# EN3503 Wastewater Engineering
## Exam 2012-2013 Solution

Yes, U can!

1. (a) (i)

| Component | Conc. (mg/L) | Conc. (mmol/L) | Conc. (meq/L) |
|---|---|---|---|
| $Ca^{2+}$ | 180 | 4.5 | 9 |
| $Mg^{2+}$ | 65 | 2.675 | 5.35 |
| $Na^{+}$ | 60 | 2.609 | 2.609 |
| $Fe^{2+}$ | 0.5 | 0.009 | 0.018 |
| | | Σ(cations) | 16.977 |
| $HCO_3^-$ | 300 | 4.918 | 4.918 |
| $CO_3^{2-}$ | 40 | 0.667 | 1.333 |
| $SO_4^{2-}$ | 60 | 0.625 | 1.25 |
| $Cl^-$ | 350 | 9.859 | 9.859 |
| | | Σ(anions) | 17.360 |

$$\text{Difference} = \frac{\Sigma \text{cations} - \Sigma \text{anions}}{\Sigma \text{cations} + \Sigma \text{anions}}$$

$$= \frac{16.977 - 17.360}{16.977 + 17.360}$$

$$= -1.115\%$$

$\because$ 10 meq/L < Σ anions ≤ 800 meq/L

$\therefore$ The percentage difference is acceptable & hence the analysis is complete.

(ii) $$\frac{[H^+][CO_3^{2-}]}{[HCO_3^-]} = 4.5\times10^{-11}$$

$$\therefore [H^+] = \frac{(4.5\times10^{-11})(4.918)}{0.667}$$

$$= 3.318\times10^{-10} \text{ mol/L}$$

$\therefore$ pH = 9.48

$$[ALK] = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$$

$$= 4.918\times10^{-3} + 2(0.667\times10^{-3}) + 10^{-4.52} - 10^{-9.48}$$

$$= 6.2822\times10^{-3} \text{ mol/L}$$

(iii) $$I = \frac{1}{2}\Sigma C_i z_i^2$$

$$= \frac{1}{2}[4(4.5+2.675+0.009+0.667+0.625) + (2.609+4.918+9.859)]\times10^{-3}$$

$$= 0.025645$$

Divalent ions: $$\log\gamma = -\frac{0.5(z_i)^2\sqrt{I}}{1+\sqrt{I}}$$

$$= -\frac{0.5(2)^2\sqrt{0.025645}}{1+\sqrt{0.025645}}$$

$$= -0.276$$

$\therefore \gamma_{Ca^{2+}} = 0.53$

Monovalent ions: $\log\gamma = -0.069$

$\therefore \gamma_{HCO_3^-} = 0.853$

$$pH_s = -\log\left(\frac{K_{a2}\,\gamma_{Ca^{2+}}[Ca^{2+}]\,\gamma_{HCO_3^-}[HCO_3^-]}{K_{sp}}\right)$$

$$= -\log\left(\frac{(4.5\times10^{-11})(0.53)(4.5)(0.853)(4.918)(10^{-6})}{4.6\times10^{-9}}\right)$$

$$= 7$$

$\therefore RI = 2pH_s - pH$

$= 2(7) - 9.48$

$= 4.52$

$\therefore$ Heavy scale will form

Yes, U can!

(b) $Q = 1500\ m^3/d$, $150\ mg/L$ of $Ca(OH)_2$ added, 90% TSS removed

Influent: $PO_4^{3-} = 12\ mg/L$ as P, $Ca^{2+} = 100\ mg/L$, $Mg^{2+} = 14\ mg/L$, $TSS = 250\ mg/L$

Effluent: $PO_4^{3-} = 0.8\ mg/L$ as P, $Ca^{2+} = 55\ mg/L$, $Mg^{2+} = 0\ mg/L$

