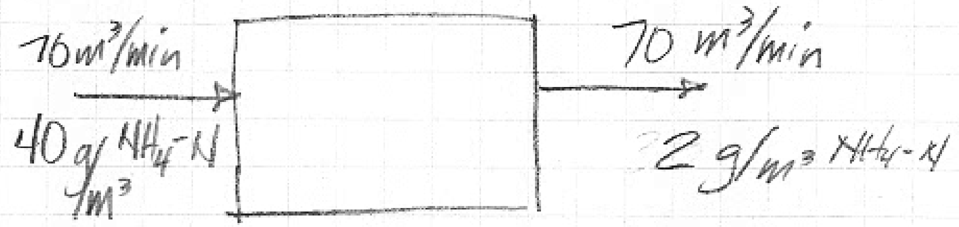
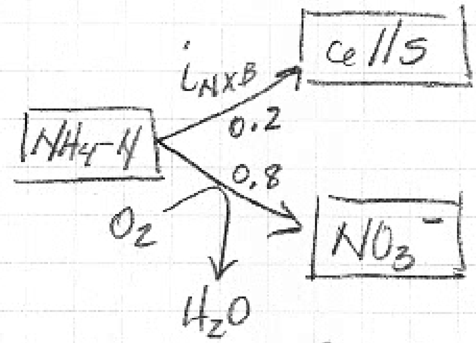
F2011 Homework 2 Solutions 30 points possible

1.



assume influent NH_4-N = 40 g/m³ with 95% remove (5% in effluent)

concept



a. O_2 only used for nitrification

(2)

$$COD/O_2 \text{ equivalent} = 4.57 \frac{g\ O_2/COD}{g\ NH_4\text{-}N}$$

$$\left(\text{from} \quad NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \qquad \frac{2(32)}{1(14)} = 4.57 \frac{g\ O_2/COD}{g\ NH_4\text{-}N}\right)$$

$$\frac{\text{mass } O_2}{d} = 0.8(40-2)\frac{g\ NH_4\text{-}N}{m^3}\left(4.57\frac{g\ O_2}{g\ NH_4\text{-}N}\right)\frac{70\ m^3}{min}\ \frac{1440\ min}{d}\ \frac{10^{-3}}{g}$$

$$\cong 14{,}000 \frac{Kg}{d}$$

b. cells: $C_5H_7NO_2$

(2)

$$i_{NXB} = \frac{14\ gN}{113\ g\ cells} = 0.124 \frac{gN}{g\ cells}$$

$$\text{mass cell formation rate} = \frac{0.2(40-2)\frac{gN}{m^3}}{0.124\frac{gN}{g\ cells}}\left(\frac{70\ m^3}{min}\right)\left(\frac{1440\ min}{d}\right)\frac{365\ d}{yr}\ \frac{MT}{10^6\ g}$$

$$= 2{,}255\ MT/yr$$

(4 points)

1. purposes

a. mass partitioning of ww component into storage (cells) and O_2-demand (nitrification)

b. dual role of NH_4-N (cells & e^- donor)

2. (3 points)

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O$$

$$CH_2O + 0.8NO_3^- + 0.8H^+ \longrightarrow 0.4N_2 + CO_2 + 1.4H_2O$$

compare

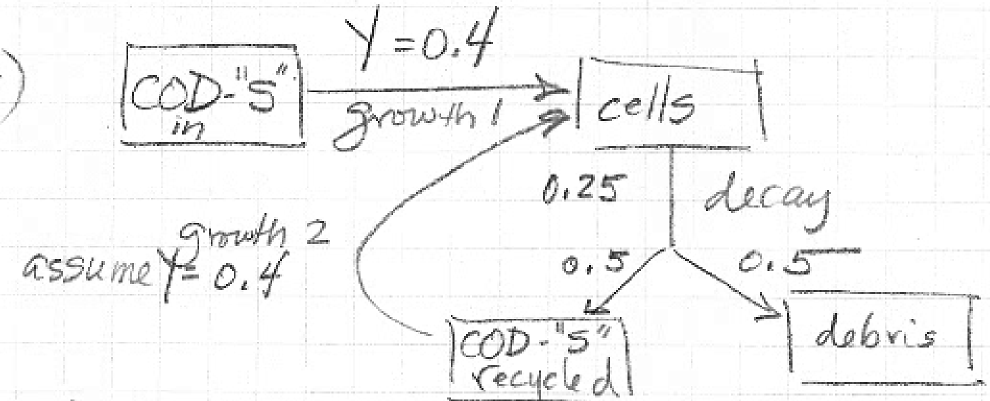
$$\frac{\left(\frac{1(32g)O_2}{1(30g)CH_2O}\right)}{\left(\frac{0.8(14g)N}{1(30g)CH_2O}\right)} = \frac{32\,gO_2}{11.2\,gNO_3\text{-}N} = 2.86\,\frac{g\,O_2}{gNO_3\text{-}N}$$

