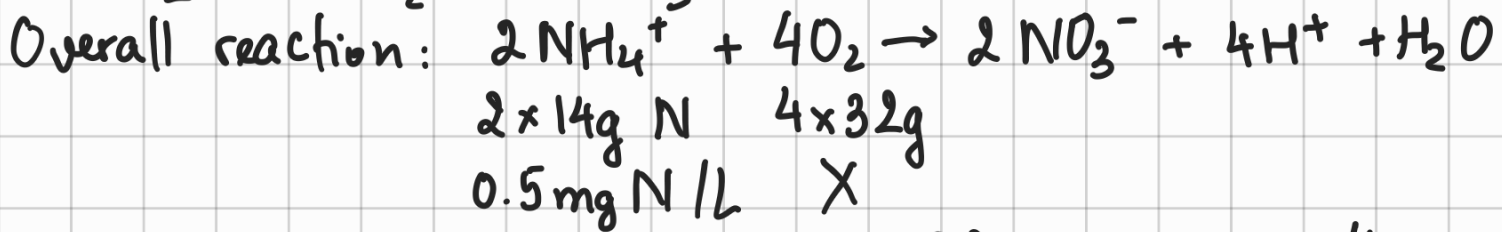
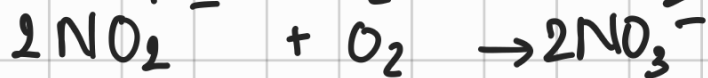


1.

- (a) - Filter wastewater sample (volume = V) through a filter with pore size $0.45 \mu\text{m}$
- Collect the filtrate and evaporate it at $103-105^\circ\text{C}$
 - The residual solids are dissolved solids in the sample (mass = M)
 - Total dissolved solids concentration = $\frac{M}{V}$

(b)



$$\Rightarrow \text{Nitrogenous BOD} = 0.5 \times \frac{4 \times 32}{2 \times 14} = 2.3 \text{ mg/L}$$

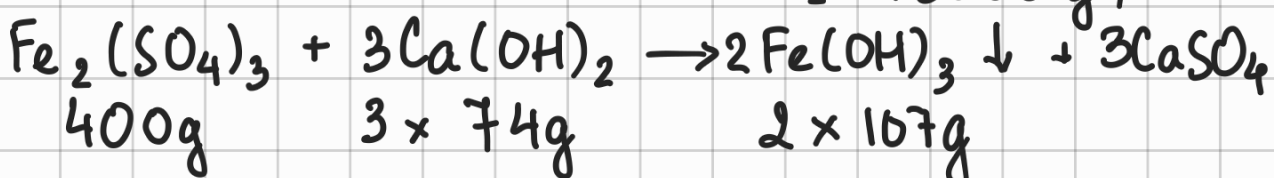
$$\text{BOD} = \text{DO}_1 - \text{DO}_f = 7.8 - 2 = 5.8 \text{ mg/L}$$

$$\text{Carbonaceous BOD} = 5.8 - 2.3 = 3.5 \text{ mg/L}$$

- (ii) Carbonaceous BOD is the amount of oxygen required to oxidize biodegradable organic matter.
- DOC represents the dissolved part of total organic matter in the waste water, measured by gram C/gram substance.

(c)

$$(i) \quad \text{Daily dose of ferric sulfate} = (1500 \text{ m}^3/\text{d})(50 \text{ g/m}^3) = 75000 \text{ g/d}$$



$$\text{Amount of Ca(OH)}_2 = 75000 \times \frac{3 \times 74}{400} = 41625 \text{ g/d}$$

$$\text{EW of Ca(OH)}_2 = \frac{74}{2} = 37 \text{ g/eq}$$

$$\text{EW of CaO} = \frac{56}{2} = 28 \text{ g/eq}$$

$$\begin{aligned} \text{Daily lime dose required} &= \frac{41625}{37} \times 28 = 31500 \text{ g/d} \\ &= 31.5 \text{ kg/d} \end{aligned}$$

$$\begin{aligned} \text{(ii) Suspended solids incoming} &= 1500 \times 60 = 90000 \text{ g/d} \\ &= 90 \text{ kg/d} \end{aligned}$$

