad \text{— (b)}$$

(c) Big fixed bed

$$\frac{C_A}{C_{A0}} = e^{-k'''H_f f} = e^{-1.4026(1.27)0.3947} = 0.03 \quad \text{--- or}\quad X_A = 97\% \quad \text{— (c)}$$