Purposes:

a. Compare stoichiometries for 2 e^- acceptors

b. get familiar with writing redox stoichiometry

3. (3 points)



a. (2) Y_{obs} = growth1 − decay + growth 2

$$= 0.4 - 0.25(0.4) + 0.4(0.5)(0.25)(0.4)$$

$$= 0.4(1 - 0.25 + 0.5(0.25)(0.4)) = 0.32\ \frac{g\,cellCOD}{gCOD\text{-}S}$$

$Y_D = 0.4(0.25)(0.5)\ gCOD\text{-}D/gCOD_S = 0.05$

0.05

0.32 + 0.0

= 0.135

13.5%

3. purpose – introduce cell decay and release of substrate COD

b. 1 iteration: debris fraction = 0.4 (0.25) 0.5

(1) = 0.05 or 5%

introduce component non-degradable organic matter

4. a. $0.45 \frac{g\ cells}{g\ COD} \times 1.42 \frac{g\ cell\ COD}{g\ cells} = 0.64 \frac{g\ cell\text{-}COD}{g\ COD\text{-}S}$

(4 points)

b. reference COD-S

(1) $-1\ COD\text{-}S + (1-Y)\ COD\text{-}O_2 + Y\ COD\ cells = 0$

OR for O_2

(2) $-1\ COD\text{-}S - (1-Y)\ O_2 + Y\ COD\ cells = 0$

reference COD-cells

(3) $-\left(\frac{1}{Y}\right) COD_S - \left(\frac{1-Y}{Y}\right) O_2 + 1\ COD\text{-}cells = 0$

from (2)

$$r = \frac{r_S}{(-1)} = \frac{r_O}{-(1-Y)} = \frac{r_X}{Y}$$

$r_S = -300 \frac{g}{m^3}\ 50{,}000 \frac{m^3}{d}$ assuming 100% removal

$r_{O_2} = -(1-0.64)(300)(50000)10^{-3} \frac{kg}{g} = 5{,}400 \frac{kg\ O_2}{d}$

$r_X = Y(-r_s) = 0.64(300)(50000)(10^{-3}) = 9600 \frac{kg\,COD_{cel}}{d}$

4. purpose

a. convert particulate organics (cells) to COD

b. write COD/O_2/cell stoichiometries

c. relate rates to stoichiometry using reference rate

$2.03\,C = 2.03\,C$ ✓
$2.98\,O = 2.98\,O$ ✓
N ✓
$4.92\,H = 4.92\,H$ ✓

5. (4 points) $1\,CH_3COO^- + 0.03\,CO_2 + 0.02\,NH_4^+ + 0.92\,H_2O \rightarrow$

$\rightarrow 0.95\,CH_4 + 0.02\,C_5H_7NO_2 + 0.98\,HCO_3^-$

a.) ref CH_3COO^-, $mw = 59$

$\psi_1 = 1$, $\psi_2 = \frac{0.03(44)}{1(59)} = 0.022$, $\psi_3 = \frac{0.02(18)}{1(59)} = 0.006$

$\psi_4 = \frac{0.92(18)}{1(59)} = 0.281$, $\psi_5 = \frac{0.95(16)}{1(59)} = 0.258$

$\psi_6 = \frac{0.02(113)}{1(59)} = 0.038$ $\psi_7 = \frac{0.98(61)}{1(59)} = 1.01$