$$\begin{aligned} \text{Precipitate produced} &= 75000 \times \frac{2 \times 107}{400} = 40125 \text{ g/d} \\ &= 40.125 \text{ kg/d} \end{aligned}$$

$$\begin{aligned} \text{Daily amount of solids coming into the sedimentation tank} \\ &= 90 + 40.125 = 130.125 \text{ kg/d} \end{aligned}$$

$$\begin{aligned} \text{Daily amount of solids produced from the sedimentation tank} \\ &= 90\% \times 130.125 = 117.1 \text{ kg/d} \end{aligned}$$

$$\text{(d) Volume} = \frac{2.2}{24} \times 25000 = 2292 \text{ m}^3$$

$$\text{Depth} = \frac{2292}{48 \times 12} = 3.98 \text{ m}$$

$$\begin{aligned} \text{Horizontal flow velocity} &= \frac{25000}{3.98 \times 12} = 523.5 \text{ m/d} \\ &= 0.0061 \text{ m/s} < 0.02 \text{ m/s} \end{aligned}$$

Hence, resuspension will not occur.

2.

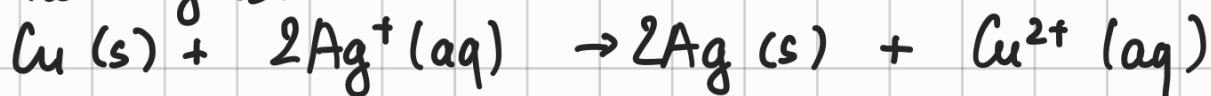
(a)

(i) When alum is dissolved in water, it releases Al^{3+} ions. Al^{3+} ions reduce the negatively charged surface of suspended solids and destabilize the colloidal particles. Thus the particles start to stick together when make contact. Aluminum precipitate can also enmesh the colloids and settle for enhanced removal of suspended solids.

(ii) The flow regime in a mechanical flocculation system is laminar flow. During flocculation, particles come together to form heavy flocs so that they can easily settle. Turbulent flow would disrupt the formation of flocs; hence, flocculation system is designed to have laminar flow

(b)

(i) Since E° of Ag^+ reduction is higher than E° of Cu^{2+} reduction, the overall reaction that can proceed spontaneously is:



(iii) $E^\circ_{cell} = 0.80 - 0.34 = 0.46 \text{ V}$

$$E_{cell} = E^\circ_{cell} - \frac{0.059}{n} \log Q$$

$$0.62 = 0.46 - \frac{0.059}{2} \log Q$$

$$\Rightarrow Q = 3.77 \times 10^{-6}$$

$$Q = \frac{[Cu^{2+}]}{[Ag^+]^2} \Rightarrow [Cu^{2+}] = 3.77 \times 10^{-6} \times 1^2$$
$$= 3.77 \times 10^{-6} \text{ mole/L}$$
$$= 2.4 \times 10^{-4} \text{ g/L}$$

⇒ Concentration of Cu^{2+} ion = 0.24 mg/L

(iii) The concentration of Cu^{2+} is much smaller than the concentration of Ag^+

(c) When 50% of the flow area is clogged:

$$h_L = \frac{1}{C} \left(\frac{V^2 - v^2}{2g} \right) = \frac{1}{0.6} \left(\frac{V^2 - 0.4^2}{2 \times 9.81} \right) = 0.20 \text{ m}$$

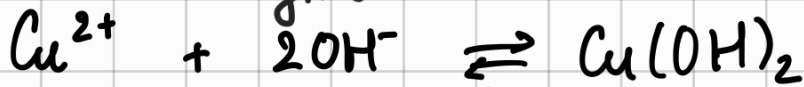
$$\Rightarrow V = 1.6 \text{ m/s}$$

$$Q = A \times v = (2 \times 1.5) \times 0.4 = 1.2 \text{ m}^3/\text{s}$$

$$\text{Flow area of the clogged bar screen} = \frac{1.2}{1.6} = 0.75 \text{ m}^2$$

$$\text{Flow area of the clean bar screen} = \frac{0.75}{0.50} = 1.5 \text{ m}^2$$

