1(a)(i)

$$\frac{C_i - C_e}{C_i} = \%\ \text{removal} \Rightarrow \frac{C_e}{C_i} = 1 - \%\ \text{removal} \Rightarrow \log_{10}\left(\frac{C_i}{C_e}\right) = \log_{10}\left(\frac{1}{1 - \%\ \text{removal}}\right)$$

$$\log_{10}\left(\frac{C_i}{C_e}\right) = k \times Ct \Rightarrow k = \log_{10}\left(\frac{C_i}{C_e}\right)/Ct = \log_{10}\left(\frac{1}{1 - \%\ \text{removal}}\right)/Ct$$

$$\text{Disinfectant A: } k = \log_{10}\left(\frac{1}{1 - 0.99}\right)/0.10 = 20$$

$$\text{Disinfectant B: } k = \log_{10}\left(\frac{1}{1 - 0.99}\right)/0.15 = 13.33$$

$$\text{Disinfectant C: } k = \log_{10}\left(\frac{1}{1 - 0.9999}\right)/0.15 = 26.67 (\text{largest} \Rightarrow \text{choose C})$$

$$\text{Disinfectant D: } k = \log_{10}\left(\frac{1}{1 - 0.99999}\right)/0.25 = 20$$

1(a)(ii)

At high pH, HOCL dissociates to OCl^-. OCl^- is 20-100 times less effective as disinfectant. Therefore, it is desirable for chlorination to have pH 7 or less to obtain more HOCl.

1(a)(iii)

At breakpoint: Chlorine dosage = Chlorine demand + Chlorine residual = 0.3 + 0.5 = 0.8mg/L

At free chlorine of 0.5mg/L : Chlorine dosage = 0.8 + 0.5 = 1.3 mg/L

1(b)

$$MW_{C_6H_{12}O_6} = 180;\ MW_{C_5H_7NO_2} = 113;\ MW_{C_6H_6} = 78$$

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O$$

$$\text{TON of wastewater A} = \frac{14}{113} \times [C_5H_7NO_2]_A \text{ in mg/L}$$

$$\text{TON of wastewater}_{\text{mixed}} = 10\ \text{mg/L} = \frac{\frac{14}{113} \times [C_5H_7NO_2]_A \times Q_A}{Q_A + Q_B} = \frac{\frac{14}{113} \times [C_5H_7NO_2]_A \times 200}{200 + 50}$$

$$\therefore \text{Concentration of } C_5H_7NO_2 \text{ in wastewater A} = [C_5H_7NO_2]_A = 100.89\ \text{mg/L}$$

$$[C_6H_{12}O_6]_{\text{mixed}} = 130\ \text{mg/L} = \frac{[C_6H_{12}O_6]_A \times Q_A + [C_6H_{12}O_6]_B \times Q_B}{Q_A + Q_B} = \frac{150 \times 200 + [C_6H_{12}O_6]_B \times 50}{200 + 50}$$

$$\therefore \text{Concentration of } C_6H_{12}O_6 \text{ in wastewater B} = [C_6H_{12}O_6]_B = 50\ \text{mg/L}$$

$$\text{TOC of wastewater}_{\text{mixed}} = 112\ \text{mg/L} = \frac{\left\{\left[\frac{72}{180}(150) + \frac{60}{113}(100.89)\right] \times 200 + \left[\frac{72}{180}(50) + \frac{72}{78}[C_6H_6]\right] \times 50\right\}}{200 + 50}$$

$$\therefore \text{Concentration of } C_6H_6 \text{ in wastewater B} = [C_6H_6]_B = 92.86\ \text{mg/L}$$

$$COD_A = COD_{C_6H_{12}O_6} + COD_{C_5H_7NO_2} = \frac{192}{180}(150) + \frac{160}{113}(100.89) = 302.853\ \text{mg/L}$$

$$\therefore \text{Biological treatability of wastewater A} = \frac{BOD_A}{COD_A} = \frac{220}{302.853} = 0.73$$

$$COD_B = COD_{C_6H_{12}O_6} + COD_{C_6H_6} = \frac{192}{180}(50) + \frac{240}{78}(92.86) = 339.056 \text{ mg/L}$$

$$\therefore \text{Biological treatability of wastewater B} = \frac{BOD_B}{COD_B} = \frac{50}{339.056} = 0.15$$

For checking purpose only:
Biological treatability of mixed wastewater

$$= \frac{BOD_A \times Q_A + BOD_B \times Q_B}{COD_A \times Q_A + COD_B \times Q_B} = \frac{220 \times 200 + 50 \times 50}{302.853 \times 200 + 339.056 \times 50} = 0.6 \text{ (OK!)}$$

2(a)

Material A:

$$d_B = d_A\left(\frac{S_A - 1}{S_B - 1}\right)^{2/3} = 2.5\left(\frac{1.5 - 1}{1.5 - 1}\right)^{2/3} = 2.5 \text{ mm (not compatible!)}$$

$$d_C = d_A\left(\frac{S_A - 1}{S_C - 1}\right)^{2/3} = 2.5\left(\frac{1.5 - 1}{2.4 - 1}\right)^{2/3} = 1.3 \text{ mm (not compatible!)}$$

$$d_D = d_A\left(\frac{S_A - 1}{S_D - 1}\right)^{2/3} = 2.5\left(\frac{1.5 - 1}{3.4 - 1}\right)^{2/3} = 0.9 \text{ mm (not compatible!)}$$