$10Ca^{2+} + 6PO_4^{3-} + 2OH^- \leftrightarrow Ca_{10}(PO_4)_6(OH)_2$

molar mass $Ca_{10}(PO_4)_6(OH)_2 = 10(40) + 6(31+64) + 2(17) = 1004$

$[Ca_{10}(PO_4)_6(OH)_2] = \frac{1}{6} \times \frac{1004}{31} \times 11.2 = \underline{60.456\ mg/L}$

$Mg^{2+} + 2OH^- \leftrightarrow Mg(OH)_2$

$[Mg(OH)_2] = \frac{58.3}{24.3} \times 14 = \underline{33.588\ mg/L}$

$[Ca^{2+}] = \frac{10}{6} \times \frac{40}{31} \times 11.2 = 24.086\ mg/L$

$\therefore$ leftover $[Ca^{2+}] = 100 - 55 - 24.086 = \underline{20.914\ mg/L}$

$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3$

$[CaCO_3] = \frac{100}{40} \times 20.914 = \underline{52.285\ mg/L}$

$90\%\ TSS = \underline{225\ mg/L}$

$\therefore$ Mass of sludge solids $= 1.5\,[150 + 225 + 60.456 + 33.588 + 52.285]$

$= \underline{782\ kg/d}$

2. (a) $Q = 20000 \times 0.5 = 10000\ m^3/d$

For average flow, $A = \frac{Q}{SOR} = \frac{10000\ m^3/d}{30\ m^3/m^2d} = \frac{1000}{3} m^2$

$\therefore \frac{1}{4}\pi D^2 = \frac{1}{3}(1000)$

$\therefore \underline{D = 20.6\ m}$

Weir loading $= \frac{Q}{perimeter} = \frac{10000}{\pi(20.6)} = \underline{154.52\ m^3/md}$

(b) For average flow, $L = \frac{Q}{(SOR)W} = \frac{10000}{(30)(7)} = \underline{47.62\ m}$

Assume in laminar flow,

$V_p = \frac{g(s-1)d_p^2}{18\nu} = \frac{9.81(0.02)(10^{-4})^2}{18(0.89 \times 10^{-6})} = 1.225 \times 10^{-4}\ m/s = 10.58\ m/d$

$\therefore$ Removal efficiency, $X_r = \frac{V_p}{SOR} = \frac{10.58}{30} = \underline{35.27\%}$

Check, $N_R = \frac{V_p d}{\nu} = \frac{(1.225 \times 10^{-4})(10^{-4})}{0.89 \times 10^{-6}} = 0.01376 < 1$, $\therefore$ Assumption is valid!

(c) $V_H = \left[\frac{8k(s-1)gd}{f}\right]^{1/2} = \left[\frac{8(0.05)(1.02-1)(9.81)(10^{-4})}{0.02}\right]^{1/2} = 0.01981\ m/s = 1711.5\ m/d$

At peak hour, $V_c = SOR = 2.2(30) = 66\ m/d \ll V_H$

$\therefore$ Scouring will not happen

(d) Average, $t = \frac{V}{Q} = \frac{47.62(7)(3)}{10000} = 0.1d = 2.4hr$ Peak, $t = \frac{V}{Q} = \frac{47.62(7)(3)}{10000 \times 2.2} = 0.045d = 1.091hr$

BOD removal $= \frac{2.4}{0.018 + 0.02(2.4)} = \underline{36.364\%}$ BOD removal $= \frac{1.091}{0.018 + 0.02(1.091)} = \underline{27.398\%}$

TSS removal $= \frac{2.4}{0.0075 + 0.014(2.4)} = \underline{58.394\%}$ TSS removal $= \frac{1.091}{0.0075 + 0.014(1.091)} = \underline{47.906\%}$

3. (a)(i) $NH_4^+ - N = \frac{K_n(1 + K_{dn}\theta_x)}{\theta_x\left[q_{mn}\left(\frac{DO}{K_o + DO}\right) - K_{dn}\right] - 1}$

$= \frac{0.74(1 + 0.1(30))}{30\left[0.8\left(\frac{4}{0.5+4}\right) - 0.1\right] - 1}$

