Homework #3 - Solutions

Due: June 02, 2016 (Thu), in class

1 You set up an experiment to determine the overall mass transfer coefficient, K_L for gas-liquid transfer of oxygen and ethanol in a well-mixed reactor. The results of the experiment, the unitless Henry's law constants, and the diffusion coefficients in water are as follows:

Compounds	K_L (m/s)	H_u	D_w (m^2/s)
Oxygen, O_2	2.0×10^{-5}	30	2.1×10^{-9}
Ethanol, C_2H_5OH	4.1×10^{-7}	2.7×10^{-4}	1.2×10^{-9}

Using the ratio of mass transfer coefficients in gas and liquid phase of 100 (i.e., k_G/k_L = 100), answer the following questions.

i) For oxygen and ethanol, determine whether gas or liquid phase will control the mass transfer. Show your reasoning. (10 points)

Answer)

For oxygen:

$$\frac{k_G H_{CC}}{k_L} = 100\times30 = 3000 \gg 1 \quad \frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{H_u k_G} \approx \frac{1}{k_L}; \text{ liquid phase controls}$$

For ethanol:

$$\frac{k_G H_{CC}}{k_L} = 100\times2.7\times10^{-4} = 0.027 \ll 1 \quad \frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{H_u k_G} \approx \frac{1}{H_u k_G}; \text{ gas phase controls}$$

ii) From the conclusion above, determine the liquid film thickness. (5 points)

Answer)

Use data for oxygen:

$K_L = k_L = D_m^L / \delta_L$

$$\delta_L = \frac{D_m^L}{K_L} = \frac{2.1\times10^{-9}\, m^2/s}{2.0\times10^{-5}\, m/s} = 1.05\times10^{-4}\, m = 0.11\, mm$$

2. An advanced oxidation processes is operated in a steady-state, continuously-stirred tank reactor with a hydraulic retention time of 1 min to remove n-dimethylnitrosanmine (NDMA). Determine the hydroxyl radical concentration that should be maintained in the reactor to achieve 95% removal of NDMA by the reactor. The 2nd order rate constant for the reaction of hydroxyl radical with NDMA is 4.0 × 10^8 L/mole-s.

(20 points)

(Answer)

For following the reaction between NDMA and hydroxyl radical,

$NDMA + HO\cdot \rightarrow P$

the reaction rate is expressed in second order:

$$\frac{dC_{NDMA}}{dt} = -k_2 C_{HO\cdot}\, C_{NDMA}$$

As $C_{HO\cdot}$ *is constant in a CSTR, the reaction rate expression can be written as:*

$$\frac{dC_{NDMA}}{dt} = -k_1 C_{NDMA} \qquad \textit{where} \;\; k_1 = k_2 C_{HO\cdot}$$

For a first-order reaction in a CSTR, following equation can be used:

$$\frac{C}{C_0} = \frac{1}{1+k_1\tau}$$

Therefore,

$$k_1 = \frac{1}{\tau}\cdot\left(\frac{C_0}{C}-1\right) = \frac{1}{1\,\text{min}}\cdot\left(\frac{100}{5}-1\right) = 19\,\text{min}^{-1} = 0.317\, s^{-1}$$

As $C_{HO\cdot} = \frac{k_1}{k_2}$ *, the required hydroxyl radical concentration is:*

$$C_{HO\cdot} = \frac{0.317\ s^{-1}}{4\times 10^{8}\ L/mole-s} = 7.9\times 10^{-10}\ M$$

3. Briefly (in one or two paragraphs for each) describe the following two biological treatment processes for wastewater treatment: i) rotating biological contactor (RBC) and ii) upflow anaerobic sludge blanket (UASB).

(15 points)

Answer)

i) RBC consists of a series of closely spaced, parallel discs mounted on a rotating shaft which is supported just above the surface of the wastewater. Microorganisms grow on the surface of the discs where biological degradation of the wastewater pollutants takes place. The attached microorganisms (biofilm) take up oxygen while exposed to the atmospheric air, and organic substrates and other nutrients while submerged in the wastewater. The rotation sloughs off excess solids generated.

ii) UASB uses an anaerobic process whilst forming a blanket of granular sludge which suspends in the tank. Wastewater flows upwards through the blanket and is processed (degraded) by the anaerobic microorganisms. The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants. Small sludge granules begin to form whose surface area is covered in aggregations of bacteria.

