Homework #3

Due: Oct 27, 23:59

*** Answer the following questions. Be sure to clearly show the procedures to solve the problems.**

A chemostat having V = 2,000 m^3 receives a flow rate of Q = 1,000 m^3/d of wastewater containing S^0 = 500 mg BOD_L/L. Also included in the wastewater is the inert biomass X_i^0 = 50 mg VSS/L. The following parameters are found for aerobic biodegradation:

$\hat{q} = 20\ g\ BOD_L/g\ VSS_a - d$

$Y = 0.42\ g\ VSS_a/g\ BOD_L$

$K = 20\ mg\ BOD_L/L$

$b = 0.15/d$

$f_d = 0.8$

$k_1 = 0.12\ g\ COD_p/g\ BOD_L$

$k_2 = 0.09\ g\ COD_p/g\ VSS_a - d$

$\hat{q}_{UAP} = 1.8\ g\ COD_p/g\ VSS_a - d$

$K_{UAP} = 100\ mg\ COD_p/L$

$\hat{q}_{BAP} = 0.1\ g\ COD_p/g\ VSS_a - d$

$K_{BAP} = 85\ mg\ COD_p/L$

1. Calculate $S_{\min}$, $\theta_x^{\min}$ and θ_x of the chemostat. (10 points)

2. Calculate effluent VSS, COD and BOD_L. (30 points)

3. Calculate the effluent N and P concentrations when influent concentrations are 50 mg NH_4-N/L and 10 mg PO_4-P/L, respectively. (20 points)

4. Calculate the amount of O_2 that should be supplied to the reactor when influent and effluent DO are 6 and 2 mg/L, respectively. (20 points)

5. Assuming that the influent also contains biodegradable particulate organic matter with a concentration of 100 mg COD/L and the

hydrolysis rate coefficient is k_{hyd} = 0.2/d, recalculate the effluent VSS, COD, and BOD_L. (30 points)

Hints:

- Consider active and inert biomass, and particulate organic matter supplied from the influent (if there is any) as components of VSS.
  ($X_v = X_a + X_i + S_p$; in mg VSS/L)
  (for COD→VSS conversion of S_p, assume S_p has the chemical formula as that for biomass)

- Effluent COD should include COD of the substrate, SMP, and VSS
  (eff. COD = substrate COD + SMP COD + VSS COD)
  · Conversion needed for VSS: recall 1.42 g COD/g VSS for biomass ($C_5H_7O_2N$)

- BOD_L stands for "ultimate BOD", the oxygen demand for all biodegradable organic matter
  · S^0 is given as "BOD_L/L", so substrate is assumed to be fully biodegradable
  · SMP is fully biodegradable
  · active biomass is partially biodegradable (biodegradable fraction = f_d)
  · inert biomass is non-biodegradable
  So: eff. BOD_L
  = substrate BOD_L (=COD) + SMP BOD_L (=COD) + f_d × active biomass COD

Solution)

1) $S_{\min}$, $\theta_x^{\min}$ and θ_x

$$S_{\min} = K\frac{b}{Y\hat{q}-b} = (20\ mg\ BOD_L/L)\frac{0.15/d}{(0.42\ g\ VSS_a/g\ BOD_L)(20\ g\ BOD_L/g\ VSS_a-d)-0.15/d}$$
$$= 0.36\ mg\ BOD_L/L$$

$$\theta_x^{\min} = \frac{K+S^0}{S^0(Y\hat{q}-b)-bK} = \frac{(20+500)\ mg\ BOD_L/L}{(500\ mg\ BOD_L/L)(0.42\cdot 20/d-0.15/d)-(20\ mg\ BOD_L/L)(0.15/d)}$$
$$= 0.126\ d$$

$$\theta_x = \theta = \frac{V}{Q} = \frac{2000m^3}{1000\ m^3/d} = 2\ d$$

$$\frac{\theta_x}{\theta_x^{\min}} = SF = \frac{2\,d}{0.126\,d} = 16 \textit{ (SF of 16 for washout)}$$