$$(d) [\text{Cu}^{2+}] = \frac{20 \text{ mg/L}}{64 \text{ g/mol}} = 3.125 \times 10^{-4} \text{ mol/L}$$



$$K_{sp} = [\text{Cu}^{2+}][\text{OH}^-]^2 \Rightarrow [\text{OH}^-] = \sqrt{\frac{K_{sp}}{[\text{Cu}^{2+}]}}$$

$$[\text{OH}^-] = \sqrt{\frac{4.18 \times 10^{-20}}{3.125 \times 10^{-4}}} = 1.16 \times 10^{-8} \text{ mol/L}$$



⇒ 1 mol of CaO releases 2 mol of OH^-

$$\text{Minimal lime dosage} = \frac{1.16 \times 10^{-8}}{2} \times 56 = 3.24 \times 10^{-7} \text{ g/L} \\ = 3.24 \times 10^{-4} \text{ mg/L}$$

(e) Method 1: Removal efficiency = $\frac{C_{in} - C_{eff}}{C_{in}}$

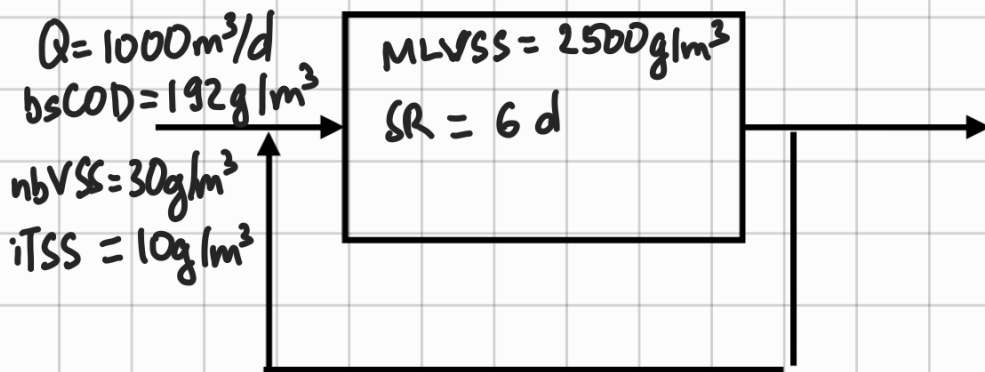
Method 2: Flow-weighted removal efficiency

$$= \frac{Q_{in} C_{in} - Q_{eff} C_{eff}}{Q_{in} C_{in}}$$

$$= \frac{C_{in} - (Q_{eff}/Q_{in}) C_{eff}}{C_{in}}$$

3.

(a)



(i) $S = \frac{k_s (1 + k_d \theta_x)}{\theta_x (4k - k_d) - 1} = \frac{10 (1 + 0.1 \times 6)}{6 (0.4 \times 12.5 - 0.1) - 1} = 0.563 \text{ g/m}^3$
 $\Rightarrow \text{bsCOD}_e = 0.563 \text{ g/m}^3$

(ii) $X_{o,i} = 30 \text{ g/m}^3$
 $X_T = 2500 \text{ g/m}^3$

$$X_T = \frac{\theta_x}{\theta} \left(X_{o,i} + \frac{Y(S_0 - S)(1 + f_d k_d \theta_x)}{1 + k_d \theta_x} \right)$$

$$2500 = \frac{6}{\theta} \left(30 + \frac{0.4(192 - 0.563)(1 + 0.15 \times 0.1 \times 6)}{1 + 0.1 \times 6} \right)$$

$$\Rightarrow \theta = 0.197 \text{ d}$$

$$(iii) V = Q\theta = 1000 \times 0.197 = 197 \text{ m}^3$$

$$P_{x_T, VSS} = \frac{x_T V}{\theta_c} = \frac{2500 \times 197}{6} = 82083 \text{ g/d} \\ = 82.1 \text{ kg/d}$$