4. A CSTR without solids recycle is used to treat a wastewater containing 100 mg/L phenol at 20℃. Using the following kinetic coefficients at 20℃, determine i) the minimal hydraulic retention time (HRT) in days at which the biomass can be washed out faster than they can grow, ii) the minimum HRT at 10℃, assuming the temperature coefficient Θ is 1.07 for k and 1.04 for b, iii) the effluent phenol and biomass concentration at an HRT of 7.0 d at 20℃.

$k = 0.80\ g\ phenol/g\ VSS/d$

$K_s = 0.15\ mg\ phenol/L$

$Y = 0.45\ g\ VSS/g\ phenol$

$b = 0.08\ /d$

Hint 1: When there's no solids recycle, SRT should be the same as HRT.

Hint 2: The modified van't Hoff-Arrhenius relationship, $k_2/k_1 = \theta^{(T_2 - T_1)}$, applies to both k and b. Assume Y and K_s are not functions of temperature.

(30 points)

Answer)

i)

Since $K_s \ll S^0$,

$$SRT_{\min} = \frac{1}{Yk - b} = \frac{1}{0.45\ g\ VSS/g\ phenol \cdot 0.80\ g\ phenol/g\ VSS/d - 0.08/d}$$

$= 3.57\ d$

ii)

$k_{10} = k_{20} \cdot \theta^{(10-20)} = 0.8 \cdot 1.07^{-10} = 0.41\ g\ phenol/g\ VSS/d$

$b_{10} = b_{20} \cdot \theta^{(10-20)} = 0.08 \cdot 1.04^{-10} = 0.054/d$

$$SRT_{\min} = \frac{1}{Yk - b} = \frac{1}{0.45\ g\ VSS/g\ phenol \cdot 0.41\ g\ phenol/g\ VSS/d - 0.054/d}$$

$= 7.66\ d$

iii)

$$S = \frac{K_s(1 + b \cdot SRT)}{SRT(Yk - b) - 1}$$

$$= \frac{0.15\ mg\ phenol/L \cdot (1 + 0.08/d \cdot 7.0\ d)}{7.0\ d \cdot (0.45\ g\ VSS/g\ phenol \cdot 0.80\ g\ phenol/g\ VSS/d - 0.08/d) - 1}$$

$= 0.24\ mg\ phenol/L$

$$X_a = \left(\frac{SRT}{\tau}\right)\left[\frac{Y(S^0 - S)}{1 + b \cdot SRT}\right] = \frac{Y(S^0 - S)}{1 + b \cdot SRT}$$

$$= \frac{0.45\ g\ VSS/g\ phenol \cdot (100 - 0.24)\ mg\ phenol/L}{1 + 0.08/d \cdot 7.0\ d} \times 10^{-3}\ g\ phenol/mg\ phenol \times 10^{3}\ mg\ VSS/g\ VSS$$

$$= 28.8\ mg\ VSS/L$$

5. A complete-mix activated sludge process with secondary clarification and sludge recycle is used to treat a wastewater at a flowrate of 1,000 m^3/d with a bsCOD of 2,000 mg/L. The MLSS concentration is 3,300 mg/L, MLVSS/MLSS ratio is 0.80, effluent TSS concentration is 20 mg/L, HRT is 24 h, recycle MLSS concentration is 10,000 mg/L, and waste sludge flowrate is 85.5 m^3/d. Using the given information, determine i) the system SRT, ii) the F/M ratio in g bsCOD/g VSS/d, iii) the observed yield in g TSS/g bsCOD, and iv) the true yield in g VSS/g bsCOD. Assume that the effluent bsCOD concentration is negligible compared to the influent concentration, and influent nbVSS is negligible. Use the following parameters.

$$b = 0.10\ g\ VSS/g\ VSS/d$$

$$f_d = 0.15\ g\ VSS/g\ VSS$$

(40 points)

Answer)

i)

