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1.

(a) $TS = \dfrac{66.094 - 65.942}{50} = 0.00304\ g/mL = 3040\ mg/L$

$VS = \dfrac{66.094 - 66.003}{50} = 0.00182\ g/mL = 1820\ mg/L$

(b) Wastewater sample $\xrightarrow[\text{pore size } 0.45\mu m]{\text{Filter with}}$ Filtrate $\xrightarrow[\text{at } 103°C]{\text{Dry}}$ Dissolved solids

- Filter waste water sample through filter with pore size 0.45μm
- Evaporate and dry the filtrate at 103-105°C
- The residual solids are dissolved solids in the sample
- Mass of dissolved solids = Mass of dish with dry solids − Mass of empty dish
- TDS concentration $= \dfrac{\text{Mass of dissolved solids}}{\text{Volume of sample}}$

(c)

(i) $3C_6H_5OH + 2Cr_2O_7^{2-} + 16H^+ \rightarrow 3C_6H_4O_2 + 4Cr^{3+} + 11H_2O$

$3 \times 94g \qquad 2 \times 216g$

1g of phenol requires $\dfrac{2 \times 216}{3 \times 94} = 1.53g$ of dichromate

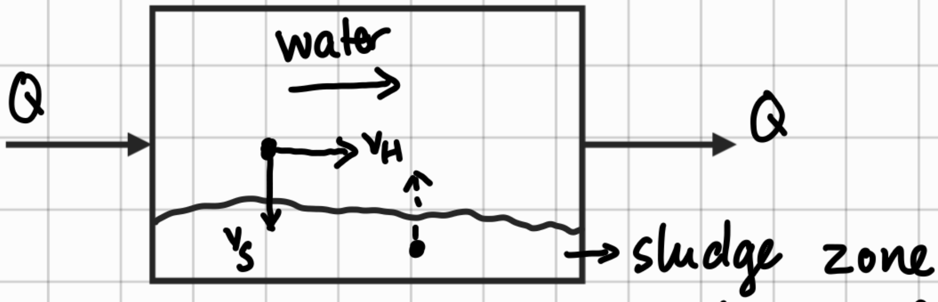
EW of $Cr_2O_7^{2-} = \dfrac{216}{6} = 36\ g/eq$

EW of $O_2 = \dfrac{32}{4} = 8\ g/eq$

COD of phenol $= \dfrac{1.53}{36} \times 8 = 0.34\ g\ O_2/g$ phenol

(ii) We need less amount of oxygen than dichromate to oxidize phenol

(d)



The projectile of the particle in the sedimentation tank depends on verticle settling and horizontal movement of the water. If the horizontal flow velocity exceeds the allowable scour velocity, resuspension will occur.

(e)

(i) $SOR = \dfrac{80000\ m^3/d}{4 \times 48m \times 12m} = 34.7\ m/d = 4 \times 10^{-4}\ m/s$

(ii) For 100% of flocs removal, the settling velocity of the particles must be at least 4×10^{-4} m/s, i.e. $v_s \geqslant SOR$

(iii) $v_s = \dfrac{g(\rho_s - \rho)d^2}{18\mu} \geqslant SOR$

$\Rightarrow \dfrac{9.81\,(1030 - 1000)\,d^2}{18\,(0.89 \times 10^{-3})} \geqslant 4 \times 10^{-4}$

$\Rightarrow d \geqslant 1.48 \times 10^{-4}\ m = 148\,\mu m$

$Re = \dfrac{\rho d v_s}{\mu} = \dfrac{1000 \times 1.48 \times 10^{-4} \times 4 \times 10^{-4}}{0.89 \times 10^{-3}} = 0.067 < 1$

(iv) Higher temperature results in lower water viscosity and thus larger settling velocity. Therefore, the removal efficiency will increase.

2.

(a) Amount of suspended solids to be removed

$= (1000 m^3/d)(100 g/m^3) \times 80\% = 80000\ g/day$

Amount of copper ions to be removed

$= (1000 m^3/d)(50 g/m^3) \times 95\% = 47500\ g/day$

$$Cu^{2+} + 2OH^- \rightleftharpoons Cu(OH)_2 \downarrow$$

64g → 98g

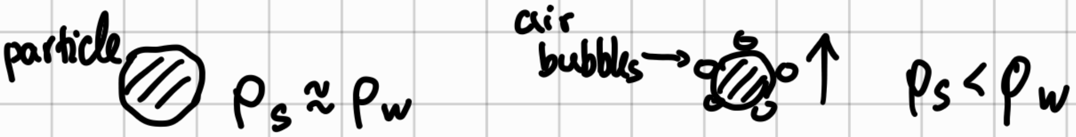
47500 g → $47500 \times \frac{98}{64} = 72734\ g$

Daily solid production $= 80000 + 72734 = 152734\ g$

$= 152.7\ kg$

(b)

(i) Air is pumped into the wastewater, and air bubbles attach to suspended solids in the stream. Consequently, the density of the solids reduces, becoming lighter than water. The solids will then move upwards and be removed from the top of the flotation unit.



