

ENS002 - Waste Water Engineering AY21/22 sem 1 | Chia Peiwen

1a) TS, TVS, VSS, TDS Volume = $85 \times 10^3 \text{ L}$

$$\begin{aligned} \text{TS} &= 85.490 - 85.337 \\ &= 0.153 \text{ g} \quad \text{concentration} = \frac{0.153 \text{ g}}{85 \times 10^3 \text{ L}} = 1.8 \text{ g/L} \\ \text{TVS} &= 85.490 - 85.375 \\ &= 0.115 \text{ g} \quad \text{concentration} = \frac{0.115 \text{ g}}{85 \times 10^3 \text{ L}} = 1.35 \text{ g/L} \end{aligned}$$

Volume = $200 \times 10^3 \text{ L}$

$$\begin{aligned} \text{TSS} &= 0.1530 - 0.1400 \\ &= 0.0130 \text{ g} \quad \text{concentration} = \frac{0.0130}{200 \times 10^3} = 0.065 \text{ g/L} \\ \text{VSS} &= 0.1530 - 0.1426 \\ &= 0.0104 \text{ g} \quad \text{concentration} = \frac{0.0104}{200 \times 10^3} = 0.052 \text{ g/L} \\ \text{TDS} &= \text{TS} - \text{TSS} \\ &= 0.153 - 0.0130 \\ &= 0.14 \text{ g} \quad \text{concentration} = \frac{0.14}{85 \times 10^3} = 1.65 \text{ g/L} \end{aligned}$$

b) i) 5 Day BOD

$$\begin{aligned} \text{BOD}_5 &= 8.0 - 3.5 \\ &= 4.5 \text{ mg/L} \end{aligned}$$

ii) $\text{BOD}_t = L(1 - 10^{-kt})$

$$\begin{aligned} &= 8(1 - 10^{-(0.1)(20)}) \\ &= 7.92 \text{ mg/L} \end{aligned}$$

$$1c) \quad Q_{in} = Q_{eff} + Q_d$$

$$Q_d = 1000 - 750 \\ = 250 \text{ m}^3/\text{d}$$

$$SS_d = \frac{1000 \text{ m}^3/\text{d} (20 \text{ g}/\text{m}^3) - 750 (0.5 \text{ g}/\text{m}^3)}{250 \text{ m}^3/\text{d}} \\ = 78.5 \text{ g}/\text{m}^3 \\ = 78.5 \text{ mg}/\text{L}$$

$$\% \text{ Removal efficiency} = \frac{SS_{in} - SS_{eff}}{SS_{in}} \\ = \frac{20 - 0.5}{20} \times 100\% \\ = 97.5\%$$

c)	Sedimentation	Air Flotation
Sludge collection Point	At the bottom of the tank	At the top of the tank.
Target of treatment	Particles with specific gravity > 1	Particles with specific gravity < 1
Additional chemicals/ bubbling	coagulants to be added for better floc density.	Air bubbles pumped through nozzles at the bottom of the tank for particles to attach to and float up.

2a) i) For $Al_2(SO_4)_3 \cdot 14H_2O$

no. of mol of 1g $Al_2(SO_4)_3 \cdot 14H_2O$

$$= \frac{1}{2(27) + 3(32 + 4(16)) + 14(2+16)}$$

$$= 0.0016835 \text{ mol}$$

$$\text{Mass of } HCO_3^- = 0.0016835 \times (1 + 12 + 3(16)) \times 6$$

$$= 0.61616 \text{ g}$$

$$\text{Alkalinity consumed as } CaCO_3 = 0.61616 \div \frac{61}{50}$$

$$= 0.51 \text{ g}$$

For $Fe_2(SO_4)_3 \cdot 9H_2O$

no. of mol of 1g $Fe_2(SO_4)_3 \cdot 9H_2O$

$$= \frac{1}{2(56) + 3(32 + 4 \times 16) + 9(2+16)}$$

$$= 0.0017794 \text{ mol}$$

$$\text{Mass of } HCO_3^- = 0.0017794 \times 6 \times (1 + 12 + 3 \times 16)$$

$$= 0.65126 \text{ g}$$

$$\text{Alkalinity as } CaCO_3 = 0.65126 \div \frac{61}{50}$$

$$= 0.534 \text{ g}$$

ii) For aluminium Sulphate

Mass of precipitate $Al(OH)_3$

$$= 0.0016835 \times 2 \times (27 + 3(1+16))$$

$$= 0.263 \text{ g}$$

For ferric Sulphate

Mass of precipitate $Fe(OH)_3$

$$= 0.0017794 \text{ mol} \times 2 \times (56 + 3(1+16))$$

$$= 0.381 \text{ g}$$

2a ii) Amount of alkalinity consumed by alum is less than that of ferric sulphate. The amount of chemical precipitate produced by aluminium sulphate is also less than that of ferric sulphate. Hence, based on these two factors, aluminium sulphate works better as a coagulant than ferric sulphate.

b i)

Using Stokes' Law,

$$v_s = \frac{(s_s - s_w) d^2 g}{18 \mu}$$

$$= \frac{(2.65 - 1) (200 \times 10^{-6})^2 (9.81)}{18 \times 1.306 \times 10^{-6}}$$

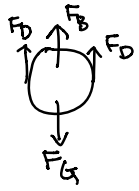
$$= 0.0275 \text{ m/s}$$

checking: $Re = \frac{(200 \times 10^{-6}) \times 0.0275}{1.306 \times 10^{-6}}$

$$= 4.213 > 1$$

For Stokes' Law to be applicable, $Re < 1$. Based on the calculations, $Re = 4.21 > 1$. \therefore Stokes' Law not applicable in this scenario to determine terminal settling velocity of sand.

ii) when Stokes' Law not appropriate, Use particle settling theory.