2) Effluent VSS, COD, BOD_L

Firstly, we need to determine the effluent substrate and active biomass concentrations:

$$S = K\frac{1+b\theta_x}{Y\hat{q}\theta_x - (1+b\theta_x)}$$

$$= (20\,mg\ BOD_L/L)\frac{1+(0.15/d)(2\,d)}{(0.42\ g\ VSS_a/g\ BOD_L)(20\ g\ BOD_L/g\ VSS_a - d)(2\,d) - (1+(0.15/d)(2\,d))}$$

$$= 1.7\,mg\ BOD_L/L$$

$$X_a = Y(S^0 - S)\frac{1}{1+b\theta_x} = (0.42\ g\ VSS_a/g\ BOD_L)(500-1.7\,mg\ BOD_L/L)\frac{1}{1+(0.15/d)(2\,d)}$$

$$= 161\,mg\ VSS_a/L$$

Calculate the effluent inert VSS concentration:

$$X_i = X_i^0 + X_a(1-f_d)b\theta_x$$

$$= 50\,mg\ VSS_i/L + (161\,mg\ VSS_a/L)(1-0.8g\ VSS_i/g\ VSS_a)(0.15/d)(2\,d)$$

$$= 60\,mg\ VSS_i/L$$

Now,

$$X_v = X_a + X_i = 161 + 60 = 221\,mg\ VSS/L$$

Think about the composition of effluent COD & BOD_L:

Effluent COD = remaining substrate + SMP + all VSS (active biomass + inert)

Effluent BOD_L = remaining substrate + SMP + active and biodegradable biomass

** Effluent bsCOD = Effluent $sBOD_L$ = remaining substrate + SMP*

Effluent bpCOD = all VSS

Effluent $pBOD_L$ = active and biodegradable biomass

Calculate the effluent SMP

- let's first calculate the individual terms for Eqs. [3.38] & [3.39]

$$r_{ut} = -\frac{\hat{q}S}{K+S}X_a = \frac{dS}{dt} = -\frac{S^0 - S}{\theta} = -\frac{(500-1.7)\,mg\ BOD_L/L}{2\,d} = -249\,mg\ BOD_L/L-d$$

$$\hat{q}_{UAP}X_a\theta + K_{UAP} + k_1 r_{ut}\theta = 1.8\cdot 161\cdot 2 + 100 + 0.12\cdot(-249)\cdot 2 = 620\,mg\ BOD_L/L$$

$$4K_{UAP}k_1 r_{ut}\theta = 4 \cdot 100 \cdot 0.12 \cdot (-249) \cdot 2 = -23900\ (mg\ BOD_L/L)^2$$

$$K_{BAP} + (\hat{q}_{BAP} - k_2)X_a\theta = 85 + (0.1 - 0.09) \cdot 161 \cdot 2 = 88.2\ mg\ BOD_L/L$$

$$4K_{BAP}k_2 X_a\theta = 4 \cdot 85 \cdot 0.09 \cdot 161 \cdot 2 = 9850\ (mg\ BOD_L/L)^2$$

$$UAP = \frac{-620 + \sqrt{(620)^2 + 23900}}{2} = 9.5\ mg\ BOD_L/L$$

$$BAP = \frac{-88.2 + \sqrt{(88.2)^2 + 9850}}{2} = 22.3\ mg\ BOD_L/L$$

$$SMP = UAP + BAP = 9.5 + 22.3 = 31.8\ mg\ BOD_L/L$$

Biomass COD: recall that the COD value for a cell formula of $C_5H_7O_2N$ was 1.42 g COD/g cells

In sum,

$$Effluent\ COD = {}_{strate} + SMP + Biomass\ COD$$

$$= 1.7 + 31.8 + (1.42\ g\ COD/g\ VSS)X_v = 1.7 + 31.8 + 1.42 \cdot 221$$

$$= 1.7 + 31.8 + 313.8 = 347\ mg\ COD/L$$

* *Biomass accounts for most of COD – this COD can be removed by settling (but good settling property should be guaranteed)*