(ii) Gravity sedimentation removes particles from the bottom of the tank. DAF removes particles from the top of the unit.

(iii) The theoretical flow rate of air available for flotation

$$F_{air} = Q(S_{in} - S_{out})$$

The saturation of air in water is proportional to pressure

$$\frac{S_{in}}{S_{out}} = \frac{P}{P_0} \Rightarrow S_{in} = \frac{P}{P_0} S_{out}$$

Thus, $F_{air} = QS_{out}\left(\frac{P}{P_0} - 1\right)$

Flowrate of solids: $F_{solid} = QX$

Hence, A/S ratio $= \frac{F_{air}}{F_{solid}} = \frac{QS_{out}\left(\frac{P}{P_0} - 1\right)}{QX}$

$$= \frac{S_{out}}{X}\left(\frac{P}{P_0} - 1\right)$$

(c)

(i) Consider reaction:

$$Cr_2O_7^{2-}(aq) + 14H^+ + 6Cl^- \rightarrow 2Cr^{3+} + 7H_2O + 3Cl_2$$

$$E^\circ = E^\circ_{reduction} - E^\circ_{oxidation}$$
$$= 1.33 - 1.36$$
$$= -0.03\ V < 0$$

⇒ the reaction occurs in the opposite direction

⇒ chloride could not be oxidized by dichromate under standard conditions

(ii) The redox reaction may proceed as written if the reaction potential $E^\circ_{overall} > 0$.

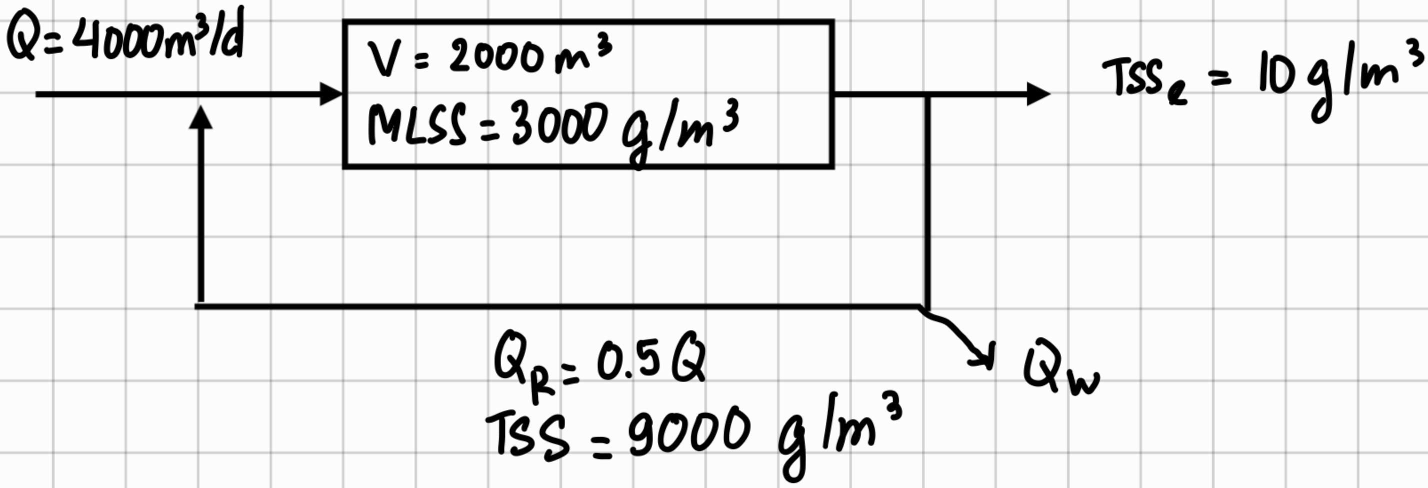
Since $E^\circ < 0$, $\log Q$ must be negative, or $Q < 1$

$$\Rightarrow Q = \frac{[Cr^{3+}]^2 (P_{Cl_2})^3}{[Cr_2O_7^{2-}][Cl^-]^6[H^+]^{14}} < 1$$

Q can be less than 1 when $[H^+]$ is very large, or the condition is very acidic.

3.