$= 0.171 \, mg/L < 0.2 \, mg/L$

∴ The effluent conc. meets the requirement

(ii) $S = \frac{K_s(1 + K_d\theta_x)}{\theta_x(Yk - K_d) - 1}$

$= \frac{20(1 + 0.2(30))}{30(10 - 0.2) - 1}$

$= \underline{0.478 \, mg/L}$

$P_{x,bio,het} = Q\left\{\frac{Y(S_o - S)(1 + f_d K_d \theta_x)}{1 + K_d\theta_x}\right\}$

$= 0.024\left\{\frac{0.4(250 - 0.478)(1 + 0.2(0.2)(30))}{1 + (0.2)(30)}\right\}$

$= 0.753 \, kg/d$

$P_{x,bio,nit} = Q\left\{\frac{Y_n\left[N_o - \left(\frac{14}{113}\right)\frac{P_{x,bio,het}}{Q} - N\right](1 + f_{dn} K_{dn}\theta_x)}{1 + K_{dn}\theta_x}\right\}$

$= 0.024\left\{\frac{0.12\left[60 - \left(\frac{14}{113}\right)\frac{753}{24} - 0.171\right](1 + 0.2(0.1)(30))}{1 + (0.1)(30)}\right\}$

$= 0.537 \, kg/d$

$NO_3^- - N = TKN - NH_4^+ - N - \frac{14}{113}\frac{(P_{x,bio,het} + P_{x,bio,nit})}{Q}$

$= 60 - 0.171 - \frac{14}{113}\frac{(753 + 537)}{24}$

$= \underline{53.17 \, mg/L}$

(iii) VSS wasting rate $= P_{x,bio,het} + P_{x,bio,nit}$

$= 0.753 + 0.537$

$= \underline{1.29 \, kg/d}$

(a) (iv) $P_{x,bio,total} = \frac{(MLVSS)(V)}{\theta_x}$

$\therefore V = \frac{(1.29\times10^3)(30)}{10000}$

$= 3.87 m^3$

(v) Effluent $P = P_o - \frac{3.1}{116.1}\frac{(P_{x,bio,het} + P_{x,bio,nit})}{Q}$

$= 5 - \frac{3.1}{116.1}\frac{1.29\times10^3}{24}$

$= 3.565\ mgP/L$

(b) $Q(4.57)\left(TKN_0 - NH_4^+\text{-}N_e - \frac{14}{113}\frac{P_{x,bio}}{Q}\right) - 1.42\,P_{x,bio,nitrifiers}$

Conversion from unit-N to unit-COD/$O_2$ because the latter term is in unit of N, we must convert it into the unit we want which is in this case is Oxygen

Total amount of nitrogen utilized in the reactor. In a simple case, we may take $TKN_0 - (NH_4^+ N_e)$ to be the $NO_3^-$ produced or $NH_4^+$ utilized by cells. However we must also take into account the amount of Nitrogen to produce the cells, which is $(14/113)(P_{x,bio}/Q)$. By assuming the formula of the cells be $C_5H_7O_2N$, we get $\frac{N}{cells} = \frac{14}{113}$.

1.42 is the conversion of VSS to the COD aerobic. The whole term means the oxygen equivalent that goes inside cells. By substracting this term, we can get the oxygen equivalent for the biodegradation.

(c) Denitrifiers are heterotroph bacteria, they need substrate in order to grow and do their job. Because most of the substrate are being utilized in MBR1 which left only a small amount of food for denitrifiers, additional bCOD is needed.