F_G - Gravitational force, F_D = Frictional Drag force

$$= \rho_p g V_p = \frac{C_d A_p \rho_w v_p}{2}$$

particle settling velocity

F_B - Buoyancy force

$$= \rho_w g V_p$$

Volume of particle

Terminal velocity is reached when $F_G = F_D + F_B$

$$\therefore v_p = \sqrt{\frac{4g}{C_d} \left(\frac{\rho_p - \rho_w}{\rho_w} \right) d_p}$$

$$= \sqrt{\frac{4g}{3C_d} (s \rho_p - 1) d_p}$$

c) Analysis of scaling potential using Langelier Saturation Index (LSI)

$$LSI = pH - pH_s$$

pH - measured pH of wastewater

pH_s - saturation pH for CaCO₃

Scaling occurs when LSI > 0

For LSI > 0 pH > pH_s

LSI > 0 indicates that the water is supersaturated with respect to CaCO₃, hence scaling may likely occur.

3a) i) when SRT is increased.

The effluent phosphorous concentration will decrease. When SRT is increased, the time spent in the aerobic and anaerobic condition will increase. Hence, there will be increase in the net removal of phosphorous.

ii) The influent readily biodegradable COD concentration increases. The effluent phosphorous concentration will increase. Readily biodegradable COD comprises of Volatile fatty acids (VFA), which is taken in by Acetyl-CoA to produce PHA granules during the anaerobic condition. When switched over to aerobic condition, these PHA granules will be degraded to provide energy required for Poly-P granules to take in phosphate.

$\therefore \uparrow \text{rbCOD} \rightarrow \uparrow \text{VFA} \rightarrow \uparrow \text{PHA granules} \rightarrow \uparrow \text{Energy for Poly-P}$
 \downarrow
 $\uparrow \text{P intake}$

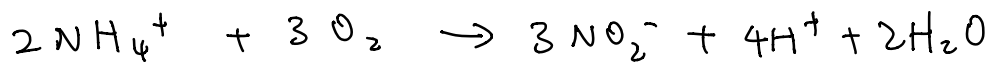
iii) Clarifier effluent SS concentration increases.

The effluent phosphorous concentration will increase. The phosphate accumulating organisms (PAOs) are attached onto the suspended solids, so increase in clarifier effluent SS concentration will reduce the number of PAOs in the tank, reducing removal of P.

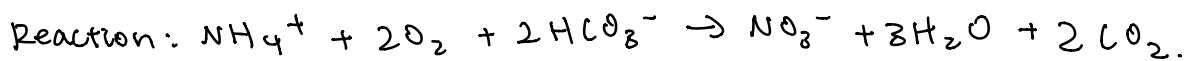
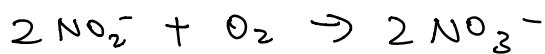
3iv) Higher Nitrate concentration in returned activated sludge
There will be no change in the effluent phosphorus concentration
since nitrate concentration does not affect PAO₃ processes.

b) Nitrogen removal process

1st step: Nitrification - ammonium is converted to nitrite by
ammonium oxidizing bacteria (AOB) e.g. nitrosomonas



Nitrite is then oxidised by nitrogen oxidizing bacteria (NOB)
e.g. nitrobacter to form nitrate.



Optimal process operating condition: High concentration of O₂.
Alkalinity is consumed in nitrification.

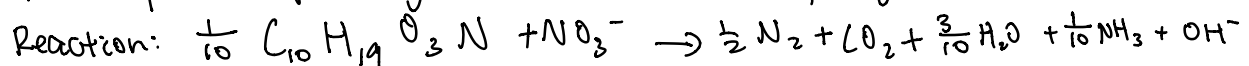
2nd step: Denitrification - convert nitrate into N₂ gas.

Denitrifying bacteria are facultative aerobes, they use NO₃⁻ or NO₂⁻
as electron acceptors when DO is low.

They make use of both organics and inorganics as electron donors.

Alkalinity is generated in denitrification.