Applying the same logic as we used in class to get SRT of active biomass for TSS:

$$SRT = \frac{VX_{TSS}}{(Q - Q^w)X^e_{TSS} + Q^w X^r_{TSS}}$$

$$V = Q\tau = 1000\ m^3/d \cdot 1\ d = 1000\ m^3$$

$$= \frac{1000\ m^3 \cdot 3300\ mg/L}{(1000 - 85.5)\ m^3/d \cdot 20\ mg/L + 85.5\ m^3/d \cdot 10000\ mg/L} = 3.8\ d$$

ii)

$$F/M = \frac{QS^0}{VX_{VSS}} = \frac{1000\ m^3/d \cdot 2000\ g\ bsCOD/m^3}{1000\ m^3 \cdot 3300\ g\ TSS/m^3 \cdot 0.80\ g\ VSS/g\ TSS} = 0.76\ g\ bsCOD/g\ VSS/d$$

iii)

$$Y_{obs} = \frac{P_{X,TSS}}{Q(S^0 - S)} = \frac{X_{TSS} \cdot V}{Q(S^0 - S) \cdot SRT} = \left(\frac{\tau}{SRT}\right)\frac{X_{TSS}}{S^0}$$

$$= \frac{1\ d}{3.8\ d} \cdot \frac{3300\ mg\ TSS/L}{2000\ mg\ bsCOD/L} = 0.43\ g\ TSS/g\ bsCOD$$

iv)

$$Y_{obs} = 0.80\ g\ VSS/g\ TSS \cdot 0.43\ g\ TSS/g\ bsCOD = 0.35\ g\ VSS/g\ bsCOD$$

$$Y_{obs} = \frac{Y}{1 + b \cdot SRT} + \frac{f_d \cdot b \cdot Y \cdot SRT}{1 + b \cdot SRT} = Y \cdot \frac{1 + f_d \cdot b \cdot SRT}{1 + b \cdot SRT}$$

$$Y = Y_{obs} \cdot \frac{1 + b \cdot SRT}{1 + f_d \cdot b \cdot SRT} = 0.35\ g\ VSS/g\ bsCOD \cdot \frac{1 + 0.10/d \cdot 3.8\ d}{1 + 0.15 \cdot 0.10/d \cdot 3.8\ d}$$

$$= 0.46\ g\ VSS/g\ bsCOD$$

5. The overall reaction for denitrification using methanol as an electron donor is written as below. As can be seen by the reaction, nitrate is used not only as an electron acceptor but also as a source of nitrogen for cell synthesis. Using the reaction stoichiometry, calculate the amount of nitrogen consumed by i) assimilatory nitrate reduction and ii) dissimilatory nitrate reduction as g NO_3-N/g COD.

$$0.1667 CH_3OH + 0.1561 NO_3^- + 0.1561 H^+ \rightarrow 0.00954 C_5H_7O_2N + 0.0733 N_2 + 0.3781 H_2O + 0.119 CO_2$$

Hint: Use the following reaction for the aerobic oxidation of methanol:

$$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$$

(20 points)

Answer)

Ethanol COD: $\frac{3 \times 32\ g\ O_2}{2\ mole\ methanol} = 48\ g\ COD/mole\ methanol$

i)

0.00954 mole nitrogen is used for cells from 0.1667 mole methanol.

$$\frac{0.00954\ mole\ NO_3-N \times 14\ g\ NO_3-N/mole}{0.1667\ mole\ methanol \times 48\ g\ COD/mole} = 0.0167\ g\ NO_3-N/g\ COD$$

ii)

0.0733×2 = 0.1466 mole nitrogen is used as electron acceptor, being reduced into nitrogen gas from 0.1667 mole methanol.

$$\frac{0.1466\ mole\ NO_3-N \times 14\ g\ NO_3-N/mole}{0.1667\ mole\ methanol \times 48\ g\ COD/mole} = 0.256\ g\ NO_3-N/g\ COD$$

6. The following compounds, although not mentioned in the class, have recently been identified to occur in wastewater and natural water bodies, and may cause concerns in human health or aquatic ecosystem. These compounds are referred to as “emerging contaminants” (and there are many, many more examples). From literature search, identify the major uses of each (or each group) of the compounds.

   i) triclosan

   ii) ibuprofen

   iii) bisphenol A

   iv) perfluorochemicals (PFCs)

(20 points)

Answer)

i) triclosan: antibacterial agents (used in toothpastes, detergents, soaps, toys, etc.)

ii) ibuprofen: analgesic (drugs used to relieve pain, fever, and inflammation)

iii) bisphenol A: plastic production (e.g., polycarbonate bottles)

iv) perfluorochemicals: used as surfactants, surface coating material, or additives for various products including textiles, papers, plastic wraps, etc., and industrial processes including electronic device and semiconductor manufacturing. Also used as a *fire-fighting foam.*