Tyler Bradley | ENVE 660 | HW 5 | 3/8/18

(1) $X_{O_3} = 0.03$

$k_L a_L = 18 \frac{1}{hr}$

gas transfer limited by interfacial transport

$k_L a_L << \frac{Q_g H}{V_L}$

$r_d = -k_d C_{O_3} = -K C_L$

k_d @ pH = 8 & T = 25°C = $12 \frac{1}{hr}$

$H_{pm} = 90.9 \frac{atm}{mol/L_L}$

a) find C_{O_3} if $Q_{in} = Q_{out} = 0$

$$r_L = k_L a_L (C^*_{L,in} - C_L)$$

$$V \frac{dC_L}{dt}^{\,0} = r_L V - r_d V$$

$P_{O_3} = (0.03)(1\ atm) = 0.03\ atm$

$$C_L^* = \frac{P_{O_3}}{H_{pm}} = \frac{0.03\ atm}{90.9 \frac{atm}{mol/L}} = 3.3 \times 10^{-4} \frac{mol}{L}$$

$$0 = k_L a_L (C_L^* - C_L) - k_d C_L$$
$$= k_L a_L C_L^* - C_L (k_L a_L + k_d)$$
$$C_L = \frac{k_L a_L C_L^*}{k_L a_L + k_d} = \frac{(18 \frac{1}{hr})(3.3 \times 10^{-4} \frac{mol}{L})}{(18 \frac{1}{hr}) + (12 \frac{1}{hr})}$$

$$\boxed{C_L = 1.98 \times 10^{-4} \frac{mol}{L}}$$

b) CFSTR $\tau = 15\ min$

Assume
steady state
$C_{L,in} = 0$

$$V \frac{dC_L}{dt}^{\,0} = Q C_{L,in}^{\,0} - Q C_{L,out} + r_L V + r_d V$$
$$0 = -\frac{Q_L}{V} C_{L,out} + k_L a_L (C_L^* - C_{L,out}) - k_d C_{L,out}$$
$$= k_L a_L C_L^* - C_{L,out}\left(k_L a_L + k_d + \frac{1}{\tau}\right)$$

$$\tau = \frac{V}{Q}$$

$$C_{L,out} = \frac{k_L a_L C_L^*}{(k_L a_L + k_d + \frac{1}{\tau})} = \frac{(18 \frac{1}{hr})(3.3 \times 10^{-4} \frac{mol}{L})}{\left[18 \frac{1}{hr} + 12 \frac{1}{hr} + \frac{1}{15\ min}\left(\frac{60\ min}{1\ hr}\right)\right]}$$

$$\boxed{C_{L,out} = 1.75 \times 10^{-4} \frac{mol}{L}}$$

(2) $T = 25°C$

$Q_L = 500\ L/min$

$h = 2\ m$

$d = 1\ m$

$R = 2$

$H_{cc} = 0.023$

$k_L = 1 \times 10^{-4}\ m/s$

$k_g = 2.5 \times 10^{-3}\ \frac{m}{s}$

$a_R = 105\ m^2/m^3$

find $\frac{Q_L}{A_r}$ and $\frac{Q_g}{A_r}$

a) $R = \frac{Q_g H_{cc}}{Q_L}$ $\quad Q_L = \left(500 \frac{L}{min}\right)\left(\frac{1\ min}{60\ s}\right)\left(\frac{1\ m^3}{1000\ L}\right) = 0.0083\ \frac{m^3}{s}$

$$Q_g = \frac{R Q_L}{H_{cc}} = \frac{2\left(0.0083 \frac{m^3}{s}\right)}{0.023} = 0.722\ \frac{m^3}{s}$$

$$\frac{Q_L \rho_L}{A_r} = \frac{\left(0.0083 \frac{m^3}{s}\right)\left(997 \frac{kg}{m^3}\right)}{\pi\left(\frac{1\ m}{2}\right)^2} = \boxed{10.5\ \frac{kg}{m^2 \cdot s}}$$

$$\frac{Q_g \rho_g}{A_r} = \frac{\left(\cancel{0.0083}\ 0.722 \frac{m^3}{s}\right)\left(1.225 \frac{kg}{m^3}\right)}{\pi(0.5\ m)^2} = \boxed{1.126\ \frac{kg}{m^2 \cdot s}}$$

b) HTU = ?

$$HTU = \frac{Q_L/A_r}{K_L a_R} \qquad K_L = \left(\frac{1}{k_L} + \frac{1}{k_g H}\right)^{-1} = \left(\frac{1}{1\times10^{-4} \frac{m}{s}} + \frac{1}{(2.5\times10^{-3})(0.023)}\right)^{-1}$$

$$K_L = 3.651 \times 10^{-5}\ \frac{m}{s}$$

$$HTU = \frac{\left(0.0083 \frac{m^3}{s}\right)}{\left(3.651\times10^{-5} \frac{m}{s}\right)\left(105 \frac{m^2}{m^3}\right)\left(\pi(0.5\ m)^2\right)} = \boxed{2.76\ m}$$

c) $\eta = ?$

$$\eta = 1 - \frac{\frac{R-1}{R}}{\exp\left(\frac{K_L a_r}{Q_L/A_r} \cdot \frac{R-1}{R} z\right) - \frac{1}{R}}$$

$$= 1 - \left[\frac{\frac{2-1}{2}}{\exp\left[\frac{\left(3.651\times10^{-5} \frac{m}{s}\right)\left(105 \frac{m^2}{m^3}\right)}{\left(0.0083 \frac{m^3}{s}\right)/\left(\pi(0.5)^2\right)} \frac{2-1}{2}\ 2\right] - \frac{1}{2}}\right] = 1 - \frac{0.5}{1.801 - 0.5}$$

$$\boxed{\eta = 0.616}$$

d) what would happen to v_L, $K_L a_r$, and HTU if $d = \frac{d_0}{2}$

$v_L = \frac{Q}{A_r} \rightarrow v_L$ would increase as the A_r is smaller

$K_L a_L =$

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(3) Extra-Credit

$$\equiv S + A \rightleftharpoons \equiv SA$$

$q_{\equiv SA}$ = adsorption density for sites occupied by single A molecule
$q_{\equiv S}$ = adsorption density for unoccupied sites

↳ write equation for $q_{\equiv SA}$ at given concentration C_A

$q_{max} = q_{total} = \text{constant} = q_{\equiv S} + q_{\equiv SA}$

First we can define a mass balance for q

$$q(\equiv S)_{total} = q_{\equiv S} + q_{\equiv SA}$$

from the chemical reaction we can write a equilibrium constant as follows:

$$K = \frac{q_{\equiv SA}}{q_{\equiv S}\, C_A}$$

Solving the MB eq. for $q_{\equiv S}$:

$$q_{\equiv S} = q(\equiv S)_{total} - q_{\equiv SA}$$

$$K = \frac{q_{\equiv SA}}{(q(\equiv S)_{tot} - q_{\equiv SA})\, C_A}$$

$$K C_A\, q(\equiv S)_{tot} - K C_A\, q_{\equiv SA} = q_{\equiv SA}$$

$$q_{\equiv SA}(1 + K C_A) = K C_A\, q(\equiv S)_{tot}$$

$$\boxed{q_{\equiv SA} = \frac{K C_A\, q(\equiv S)_{tot}}{(1 + K C_A)}}$$