(d) $Y_{obs} = \frac{Y(1 + f_d k_d \theta_x)}{1 + k_d\theta_x}$

$= \frac{0.19(1+(0.2)(0.06)(20))}{1+0.06(20)}$

$= 0.1071$

$\therefore f_s^0 = 1.98(0.1071) = 0.212$

$R_d = \frac{1}{12}CH_3CH_2OH + \frac{1}{4}H_2O = \frac{1}{6}CO_2 + H^+ + e^-$

$R_a = \left(\frac{1}{5}NO_3^- + \frac{6}{5}H^+ + e^- = \frac{1}{10}N_2 + \frac{3}{5}H_2O\right)0.788$

$R_s = \left(\frac{5}{28}CO_2 + \frac{1}{28}NO_3^- + \frac{29}{28}H^+ + e^- = \frac{1}{28}C_5H_7O_2N + \frac{11}{28}H_2O\right)0.212$

(e) $2.86\left[(NO_3^- N_0) - (NO_3^- - N_e) - \frac{14}{113}\frac{P_{x,bio}}{Q}\right]$ → The whole term here is in unit of COD, which is the electron acceptor utilization of the reaction. So in order to get the amount of extra COD (the electron donor), we simply divide the whole term with fe.

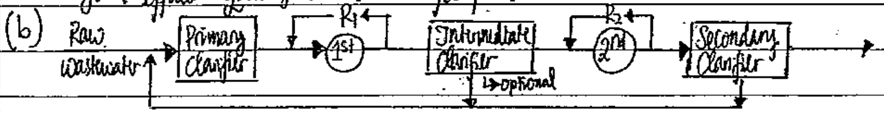
Numerical value of fe = 0.788

This is the conversion from unit-N to unit oxygen. So the whole term will be in unit of COD

Explanation of this is similar to the above except the cells utilize $NO_3^-$ instead of $NH_4^+$ in the reaction.

4. (a) No, I don't agree. Trickling filter may give a low cost and a low maintenance process but for the small footprint, it may not be. The activated sludge process & the anaerobic contact process are the better alternatives to achieve a good effluent quality and a small footprint.

(b)




(c) (i) Empirical formula which obtained by observation of numerous similar experiments

(ii) Overall efficiency $= \frac{300-20}{300} \times 100\% = \frac{280}{3}\%$

$$\frac{300-(1-\frac{E_1}{100})(1-\frac{E_2}{100})300}{300} = \frac{2.8}{3}$$

$$(1-\frac{E}{100})^2 = \frac{1}{15}$$

$$\therefore E = 74.18\%$$

$F = F_1 = F_2$

$$F = \frac{1+R}{(1+0.1R)^2} = \frac{1+2}{(1+0.1(2))^2} = \frac{25}{12} \approx 2.083$$

$W_1 = 300(1000) = 300\ kg/d$ $\qquad W_2 = (1-0.7418)(300) = 77.46\ kg/d$

$$E_1 = \frac{100}{1+0.443\sqrt{\frac{W_1}{V_1F_1}}} \qquad E_2 = \frac{100}{1+\frac{0.443}{1-E_1}\sqrt{\frac{W_2}{V_2F_2}}}$$

$$74.18 = \frac{100}{1+0.443\sqrt{\frac{300}{2.083\,V_1}}} \qquad 74.18 = \frac{100}{1+\frac{0.443}{1-0.7418}\sqrt{\frac{77.46}{V_2(2.083)}}}$$

$\therefore V_1 = 233.255\ m^3$ $\qquad \therefore V_2 = 903.389\ m^3$

$\therefore A_1 = 58.314\ m^2$ $\qquad \therefore A_2 = 225.847\ m^2$

(iii) Increasing: 1) To dilute influent wastewater
2) To maintain hydraulic load when low supply occurs

Decreasing: the wastewater is too dilute, so must decrease R

(iv) By looking at the formula, if $R\uparrow \rightarrow F\uparrow \rightarrow E \rightarrow 100\%$
So, by just considering the formula, the lowest effluent BOD we can get is 0 mg/L.
However, this is impossible because of sloughing. Each trickling filter will have a threshold value where the biofilm grows on the surface of filter cannot grow any bigger because of the fluid shear exceeds adhesion between the medium and biofilm, patches of biofilm detaches which causes sloughing.
Hence, the lowest effluent BOD in this case depends on the characteristic of the biotrickling medium and the flow rate applied.