Optimal process operating condition: Low O₂, high C



Sludge volume Index

$$3c) \text{SVI} = \frac{\text{Settled sludge volume}}{\text{MLSS}} \times 1000$$

$$= \frac{930/2 \text{ mL/L}}{3000 \text{ mg/L}} \times 1000$$

$$= 155 \text{ mL/g}$$

With $\text{SVI} = 155$, the sludge has poor settleability. This may be due to filamentous growth. Low F/M or large SRT encourages filamentous growth. Filamentous Organisms may dominate at low D as well.

$$d) i) \quad Q = 5000 \text{ m}^3/\text{d}$$

$$V = \text{HRT} \times Q$$

$$= 5000 \text{ m}^3/\text{d} \times 1 \text{ d}$$

$$= 5000 \text{ m}^3$$

$$\theta_x = \frac{1}{\mu} = \frac{YX}{(Q - Q_w) X_e + Q_w X_r}$$

$$= \frac{5000 \text{ m}^3 \times 3000 \text{ mg/L}}{(5000 - 75) \text{ m}^3 (20 \text{ mg/L}) + 75 \text{ m}^3 (9000 \text{ mg/L})}$$

$$= 19.39 \text{ days}$$

$$= 19.4$$

$$3d) \text{ ii) } MLVSS = 0.8 \times 3000 \text{ mg/L} \\ = 2400 \text{ mg/L.}$$

$$\frac{F}{M} = \frac{Q S_0}{X V} \\ = \frac{5000 \text{ m}^3/\text{d} \times 1500 \text{ mg/L}}{5000 \text{ m}^3 \times 3000 \text{ mg/L} \times 0.8} \\ = 0.625 \text{ g BOD / g MLVSS} \cdot \text{d.}$$

$$\text{iii) } Y_{\text{obs}} \left[\frac{\text{g TSS}}{\text{g COD}} \right] = \frac{(5000 - 75) \text{ m}^3/\text{d} (20 \text{ mg/L})}{2000 \text{ mg/L} \times 5000 \text{ m}^3/\text{d}.} \\ = 0.00985 \text{ g TSS / g COD.}$$

iv) Not stable as the decay rate of biomass and volatile suspended solids (VSS) are not being considered for the calculations.

4a)	Tower trickling filter with plastic packing	Activated sludge Treatment.
Space	Facility does not take up that much since can be built vertically	Treatment facility takes up a lot of land space.
Ease of process operation.	Easy to set up and start operations	Difficult to set up and start operations
Sludge settling characteristics.	Forms a biofilm on the plastic packing material, may slough off when fluid shear force is high enough. Sludge not returned to filter.	Sludge settles on the bottom of the tank, does not resuspend unless water velocity too high. Sludge returned to tank.
Energy Requirements.	Energy needed to pump the water up the tower (not much)	Energy needed to aerate the treatment tank (A lot)
Maintenance.	Need to clean out slime layer on packing filter and disinfect with Cl_2	Need to wash and clean out tank, but not often.
Treatment flexibility	Flexible	Not flexible as the reactor conditions have to be reset

Nitrification reliability	Not reliable	Very reliable as reactor conditions can be controlled.
potential odours.	Might have odours	Unlikely to have odours
Potential for N&P removal	Low potential.	High potential due to control over reactor's conditions

$$\begin{aligned}
 \text{b) i) HRT} &= \frac{\text{Reactor Height}}{\text{upflow Velocity}} \\
 &= \frac{5 \text{ m}}{0.7 \text{ m/h}} \\
 &= 7.14 \text{ h.}
 \end{aligned}$$

$$\begin{aligned}
 \text{ii) COD loading rate} &= \frac{\text{COD} \times \text{flow rate}}{\text{volume}} \\
 &= \frac{450 \text{ mg/L} \times 3000 \text{ m}^3/\text{d}}{3000 \text{ m}^3/\text{d} \times \frac{7.14}{24} \text{ d}} \\
 &= 1512.6 \text{ g COD} / \text{m}^3 \cdot \text{d} \\
 &= 1.51 \text{ kg COD} / \text{m}^3 \cdot \text{d.}
 \end{aligned}$$

$$4c) \quad \text{SRT} = 30 \text{ d} \quad \text{VSS}_e = 200 \text{ mg/L}$$

$$P_{X, \text{VSS}} = \frac{YQ(S_0 - S)}{1 + K_d \text{SRT}} + \frac{f_d K_d YQ(S_0 - S) \cdot \text{SRT}}{1 + K_d \text{SRT}}$$

$$95\% \text{ sCOD degradation: } S_0 - S = 0.95 S_0$$

$$\begin{aligned} P_{X, \text{VSS}} &= Q_e (X_e) \quad Q_{\text{in}} = Q_e \\ &= 3000 \text{ m}^3/\text{d} \times 200 \text{ mg/L} \\ &= 600\,000 \text{ g/d} \end{aligned}$$

$$\begin{aligned} P_{X, \text{VSS}} &= \frac{YQ(S_0 - S)}{1 + K_d \text{SRT}} + \frac{f_d K_d YQ(S_0 - S) \cdot \text{SRT}}{1 + K_d \text{SRT}} \\ 600\,000 \text{ g/d} &= \frac{0.08 \times 3000 (0.95 S_0)}{1 + 0.03 \times 30} + \frac{0.15 \times 0.03 \times 0.08 \times 3000 \times 0.95 S_0 \times 30}{1 + 0.03 \times 30} \end{aligned}$$

$$\therefore S_0 = 4405 \text{ mg/L}$$