Material B:

$$d_C = d_B\left(\frac{S_B - 1}{S_C - 1}\right)^{2/3} = 2.0\left(\frac{1.5 - 1}{2.4 - 1}\right)^{2/3} = 1.0 \text{ mm (compatible! => B at top, C at bottom)}$$

$$d_D = d_B\left(\frac{S_B - 1}{S_D - 1}\right)^{2/3} = 2.0\left(\frac{1.5 - 1}{3.4 - 1}\right)^{2/3} = 0.7 \text{ mm (compatible! => B at top, D at bottom)}$$

Material C:

$$d_D = d_C\left(\frac{S_C - 1}{S_D - 1}\right)^{2/3} = 1.0\left(\frac{2.4 - 1}{3.4 - 1}\right)^{2/3} = 0.7 \text{ mm (compatible! => C at top, D at bottom)}$$

Material C and D have the same porosity => eliminate this option

2(b)(i)
Flow rate: $Q_p = Q_f \times Y_A \times Y_B = 10 \times 0.1 \times 0.2 = 0.2 \text{ L/h}$
Arsenic concentration: $C_p = C_f \times (1 - R_A) \times (1 - R_B) = 10 \times (1 - 0.2) \times (1 - 0.1) = 7.2 \text{ mg/L}$

2(b)(ii)
Advantages:

- Membrane filtration is effective for removing protozoa such as Cryptosporidium better than granular filtration which requires coagulation-flocculation step.
- Membrane filtration has high packing density which results in a smaller footprint.

Disadvantages:

- Membrane filtration is susceptible to pore blocking which is where the entrance to a pore is completely sealed by particle.
- Membrane filtration is susceptible to pore constriction which is the reduction of void volume due to adsorption of particles.

3(a)

(i) $\text{TS} = \dfrac{\text{mass of evaporating dish plus residue} - \text{mass of evaporating dish}}{\text{sample size}}$

$= \dfrac{(53.5794 - 53.5433)\text{g}\,(1000\text{mg/g})}{0.05\text{L}}$

$= 722\ \text{mg/L}$

(ii) $\text{TVS} = \dfrac{\text{mass of evaporating dish plus residue} - \text{mass of evaporating dish plus residue after ignition}}{\text{sample size}}$

$= \dfrac{(53.5794 - 53.5625)\text{g}\,(1000\text{mg/g})}{0.05\text{L}}$

$= 338\ \text{mg/L}$

(iii) $\text{TSS} = \dfrac{\text{residue on filter after drying} - \text{tare mass of filter after drying}}{\text{sample size}}$

$= \dfrac{(1.5554 - 1.5433)\text{g}\,(1000\text{mg/g})}{0.05\text{L}}$

$= 242\ \text{mg/L}$

(iv) $\text{VSS} = \dfrac{\text{residue on filter after drying} - \text{tare mass of filter after ignition}}{\text{sample size}}$

$= \dfrac{(1.5554 - 1.5476)\text{g}\,(1000\text{mg/g})}{0.05\text{L}}$

$= 156\ \text{mg/L}$

(v) $\text{TDS} = \text{TS} - \text{TSS} = 722 - 242 = 480\ \text{mg/L}$

(vi) $\text{VDS} = \text{TVS} - \text{VSS} = 338 - 156 = 182\ \text{mg/L}$

3(b)

Without recycle:

Surface area: $A = \dfrac{Q}{V_0} = \dfrac{500\ \text{m}^3/\text{d} \times 1000\ \text{L/m}^3}{8\ \text{L/m}^2 \cdot \text{min} \times 1440\text{min/d}} = 43.4\ \text{m}^2$

$\dfrac{A}{S} = \dfrac{1.3 \cdot s_a(fP - 1)}{S_a} \Rightarrow 0.008 = \dfrac{1.3 \cdot 18.7(0.5P - 1)}{4000} \Rightarrow P = 4.633\ \text{atm}$

Gauge pressure: $p = 101.35P - 101.35 = 101.35(4.633) - 101.35 = 368.17\ \text{kPa}$

With recycle:

Gauge pressure: $p = 300\ \text{kPa}$ (given)

$P = \dfrac{p + 101.35}{101.35} = \dfrac{300 + 101.35}{101.35} = 3.96\ \text{atm}$

$\dfrac{A}{S} = \dfrac{1.3 \cdot s_a(fP - 1)R}{S_a Q} \Rightarrow 0.008 = \dfrac{1.3 \cdot 18.7(0.5 \times 3.96 - 1)R}{4000 \times 500} \Rightarrow R = 671.58\ \text{m}^3/\text{d}$

Surface area: $A = \dfrac{Q + R}{V_0} = \dfrac{(500 + 671.58)\ \text{m}^3/\text{d} \times 1000\ \text{L/m}^3}{8\ \text{L/m}^2 \cdot \text{min} \times 1440\text{min/d}} = 101.7\ \text{m}^2$