$$(iv) P_{x_T, VSS} = P_{x, bio} + Q(nbVSS)$$

$$\Rightarrow P_{x, bio} = 82083 - 1000(30) = 52083 \text{ g/d}$$

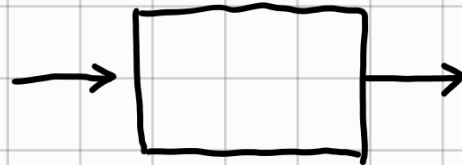
$$R_o = Q(S_o - S) - 1.42 P_{x, bio} \\ = 1000(192 - 0.563) - 1.42 \times 52083 \\ = 117479 \text{ g/d} \\ = 117.5 \text{ kg/d}$$

$$(b) V = 1000 \text{ L}$$

$$Q = 500 \text{ L/d}$$

$$S = 10 \text{ mg/L}$$

$$S_o = 1000 \text{ mg/L}$$



$$(i) \text{HRT} = \frac{V}{Q} = \frac{1000}{500} = 2 \text{ d}$$

$$(ii) R_o = (10 \text{ mg/L} \cdot \text{h})(24 \text{ h/d})(1000 \text{ L}) = 240000 \text{ mg/d} \\ = 240 \text{ g/d}$$

(iii)

O_2 consumed = COD of oxidized substrate - COD of cells

$$\Rightarrow \text{COD of cells} = Q(S_o - S) - R_o \\ = 500(1000 - 10) - 240000 \\ = 255000 \text{ mg/d}$$

$$\text{Effluent VSS conc.} = \frac{255000}{1.42 \times 500} = 359 \text{ mg/L}$$

$$(iv) P_{x, VSS} = \frac{255000}{1.42} = 179.6 \times 10^3 \text{ mg/d}$$

$$Y = \frac{P_{x, VSS}}{Q(S_0 - S)} = \frac{179.6 \times 10^3}{500(1000 - 10)} = 0.363 \text{ g VSS/g bsCOD removed}$$

4.
(a)

Condition	End products
Aerobic	$\text{CO}_2, \text{H}_2\text{O}$
Fermentation	Acetate, H_2, CO_2
Methanogenesis	CH_4, CO_2

Aerobic condition has the highest yields among the three conditions. On the other hand, bacteria responsible for methanogenesis have the slowest growth rate, and hence smallest yields.

(b) Use peak design conditions:

Daily sludge loading:

$$M_s = (420 \text{ m}^3/\text{d})(1000 \text{ kg/m}^3)(1.03)(3.4\%) \\ + (2500 \text{ m}^3/\text{d})(1.005 \times 1000 \text{ kg/m}^3)(0.23\%) \\ = 20487.15 \text{ kg/d}$$

Surface area:

$$A = \frac{M_s}{q} = \frac{20487.15}{50} = 409.7 \text{ m}^2$$

$$\text{Hydraulic loading rate} = \frac{Q}{A} = \frac{420 + 2500}{409.7} = 7.13 \text{ m}^3/\text{m}^2 \cdot \text{d}$$

(c) Amount of suspended solids to be removed:

$$M_s = (8000 \text{ m}^3/\text{d})(200 \text{ g/m}^3) = 1.6 \times 10^6 \text{ g/d} = 1600 \text{ kg/d}$$

Specific gravity of solids:

$$S_s = \frac{M_s}{\frac{M_v}{S_v} + \frac{M_f}{S_f}} = \frac{M_s}{\frac{0.75M_s}{1.3} + \frac{0.25M_s}{2.6}} = 1.49$$

Specific gravity of untreated sludge:

$$S_{sl} = \frac{M_{sl}}{\frac{M_s}{S_s} + \frac{M_w}{S_w}} = \frac{M_{sl}}{\frac{0.04M_{sl}}{1.49} + \frac{0.96M_{sl}}{1.0}} = 1.013$$

$$\begin{aligned} \text{Required digester volume} &= \frac{(1600 \text{ kg/d})(20 \text{ d})}{1.013 \times 1000 \text{ kg/m}^3 \times 0.04} \\ &= 790 \text{ m}^3 \end{aligned}$$

(d) The volatile acids produced during the anaerobic digestion process result in a pH reduction. Since methane bacteria are sensitive to pH, sufficient alkalinity is required to maintain the neutral pH.