* *SMP account for most of soluble COD*

$$Effluent\ BOD_L = {}_{strate} + SMP + active \text{ and } biodegradable\ biomass$$

$$= 1.7 + 31.8 + (1.42\ g\ COD/g\ VSS) \cdot X_a \cdot f_d = 216\ mg\ BOD_L/L$$

3) N and P

The N and P consumption rates,

$$r_N = (0.124\ g\ N/g\ VSS) \cdot (0.42\ g\ VSS/g\ \ BOD_L) \cdot (-249\ mg\ BOD_L/L-d) \cdot \frac{1 + (1 - 0.8) \cdot 0.15 \cdot 2}{1 + 0.15 \cdot 2}$$

$$= -10.6\ mg\ N/L-d$$

$$r_P = r_N \cdot 0.2\ g\,P/g\ N = -10.6 \cdot 0.2 = -2.1\ mg\ \ P/L-d$$

The effluent N and P concentrations

$$C_N = C_N^0 + r_N\theta = 50\ mg\ N/L - (10.6\ mg\ N/L-d) \cdot 2\ d = 28.8\ mg\ NH_4^+ - N/L$$

$$C_P = C_P^0 + r_P\theta = 10\ mg\ P/L - (2.1\ mg\ P/L-d) \cdot 2\ d = 5.8\ mg\ PO_4^{3-} - P/L$$

(the amount of nutrients did not limit the biological activity in the reactor)

4) O_2

The acceptor consumption in the reactor,

$$\frac{\Delta S_a}{\Delta t} = (1\ g\ O_2/g\ COD) \cdot (1000\ m^3/d)$$

$$\cdot\ [500 - 1.7 - 31.8 + 1.42(50 - 221)]\ mg\ COD/L \cdot 10^3\ L/m^3 \cdot 10^{-3} g/mg$$

$$= 2.24 \times 10^5\ g\ O_2/d$$

To support the acceptor consumption, O_2 should be supplied to the reactor with a rate of:

$$R_{O_2} = 2.24 \times 10^5\ g\ O_2/d - (1000\ m^3/d) \cdot (6-2)\ mg/L \cdot 10^3\ L/m^3 \cdot 10^{-3}\ g/mg$$

$$= 2.20 \times 10^5\ g\ O_2/d$$

(O_2 supplied by the influent DO is very small compared to the O_2 requirement – aeration is essential)

5) Effect of hydrolysis

i) effluent particulate BOD, S_p

$$S_p = \frac{S_p^0}{1 + k_{hyd}\theta} = \frac{100\ mg\ COD/L}{1 + (0.2/d)(2\ d)} = 71\ mg\ COD/L$$

ii) effluent soluble BOD, S: no change, 1.7 mg BODL/L

iii) effective S^0 considering S_p, $S^{0\prime}$:

$$S^{0\prime} = S^0 + k_{hyd} S_p \theta = 500\ mg\ COD/L + (0.2/d)(71\ mg\ COD/L)(2\ d) = 528\ mg\ BOD_L/L$$

(error in the textbook!)

iv) Effluent VSS

$$X_a = Y(S^0 - S)\frac{1}{1 + b\theta_x} = 0.42 \cdot (528 - 1.7)\frac{1}{1 + 0.15 \cdot 2} = 170\ mg\ VSS/L$$

(slight increase from 161 mg VSS/L without particulate BOD)

$$X_i = X_i^0 + X_a(1 - f_d)b\theta_x = 50\ mg\ VSS/L + (170\ mg\ VSS/L) \cdot (1 - 0.8) \cdot (0.15/d) \cdot (2\ d)$$

$$= 60\ mg\ VSS/L$$

(didn't change much – slight increase happened, but not enough to have increase in significant numbers)

$$X_v = X_a + X_i + S_p = (170 + 60)\ mg\ VSS/L + \frac{71\ mg\ COD/L}{1.42\ mg\ COD/mg\ VSS} = 280\ mg\ VSS/L$$

(Assumed that the particulate COD has the same formula, $C_5H_7O_2N$, as the

biomass)

v) SMP: let's skip the calculation and obtain value from the text:
SMP = 32.6 mg BODL/L
(slight increase from 31.8 mg BOD_L/L because of increased biomass - BAP increases)
vi) Effluent COD & BOD_L

$$Effluent\ COD = S + SMP + 1.42 \cdot X_v = 1.7 + 32.6 + 1.42 \cdot 280 = 432\ mg\ COD/L$$

$$Effluent\ BOD_L = S + SMP + 1.42 \cdot f_d \cdot X_a + S_p = 1.7 + 32.7 + 1.42 \cdot 0.8 \cdot 170 + 71 =$$
$$= 299\ mg\ BOD_L/L$$