$1CH_3COO^- + 0.022\,CO_2 + 0.006\,NH_4 + 0.281\,H_2O \rightarrow 0.258\,CH_4 + 0.038\,C_5H_7NO_2 + 1.01\,HCO_3^-$

$1.309 = 1.306$ ✓

b. $Y_1 = 1$, COD-Ac $= 1.085\,g\,COD/g\,Ac$

COD-CO_2 (e^- acceptor) $= -1.45\,g\,COD/g\,CO_2$

$Y_2 = -\frac{1.45(0.022)}{1(1.085)}$ COD-CH_4 $= 4\frac{g\,COD}{g\,CH_4}$ ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2$

$Y_2 = -0.029$ COD-cells $= 1.42$

COD everything else $= 0$

$Y_3 = \frac{0.258(4)}{1.085} = 0.95$

$Y_4 = \frac{0.038(1.42)}{1.085} = 0.05$

obviously not all CH_4 comes from CO_2

b) $1\,COD\text{-}Ac - 0.029\,COD\text{-}CO_2 \rightarrow 0.95\,COD\text{-}CH_4 + 0.05\,COD\text{-}cells$

$1 - 0.029 = 0.971$. $0.95 + 0.05 = 1.0$ (close)

1. Purpose

Learn stoich/rate application to calculating overall component transformation rates using matrix method for multiple processes in one reactor.

$$\begin{bmatrix} \nu_{i,1} \text{ or } Y_{i,1} \\ \vdots \\ \nu_{i,n} \text{ or } Y_{i,n} \end{bmatrix} * \begin{bmatrix} r_1 \\ \vdots \\ r_n \end{bmatrix}$$

multiply 2 vectors
for ith component, n reaction

for ith component

$$r_i = \sum_{j=1}^{n} \left(\nu_{i,j} \, r_j \right)$$

will be used extensively in BioWin

have already used in simple CSTR

$$r_X = (\mu_H - b_H) X_{BH}$$

6. a. $C_6H_5OH + 11H_2O \rightarrow 6CO_2 + 28H^+ + 28e^-$

5 points

$28H^+ + 28e^- + 7O_2 \rightarrow 14H_2O$

$C_6H_5OH + 7O_2 \rightarrow 6CO_2 + 3H_2O$

$$\frac{7(32)}{1(94)} = 2.38\ \frac{g\ O_2/COD}{g\ phenol}$$

a. mass added $= 500\,\frac{g\ phenol}{m^3}\ 2.38\,\frac{g\ COD}{g\ phenol} \times 1000\,\frac{m^3}{d}\ 10^{-3}\frac{kg}{g}$

$= 1{,}191.5\ kg\ \frac{phenol\ COD}{d}$

regular WW mass/d $= 450\,\frac{g\ COD}{m^3}\left(25000\,\frac{m^3}{d}\right)10^{-3}\frac{kg}{g} = 11{,}250\,\frac{kg}{d}$

$\sim 10\%$ increase in COD loading

b. <u>additional</u> $O_2 = (1-0.35)\,\frac{g\ O_2}{g\ COD_{phenol}}\left(1191.5\,\frac{kg\ COD_{phenol}}{d}\right)$

$= 774.5\ \frac{kg\ O_2}{d}$ additional

c. toxicity of phenol to WWTP bacteria
discharge of unbiodegraded phenol
volatilization of phenol during aeration

purpose: be able to assess impact of new waste / industrial waste on WWTP

(5) derive COD equiv. of CO_2 as e^- acceptor

$$8H^+ + \cancel{8e^-} + CO_2 \longrightarrow CH_4 + 2H_2O$$

$$4H_2O + CH_3COO^- \longrightarrow 2HCO_3^- + 9H^+ + \cancel{8e^-}$$

$$CH_3COO^- + CO_2 + 2H_2O \longrightarrow CH_4 + 2HCO_3^- + H^+$$

$$CH_3COO^- + 2O_2 + H^+ \longrightarrow 2CO_2 + 2H_2O$$

$$\frac{2(32)}{1(44)} = 1.45 \frac{g\,O_2}{g\,CO_2}$$

5 c. $500 \frac{kg\text{-}CH_3COO^- \text{ consumed}}{d}\left(0.258 \frac{g\,CH_4}{g\,CH_3COO^-}\right) = 129 \frac{kg\,CH_4}{d}$