3(c)(i)

$X = MLVSS = 0.85MLSS = 0.85(3000) = 2550\ \mathrm{mg/L}$

$$\frac{F}{M} = \frac{QS_0}{VX} = \frac{10000\ \mathrm{m^3/d} \times 200\ \mathrm{mg/L}}{3000\ \mathrm{m^3} \times\ 2550\ \mathrm{mg/L}} = 0.26\ \mathrm{kg\,BOD/kg\,VSS \cdot d}$$

3(c)(ii)

$$\theta = \frac{V}{Q} = \frac{3000\ \mathrm{m^3}}{10000\ \mathrm{m^3/d}} = 0.3\ \mathrm{d} = 7.2\ \mathrm{hrs}$$

3(c)(iii)

$$\text{Removal efficiency for BOD} = \frac{200 - 25}{25} \times 100\% = 87.5\%$$

$$\text{Removal efficiency for SS} = \frac{100 - 30}{100} \times 100\% = 70\%$$

4(a)

$$\text{Effluent } BOD_5 = 15\ \mathrm{mg/L} = \left(1 - \frac{E_1}{100}\right)\left(1 - \frac{E_2}{100}\right)(200)$$

Given that $E_1 = E_2 \Rightarrow \therefore E_1 = E_2 = 73\%$

$$W_1 = QS_0 = 3785\ \mathrm{m^3/d} \times 200\ \mathrm{mg/L} \times 10^3 \mathrm{L/m^3} \times 10^{-6} \mathrm{kg/mg} = 757\ \mathrm{kg/d}$$

$$F = \frac{1 + R}{(1 + R/10)^2} = \frac{1 + 1.8}{(1 + 1.8/10)^2} = 2.01$$

$$E_1 = \frac{100}{1 + 0.4432\sqrt{\frac{W_1}{V_1 F}}} = \frac{100}{1 + 0.4432\sqrt{\frac{757}{V_1 \times 2.01}}} = 73$$

$\therefore V_1 = 540.8\mathrm{m^3}$

$\therefore A_1 = \frac{V_1}{h} = \frac{540.8}{2} = 270.4\mathrm{m^2}$

$\therefore \frac{\pi d_1^2}{4} = A_1 = 270.4 \Rightarrow d_1 = 18.6\mathrm{m}$

$$W_2 = W_1\left(1 - \frac{E_2}{100}\right) = 757\left(1 - \frac{73}{100}\right) = 204.39\ \mathrm{kg/d}$$

$$E_2 = \frac{100}{1 + \frac{0.4432}{1 - E_1}\sqrt{\frac{W_2}{V_2 F}}} = \frac{100}{1 + \frac{0.4432}{1 - 0.73}\sqrt{\frac{204.39}{V_2 \times 2.01}}} = 73$$

$\therefore V_2 = 2002.9\mathrm{m^3}$

$\therefore A_2 = \frac{V_2}{h} = \frac{2002.9}{2} = 1001.4\mathrm{m^2}$

$\therefore \frac{\pi d_2^2}{4} = A_2 = 1001.4 \Rightarrow d_2 = 35.7\mathrm{m}$

4(b)

$$S_s = \frac{M_s}{\frac{M_v}{S_v} + \frac{M_f}{S_f}} = \frac{M_s}{\frac{0.8M_s}{1.01} + \frac{0.2M_s}{1.95}} = 1.118$$

Sludge with 99% water content: $S_{sl,1} = \frac{M_{sl}}{\frac{M_s}{S_s} + \frac{M_w}{S_w}} = \frac{M_{sl}}{\frac{0.01M_{sl}}{1.118} + \frac{0.99M_{sl}}{1}} = 1.001$

Sludge with 96% water content: $S_{sl,2} = \frac{M_{sl}}{\frac{M_s}{S_s} + \frac{M_w}{S_w}} = \frac{M_{sl}}{\frac{0.04M_{sl}}{1.118} + \frac{0.96M_{sl}}{1}} = 1.004$

$$\frac{V_{sl,2}}{V_{sl,1}} = \frac{S_{sl,1}P_{s,1}}{S_{sl,2}P_{s,2}} = \frac{1.001 \times 0.01}{1.004 \times 0.04} = 0.25 = 25\% \text{ (75\% reduction in volume)}$$

4(c)(i)

Volume of sludge per day, $V_{sl} = \frac{M_s}{S_{sl}\rho_w P_s} = \frac{3500\text{m}^3/\text{d} \times 0.12\text{kg/m}^3}{1.01 \times 1000\text{kg/m}^3 \times 0.05} = 8.32\text{m}^3/\text{d}$

Volume of anaerobic digester, $V = 8.32\text{m}^3/\text{d} \times 15\text{d} = 124.8\text{m}^3$

4(c)(ii)

$$\text{VLR} = \frac{QS_0}{V} = \frac{3500\text{m}^3/\text{d} \times 0.15\text{kg/m}^3}{124.8\text{m}^3} = 4.21\text{kg/m}^3\text{d}$$

Done by
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