(a)



(i) $$SRT = \frac{VX}{(Q-Q_w)X_e + Q_w X_R}$$

$$10 = \frac{2000 \times 3000}{(4000-Q_w)\times 10 + Q_w \times 9000}$$

$\Rightarrow Q_w = 62.3\ m^3/d$

(ii) $Q_w = 10\% \times 2000 = 200\ m^3/d$

$X_R = 3000\ g/m^3$

$$SRT = \frac{2000 \times 3000}{(4000-200)\times 10 + 200 \times 3000} = 9.4 \text{ days}$$

(b)

(i) $bCOD = 1.6 BOD = 1.6 \times 200 = 320\ mg/L$

(ii) $sbCOD = bCOD - rbCOD = 320 - 100 = 220\ mg/L$

(iii) $pCOD = tCOD - sCOD = 500 - 160 = 340\ mg/L$

$nbpCOD = nbCOD - nbsCOD$

$= (tCOD - bCOD) - nbsCOD$

$= 500 - 320 - 30 = 150\ mg/L$

$$nbVSS = VSS \times \frac{nbpCOD}{pCOD} = 200 \times \frac{150}{340} = 88.2\ mg/L$$

(iv) iTSS = TSS - VSS = 220 - 200 = 20 mg/L

(c)

(i) D

Longer SRT results in lower sludge production, which results in a lower amount of biological phosphorus removal, since the phosphorus is removed with the waste sludge.

(ii) D

More food → PAO grows more ⇒ takes up more P

(iii) I

More efficient biological phosphorus removal occurs at pH from 7.5 to 8.0. When pH declines, the activity of PAOs is affected

(iv) I

Low DO will result in anaerobic condition, during which PAOs release P to the wastewater

4.

(a)

(i) $pCOD_e = 1.8 \times TSS_e = 1.8 \times 120 = 216$ mg/L

$S = sCOD_e = 400 - 216 = 184$ mg/L

$$\mu = \frac{\mu_m S}{K_s + S} - k_d = \frac{0.35 \times 184}{120 + 184} - 0.03 = 0.182\ d^{-1}$$

$$\text{Theoretical SRT} = \frac{1}{\mu} = \frac{1}{0.182} = 5.5\ d$$

$$\text{Design SRT} = 1.5 \times 5.5 = 8.3\ d$$

(ii) $nbTSS_o = 0$ (since the wastewater is 100% soluble)

$$P_{x,TSS} = \frac{0.08\times 2000\times(4000-184)}{(1+0.03\times 8.3)\times 0.85} + \frac{0.15\times 0.03\times 0.08\times 2000(4000-184)8.3}{(1+0.03\times 8.3)\times 0.85}$$

$$= 575105 + 21480$$

$$= 596585 \text{ g/d}$$

$$V = \frac{(P_{x,TSS})SRT}{MLSS} = \frac{596585\times 8.3}{5000} = 990 \text{ m}^3$$

(iii) $$HRT = \frac{V}{Q} = \frac{990}{2000} = 0.495 \text{ d}$$

(iv) $$P_{x,bio} = \frac{YQ(S_o-S)}{1+k_d SRT} + \frac{f_d k_d Y Q(S_o-S)SRT}{1+k_d SRT}$$

$$= \frac{0.08\times 2000\times(4000-184)}{1+0.03\times 8.3} + \frac{0.15\times 0.03\times 0.08\times 2000(4000-184)8.3}{1+0.03\times 8.3}$$

$$= 488839 + 18258$$

$$= 507097 \text{ g/d}$$

$$\text{COD consumed} = COD_{cells} + COD_{methane}$$

$$\Rightarrow COD_{methane} = Q(S_o-S) - 1.42 P_{x,bio}$$

$$= 2000(4000-184) - 1.42\times 507097$$

$$= 6911922 \text{ g/d}$$

At 35°C: 0.40 L CH_4 / g COD

$\Rightarrow$ Methane production rate $= 0.40\times 6911922$

$= 2764768.8$ L/d

$= 2765$ m³/d

(v) Total gas production rate $= \frac{2765}{0.65} = 4254$ m³/d

(vi) $P_{X,TSS}$ = 596585 g TSS /d

(vii) Nitrogen requirement = 596585 × 0.85 × 0.12
= 60852 g N /d

Phosphorus requirement = 596585 × 0.85 × 0.02
= 10142 g P /d

(b). Water pH decreases due to insufficient alkalinity: Methane bacteria cannot function below pH 6.2.
- Nutrients (N, P) run out: Sufficient amount of nutrients must be available to ensure the proper growth of the biological community.
- Wastewater contains inhibitory substances such as oxygen, heavy metals and sulfides: Methanogenesis is susceptible to toxic species. The presence of them will hinder the activity of methane bacteria.
- Temperature could have decreased: The optimum temperature ranges for anaerobic digestion are mesophilic (30–38°C) and thermophilic (49°–57°C). If the temperature falls below 30°C, the growth of bacteria is decelerated