$\frac{r_{Ac}}{-1} = \frac{r_{CH_4}}{\psi_5}$ assume CH_4 is ideal gas @ 1 atm

$$V = \frac{NRT}{P} = \frac{\frac{129}{16}\frac{kmol\,CH_4}{d}\left(8.314 \frac{kPa\text{-}m^3}{kmol\,K}\right)(35+273\,K)}{101\,kPa}$$

$$V = 204 \frac{m^3\,CH_4}{d}$$

d) $\frac{r_{VSS}}{\psi_6} = \frac{r_{Ac}}{(-1)} = 500 \frac{kg\,Ac}{d}$ $\quad VSS = C_5H_7NO_2$

$$r_{VSS} = 500 \frac{kg\,Ac}{d}\left(0.038 \frac{kg\,VSS}{kg\,Ac}\right)$$

$$r_{VSS} = 19 \frac{kg\,VSS}{d}$$

5. purpose

practice converting stoichiometries and related rates

COD AND NITROGEN STOICHIOMETRIC AND KINETIC MATRIX FOR GROWTH AND DECAY

a. (4 points)

	Components							Rates
Process	Soluble COD S_S (mg/L COD)	Soluble NH_4-N S_{NH} (mg/L N)	Dissolved O_2, S_O (mg/L O_2)	Heterotrophic biomass, X_{BH} (mg/L COD)	Autotrophic (Nitrifying) Biomass, X_{BA} (mg/L COD)	Debris, X_D (mg/L COD)	Ammonia N in cells X_{NB} (mg/L N)	r_j
Aerobic Heterotrophic Growth	$-\frac{1}{Y_H} = -1.82$	$-i_{NXB} = -0.08$	$-(1-Y_H)/Y_H = -0.82$	1	na	na	$+i_{NXB} = 0.08$	**1 and 1a** $\mu_H X_{BH}$
Aerobic Growth of Autotrophs (Nitrification)	na	$-\left(\frac{1}{Y_A}\right)^* = -8.33$	$-(4.57-Y_A)/Y_A = -37.1$	na	1	na	$+i_{NXB} = 0.08$	**2** $\mu_A X_{BA}$
Decay and Lysis of Heterotrophs	$1-f_D = 0.98$	$i_{NXB} - f_D i_{NXD} = 0.079$	na	-1	na	$f_D = 0.02$	$-(i_{NXB} - f_D i_{NXD}) = -0.079$	**3** $b_H X_{BH}$

And reaction rates are (3 points)

$\mu_H * X_{BH}$ = growth rate for heterotrophs (d^{-1})

$\mu_A * X_{BA}$ = growth rate for autotrophs (d^{-1})

$b_H * X_{BH}$ = decay rate for heterotrophs (d^{-1})

* Could add auto cell uptake

$-\frac{1}{Y_A} - i_{NXB} = -8.41$

$$r_{NH} = -i_{NXB}\mu_A X_{BH} - \frac{1}{Y_A}\mu_A X_{BA} + (i_{NXB} - f_D i_{NXD}) b_H X_{BH}$$

(neglect autosynth.)

$$r_{NH} = -0.08\mu_H X_{BH} - 8.33\mu_A X_{BA} + 0.079 b_H X_{BH}$$

$$r_{XBH} = 1\mu_H X_{BH} - 1 b_H X_{BH} = X_{BH}(\mu_H - b_H)$$

$$r_{XBA} = 1\mu_A X_{BA}$$ (neglect auto. decay)

$$r_S = -\frac{1}{Y_H}\mu_H X_{BH} + (1-f_D) b_H X_{BH} = -1.82\mu_H X_{BH} + 0.98 b_H X_{BH}$$

$$r_O = -\frac{(1-Y_H)}{Y_H}\mu_H X_{BH} - \frac{(4.57-Y_A)}{Y_A}\mu_A X_{BA} = -1.82\mu_H X_{BH} - 37.1\mu_A X_{BA}$$

$r_D = f_D b_H X_{BH}$

$= 0.02 b_H X_{BH}$